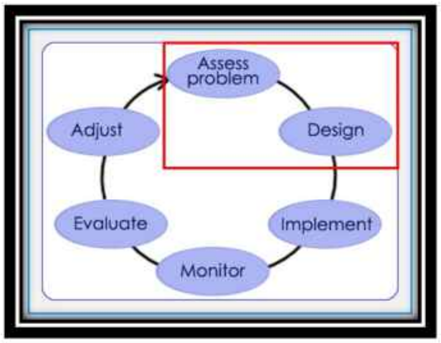

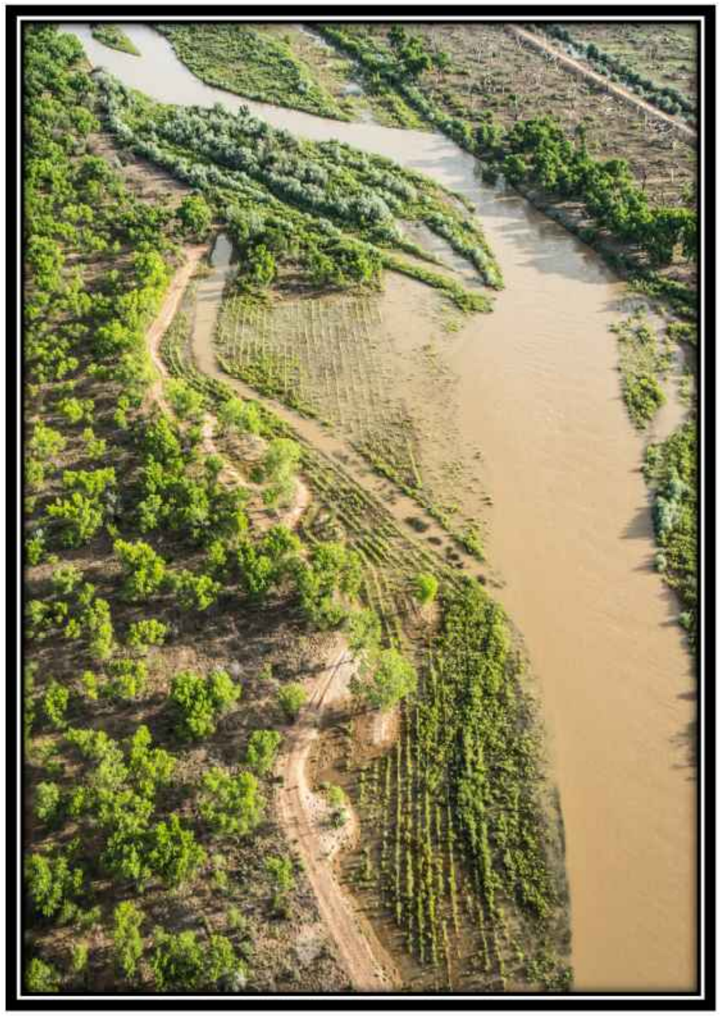

Middle Rio Grande Adaptive Management Framework:
Identifying Critical Scientific Uncertainties

May 2018

Prepared for:
U.S. Army Corps of Engineers
On Behalf of
The Middle Rio Grande
Endangered Species Collaborative Program

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DOCUMENT CONTROL SUMMARY

Title:	Middle Rio Grande Adaptive Management Framework: *Identifying Critical Scientific Uncertainties*		
Client Company:	Army Corps of Engineers, Albuquerque District		
Client Contact:	Lynette Giesen, Michael Porter		
Contract Number:	W912PP-15-C-0008		
Status:	FINAL REPORT		
GeoSystems Analysis Job #:	1520		
Project Manager:	Todd Caplan		
Author(s):	Todd Caplan, Gene Wilde, Hira Walker, Jennifer Frey, Debbie Lee		
Revision Number:	3		
Notes:			
Date:	May 2018		
Checked By:	U.S. Army Corps of Engineers, Albuquerque District, March 2018		
Issued By:			
Distribution (Number of Copies):	Client	Other	GSA Library
	1 e-copy, 1 hard-copy	Electronic copies distributed to Adaptive Management Team and Executive Committee	

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Middle Rio Grande Adaptive Management Framework: Identifying Critical Scientific Uncertainties

Citation:

Caplan, T., D. Lee, G. Wilde, H. Walker, and J. Frey. 2018. Middle Rio Grande Adaptive Management Framework: Identifying Critical Scientific Uncertainties. Prepared for the U.S. Army Corps of Engineers Albuquerque District on behalf of the Middle Rio Grande Endangered Species Collaborative Program. Prepared by GeoSystems Analysis, Inc. Albuquerque, NM. May 2018. Contract No. W912PP-15-C-0008.

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Acknowledgements: Several individuals provided key support during various project stages, including Ms. Gail Bingham (Science Panel facilitator), Ms. Monika Hobbs (New Mexico Meadow Jumping Mouse workshop and Adaptive Management [AM] Team meeting note taker), and Ms. Ariane Pinson (facilitator of Science Panel report presentation to AM Team). Clifford Dahm (Delta Science Program), Robin Gregory (University of British Columbia), David Braun and Scott VanderKooi (Glen Canyon Dam Adaptive Management Program), Chad Smith (Platte River Recovery Implementation Program), Joseph Bonneau (Missouri River Recovery Program) and David Wegner (WEST) provided valued input to the recommendations provided in Section 7 of this report. Thank you to the Middle Rio Grande Endangered Species Collaborative Program Adaptive Management Team members, the regional species subject-matter experts and the Independent Science Panel members who dedicated considerable time and effort through various stages of the project.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY xv

1 INTRODUCTION 1

1.1 Purpose and Project Focus 1

1.2 The Middle Rio Grande Endangered Species Collaborative Program 3

2 PROCESS FOR IDENTIFYING CRITICAL SCIENTIFIC UNCERTAINTIES 5

2.1 Understanding Collaborative Program "Decision Space" Regarding Science Integration into Decision Making 6

2.2 Identifying Species-Specific Scientific Uncertainties 7

2.2.1 New Mexico Meadow Jumping Mouse 10

2.2.2 Southwestern Willow Flycatcher 10

2.2.3 Yellow-Billed Cuckoo 11

2.2.4 Rio Grande Silvery Minnow 12

Technical Convening Assessment 14

Independent Science Panel Meeting Topics and Preparation 15

Independent Science Panel Selection and Management Process 16

Independent Science Panel Meeting and Report 19

3 CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE NEW MEXICO MEADOW JUMPING MOUSE 20

3.1 Identified Critical Scientific Uncertainties 20

3.2 Connectivity Among Critical Scientific Uncertainties 20

3.3 Critical Scientific Uncertainty #1: Middle Rio Grande Populations Distribution 23

3.3.1 Scientific Relevance 23

3.3.2 Management Application 23

3.3.3 Recovery Application 23

3.3.4 Study Plan Considerations 24

3.3.5 Priority Ranking 25

3.4 Critical Scientific Uncertainty #2: Genetics 25

3.4.1 Scientific Relevance 25

3.4.2 Management Application 26

3.4.3 Recovery Application 26

3.4.4 Study Plan Considerations 26

3.4.5 Priority Ranking 27

3.5 Critical Scientific Uncertainty #3: Non-Invasive Survey Methods ... 27
3.5.1 Scientific Relevance ... 27
3.5.2 Management Application ... 27
3.5.3 Recovery Application ... 28
3.5.4 Study Plan Considerations ... 28
3.5.5 Priority Ranking ... 28
3.6 Critical Scientific Uncertainty #4: Middle Rio Grande Population Habitat Attributes ... 28
3.6.1 Scientific Relevance ... 29
3.6.2 Management Application ... 29
3.6.3 Recovery Application ... 29
3.6.4 Study Plan Considerations ... 29
3.6.5 Priority Ranking ... 30
3.7 Critical Scientific Uncertainty #5: Population Dynamics ... 30
3.7.1 Scientific Relevance ... 30
3.7.2 Management Application ... 31
3.7.3 Recovery Application ... 31
3.7.4 Study Plan Considerations ... 31
3.7.5 Priority Ranking ... 31
4 CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE SOUTHWESTERN WILLOW FLYCATCHER ... 33
4.1 Critical Scientific Uncertainties ... 33
4.2 Connectivity Among Critical Scientific Uncertainties ... 33
4.3 Critical Scientific Uncertainty #1: Restoration Prioritization Strategy ... 35
4.3.1 Scientific Relevance ... 35
4.3.2 Management Application ... 35
4.3.3 Recovery Application ... 35
4.3.4 Study Plan Considerations ... 36
4.3.5 Priority Ranking ... 39
4.4 Critical Scientific Uncertainty #2: The Impacts of the Tamarisk Beetle ... 41
4.4.1 Scientific Relevance ... 41
4.4.2 Management Application ... 42
4.4.3 Recovery Application ... 42
4.4.4 Study Plan Considerations ... 43
4.4.5 Priority Ranking ... 44

4.5 Critical Scientific Uncertainty #3: Flycatcher Population Status in the Angostura Reach 46
4.5.1 Scientific Relevance 46
4.5.2 Management Application 46
4.5.3 Recovery Application 47
4.5.4 Study Plan Considerations 47
4.5.5 Priority Ranking 48
4.6 Critical Scientific Uncertainty #4: Flycatcher Metapopulation Structure and Dynamics 48
4.6.1 Scientific Relevance 48
4.6.2 Management Application 49
4.6.3 Recovery Application 49
4.6.4 Study Plan Considerations 49
4.6.5 Priority Ranking 51
5 CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE YELLOW-BILLED CUCKOO 54
5.1 Identified Critical Scientific Uncertainties 54
5.2 Connectivity Among Critical Scientific Uncertainties 54
5.3 Critical Scientific Uncertainty #1: Abiotic and Biotic Variables of Yellow-Billed Cuckoo Breeding Habitats 56
5.3.1 Scientific Relevance 56
5.3.2 Management Application 56
5.3.3 Recovery Application 57
5.3.4 Study Plan Considerations 57
5.3.5 Priority Ranking 59
5.4 Critical Scientific Uncertainty #2: Yellow-Billed Cuckoo Breeding Population Sizes, Distributions, and Trends 59
5.4.1 Scientific Relevance 59
5.4.2 Management Application 60
5.4.3 Recovery Application 60
5.4.4 Study Plan Considerations 60
5.4.5 Priority Ranking 61
5.5 Critical Scientific Uncertainty #3: Similarity in Yellow-Billed Cuckoo and Southwestern Willow Flycatcher Breeding Habitat Requirements 61
5.5.1 Scientific Relevance 61
5.5.2 Management Application 62

5.5.3 Recovery Application 62
5.5.4 Study Plan Considerations 62
5.5.5 Priority Ranking 63
5.6 Critical Scientific Uncertainty #4: Yellow-Billed Cuckoo Spatial Behavior Patterns 64
5.6.1 Scientific Relevance 64
5.6.2 Management Application 64
5.6.3 Recovery Application 64
5.6.4 Study Plan Considerations 65
5.6.5 Priority Ranking 66
6 CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE RIO GRANDE SILVERY MINNOW 69
6.1 Identified Critical Scientific Uncertainties 69
6.2 Connectivity Among Critical Scientific Uncertainties 72
6.3 Critical Scientific Uncertainty #1: Key Life History Sensitivities 74
6.3.1 Scientific Relevance 74
6.3.2 Management Application 74
6.3.3 Recovery Application 74
6.3.4 Study Plan Considerations 74
6.3.5 Priority Ranking 75
6.4 Critical Scientific Uncertainty #2: Age-Specific Survival Rates 75
6.4.1 Scientific Relevance 75
6.4.2 Management Application 76
6.4.3 Recovery Application 76
6.4.4 Study Plan Considerations 76
6.4.5 Priority Ranking 78
6.5 Critical Scientific Uncertainty #3 (and #8): Age-Specific Fecundities 78
6.5.1 Scientific Relevance 78
6.5.2 Management Application 78
6.5.3 Recovery Application 78
6.5.4 Study Plan Considerations 78
6.5.5 Priority Ranking 80
6.6 Critical Scientific Uncertainty #4 (and #13): Catch-Per-Unit-Effort Index 80
6.6.1 Scientific Relevance 80
6.6.2 Management Application 80

6.6.3 Recovery Application ... 80
6.6.4 Study Plan Considerations ... 81
6.6.5 Priority Ranking ... 82
6.7 Critical Scientific Uncertainty #5: Demographic Rates and Environmental Factors ... 83
6.7.1 Scientific Relevance ... 83
6.7.2 Management Application ... 83
6.7.3 Recovery Application ... 83
6.7.4 Study Plan Considerations ... 83
6.7.5 Priority Ranking ... 84
7 RECOMMENDED PATH FORWARD ... 87
7.1 Study Prioritization ... 87
7.2 Strategic Science Plan ... 90
7.3 Independent Science ... 91
7.3.1 How Other Adaptive Management Programs Utilize Independent Scientists ... 94
Glen Canyon Dam Adaptive Management Program ... 94
Platte River Recovery Implementation Program ... 97
Missouri River Recovery Program ... 100
8 REFERENCES ... 102

LIST OF TABLES

Table ES 1. Critical scientific uncertainties identified by regional scientists and the Rio Grande Silvery Minnow Independent Science Panel. ... xvi
Table 1. Middle Rio Grande Endangered Species Collaborative Program Designated Adaptive Management Team and Subject Matter Expert Members. ... 9
Table 2. Independent Science Panel Presentation Topics and Subject Matter Expert Presenters. ... 16
Table 3. Study framework attributes for critical scientific uncertainties for the New Mexico Meadow Jumping Mouse. ... 32
Table 4. Study framework attributes for critical scientific uncertainties for the Southwestern Willow Flycatcher. ... 52
Table 5. Study framework attributes for critical scientific uncertainties for the Yellow-Billed Cuckoo. ... 67

Table 6. Study framework attributes for critical scientific uncertainties identified for the Rio Grande Silvery Minnow. 85

Table 7. Attributes of standing science advisory panels from three U.S. Adaptive Management programs. 101

LIST OF FIGURES

Figure 1. Adaptive Management cycle. 2

Figure 2. Flow diagram illustrating the process for identifying critical scientific uncertainties. 5

Figure 3. Independent Science Panel Process. 13

Figure 4. Relationships among critical scientific uncertainties influencing management and recovery of the New Mexico Meadow Jumping Mouse in the Middle Rio Grande, New Mexico. 22

Figure 5. Relationships among critical scientific uncertainties for the Southwestern Willow Flycatcher in the Middle Rio Grande, New Mexico. 34

Figure 6. Middle Rio Grande-wide Southwestern Willow Flycatcher restoration prioritization strategy development process. 40

Figure 7. Multi-criteria habitat restoration priority strategy.* 41

Figure 8. Hypothesized model of effects on tamarisk beetle on birds* 45

Figure 9. Relationships among critical scientific uncertainties of the Yellow-billed Cuckoo in the Middle Rio Grande, New Mexico. 55

Figure 10. Interrelationships of Level 1 scientific uncertainties identified by the Independent Science Panel for the Rio Grande Silvery Minnow in the Middle Rio Grande. 73

Figure 11. Potential roles for independent science advisors through various stages of the Adaptive Management cycle. 93

LIST OF APPENDICES

Appendix A: General Convening Assessment Summary Notes 115

Appendix B-1: New Mexico Meadow Jumping Mouse Workshop Summary Notes 130

Appendix B-2: Detailed Technical Discussion – Critical Scientific Uncertainties for the New Mexico Meadow Jumping Mouse 147

Appendix C-1: Southwestern Willow Flycatcher Workshop Summary Notes 187

Appendix C-2: Detailed Technical Discussion - Critical Scientific Uncertainties for the Southwestern Willow Flycatcher 196

Appendix D-1: Yellow-Billed Cuckoo Workshop Summary Notes 249

Appendix D-2: Detailed Technical Discussion: Critical Scientific Uncertainties for the Yellow-Billed Cuckoo 262
Appendix E-1: Rio Grande Silvery Minnow Technical Convening Assessment Results Summary 312
Appendix E-2: Detailed Technical Discussion - Critical Scientific Uncertainties for the Rio Grande Silvery Minnow 353

LIST OF ACRONYMS USED

2015 Joint BA - 2015 Joint Biological Assessment
3Rs - resiliency, redundancy, and representation
ABCWUA – Albuquerque Bernalillo County Water Utility Authority
AM – Adaptive Management
AMT – Adaptive Management Team
AMWG – Adaptive Management Work Group
APA – Assessment Payers Association of the Middle Rio Grande Conservancy District
BA – Biological Assessment
BdANWR – Bosque del Apache National Wildlife Refuge
BEMP – Bosque Ecosystem Monitoring Program
BIA – Bureau of Indian Affairs
BIA SWRO – Bureau of Indian – Affairs Southwest Regional Office
BiOp – Biological Opinion
BMPs – Best Management Practices
CBD – Center for Biological Diversity
COA OSD – City of Albuquerque Open Space Division
Colaborative Program – Middle Rio Grande Endangered Species Collaborative Program
CPUE – catch-per-unit-effort
DNA – deoxyribonucleic acid
DPS – Distinct Population Segment
EC – Executive Committee
eDNA – environmental-DNA
EIS – Environmental Impact Statement
E-Review – Electronic Review
ESA – Endangered Species Act
GIS – Geographic Information System
GCDAMP – Glen Canyon Dam Adaptive Management Program
GCMRC – Grand Canyon Monitoring and Research Center
GPS – Global Positioning System
GSA – GeoSystems Analysis, Inc.
ha – hectare

HSI – Habitat Suitability Index
IRP – Independent Review Panel
ISETR - Independent Social Economic Technical Review
ISP – Independent Science Panel
ISAP – Independent Science Advisory Panel
ISAC – Independent Science Advisory Committee
KHR – Kernel-home Range
km – kilometer
LCEP – Lower Columbia Estuary Partnership
LCR – Lower Colorado River
LFCC – Low Flow Conveyance Channel
LIDAR – Light Detection and Ranging
LRG – Lower Rio Grande (LRG)
m – meter
MCP – Minimum Convex Polygon
MECs – Moore Egg Collectors
MRG – Middle Rio Grande
MRGCD – Middle Rio Grande Conservancy District
MRGESCP – Middle Rio Grande Endangered Species Collaborative Program
MRGU – Middle Grande Management Unit
MRRIC – Missouri River Recovery Implementation Committee
MRRP – Missouri River Recovery Program
mtDNA – Mitochondrial DNA
NMDGF – New Mexico Department of Game and Fish
NMISC – New Mexico Interstate Stream Commission
NMMJM – New Mexico Meadow Jumping Mouse/Mice
NMSU – New Mexico State University
NRC – National Research Council
OMB - Office of Management and Budget
PCEs – Primary Constituent Elements
PEPs – Protocol Evaluation Panels
PRRIP – Platte River Recovery Implementation Program
PVA – Population Vitality Analysis
PVER – Palo Verde Ecological Reserve
RGRU – Rio Grande Recovery Unit
RGSM – Rio Grande Silvery Minnow
RIP – Recovery Implementation Program
ROD – Record of Decision
SAB – Science Advisory Board
SDM – Structured Decision Making
SME – Subject Matter Expert

SRS – Survival and Recovery Strategy
SSA – Species Status Assessment
SSP – Strategic Science Plan
SSRS – Southern Sierra Research Station
SWA – State Wildlife Area
SWCA – SWCA Environmental Consultants
SWFL – Southwestern Willow Flycatcher
TCA – Technical Convening Assessment
TL – Total Length
TWG – Technical Work Group
UNM – University of New Mexico
USACE - U.S. Army Corps of Engineers
USBR – U.S. Bureau of Reclamation
USFS – U.S. Forest Service
USFS-RMRS – US Forest Service – Rocky Mountain Research Station
USFWS – U.S. Fish and Wildlife Service
WEST – Western Ecosystems Technology, Inc.
YBCU – yellow-billed cuckoo

EXECUTIVE SUMMARY

GeoSystems Analysis, Inc. (GSA) was contracted by the U.S. Army Corps of Engineers, Albuquerque District, to work with the Middle Rio Grande Endangered Species Collaborative Program (Collaborative Program) to identify critical scientific uncertainties (gaps in knowledge) and recommend associated studies related to four threatened and endangered fish and wildlife species that currently occupy the Middle Rio Grande (MRG). The four species include the Rio Grande silvery minnow (RGSM), the southwestern willow flycatcher (SWFL), and the New Mexico meadow jumping mouse (NMMJM), which are all three federally listed as endangered; and the yellow-billed cuckoo (YBCU), federally listed as threatened. This project was designed to fit into a larger effort of the Collaborative Program to move towards Adaptive Management as a central component of its activities.

The GSA project team developed structured processes and forums designed to solicit and document the range of scientific perspectives from regional scientists regarding what they deem to be the most critical scientific uncertainties to be resolved to advance water management and habitat restoration decisions. The processes implemented differed somewhat between species, depending largely upon the level of scientific agreement, but generally included combinations of questionnaires, personal interviews, and technical workshops. The process implemented to identify critical uncertainties for the RGSM was considerably more rigorous and utilized an Independent Science Panel (ISP) due to wide-ranging and often conflicting scientific perspectives among regional scientists.

The critical scientific uncertainties identified and addressed in this report do not represent the opinions of the GSA team, who served as a third-party neutral process manager. Rather, they constitute GSA's summarization of perspectives expressed by participating expert scientists as documented in species workshops and the ISP report. Workshop summary notes are provided in the appendices of this report. The ISP report and other supporting documentation from the panel meeting can be found online at: https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/RGSM%20Panel%20Workshop.html.

A list of the critical scientific uncertainties identified during species forums are displayed in Table ES 1. When reviewing this table and the main-body report, it is important to understand that the participating expert scientists did not necessarily reach consensus on all uncertainties, nor was that considered an attainable goal, given the level of uncertainty around many aspects of the life-history of each species. Rather, the scientific uncertainties for three of the four species identified through this project reflect the *majority opinion* of the scientists who participated in each technical workshop, and those of the fourth species, the RGSM, were identified by the ISP. More detail on the rationale and structured approach for identifying critical scientific uncertainties can be found in Section 2.

Table ES 1. Critical scientific uncertainties identified by regional scientists and the Rio Grande Silvery Minnow Independent Science Panel.

Species	**Scientific Uncertainty**
New Mexico Meadow Jumping Mouse	1. Where are MRG populations located? 2. What is the genetic variation within and between populations? 3. How do invasive survey methods compare to non-invasive methods? 4. What are the attributes for foraging, day nesting, maternal nesting, and hibernation habitat in the MRG? 5. What are the population dynamics?
Southwestern Willow Flycatcher	1. What site selection and prioritization procedures contribute to the successful restoration of SWFL breeding habitats along the MRG? 2. What are the impacts of the tamarisk beetle (*Diorhabda*) on SWFL breeding habitats in the MRG? 3. What are the sizes, distributions, and status of SWFL populations along the Angustora Reach of the MRG? 4. What is the connectivity among SWFL populations in the MRG?
Yellow-billed Cuckoo	1. Which abiotic and biotic variables predict suitable YBCU habitats in the MRG across multiple spatial and temporal scales? 2. What are YBCU breeding population sizes, distributions, and trends in the MRG? 3. How similar are the YBCU and the SWFL in their breeding habitat requirements in the MRG? 4. What are the YBCU spatial behavior patterns in the MRG within and among years?
Rio Grande Silvery Minnow	1. What are the key life-history sensitivities of RGSM and which age-specific survival and fecundity rates most affect the rate of population change? 2. What are the survival rates, and estimates of their natural (process) variability, of different age classes of RGSM? 3. What is the fecundity of RGSM and how does it vary with age or size? 4. What is the relationship between the annual catch-per-unit-effort index and true RGSM population size? 5. How do key RGSM vital rates vary as a function of hydrologic factors, abiotic environmental factors, and biotic factors?

This report is organized into seven main-body sections. Section 1 addresses the overall project goals and objectives, and how these fit within the broader Adaptive Management Framework of the Collaborative Program. Section 2 provides general background information on the Collaborative Program along with detailed descriptions of the processes implemented by the GSA Team for soliciting and documenting scientific perspectives of critical uncertainties for each of the four species.

Sections 3 through 5 summarize the critical uncertainties identified by regional scientists for the NMMJM, SWLF, and YBCU, respectively. Section 6 summarizes critical scientific uncertainties identified for the RGSM by an ISP. Study design considerations are provided by the GSA project team, as informed by the workshops and the ISP for each critical scientific uncertainty to guide Collaborative Program stakeholders charged with developing detailed study plans and/or requests for proposals.

Sections 3 through 6 provide brief, high-level overviews focusing on the key elements considered of greatest interest to managers and decision makers. More detailed scientific background discussions and relevant literature citations for each of the four species are provided in the back of the report as appendices.

The final report section (Section 7) recommends specific steps for the Collaborative Program to consider for prioritizing and implementing the scientific investigations presented in the preceding sections. The recommendations center on three principle steps: (1) using a Structured Decision Making (SDM) process to prioritize study recommendations based upon direct linkages to well defined management objectives and performance measures, (2) developing a multi-year Strategic Science Plan (SSP) that incorporates results from the SDM process, and (3) establishing a standing Independent Science Advisory Committee to provide outside peer review and support to the Collaborative Program with implementing the SSP through various stages of the Adaptive Management cycle.

1 INTRODUCTION

1.1 Purpose and Project Focus

GeoSystems Analysis, Inc. (GSA) was contracted by the U.S. Army Corps of Engineers, Albuquerque District (USACE), to work with the Middle Rio Grande Endangered Species Collaborative Program (MRGESCP or Collaborative Program) to identify critical scientific uncertainties (gaps in knowledge) and recommend associated studies related to four threatened and endangered fish and wildlife species that currently occupy the Middle Rio Grande (MRG). The four species include the Rio Grande silvery minnow (*Hybognathus amarus*; RGSM), the southwestern willow flycatcher (*Empidonax traillii extimus*; SWFL), the yellow-billed cuckoo (*Coccyzus americanus*; YBCU) and the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*; NMMJM). This project was designed to fit into a larger effort of the Collaborative Program to move towards Adaptive Management (AM) as a central component of its activities.

AM is a structured, iterative process of robust decision-making in the face of uncertainty, with an aim to reduce uncertainty over time via system monitoring (Holling 1978, Walters 1986). Developed by C.S. Holling and Carl Walters, AM emphasizes the identification of critical uncertainties regarding natural resource dynamics and the design of diagnostic management experiments to reduce these uncertainties (Walters 2007, as cited in Rish et al. 2013). AM is not static; rather, it is a continuous, iterative process that applies knowledge gained through each step of the AM cycle (Figure 1) to systematically narrow and refine the list of uncertainties in order to improve the next round of management actions. The true measure of successful AM is in how well it helps meet environmental, social and economic goals, increases scientific knowledge, and reduces tensions among stakeholders (National Research Council [NRC] 2004).

GSA was tasked with building on the foundation established in the Murray et al. (2011) report, *Middle Rio Grande Adaptive Management Plan Version 1*, developed for the Collaborative Program. In that report, the authors developed a comprehensive conceptual basis for an AM framework as a first step towards guiding the Collaborative Program towards an implementable AM Plan. Murray et al. (2011) provided a detailed overview of AM principles and implementation procedures, and provided numerous hypothetical application examples, including lists of potential critical scientific uncertainties associated with the RGSM and the SWFL. The authors acknowledged that extensive additional work with Collaborative Program signatories would be required to operationalize an AM Plan, including the need for implementing a structured process to identify critical scientific data gaps and study questions considered most pressing for reducing uncertainty and informing management decisions.

Hence, the scope of this contract focused on working with the Collaborative Program signatories to develop and test structured processes for identifying critical scientific uncertainties associated with the RGSM, SWFL, YBCU and NMMJM. From a decision analysis perspective, critical uncertainties are gaps in knowledge of a system which significantly affect the relative performance of alternative management decisions against stated objectives (Murray et al. 2011). Reducing critical uncertainties can therefore change or refine the choice of management actions. Other uncertainties may limit our understanding of system behavior, but have less impact on management decisions.

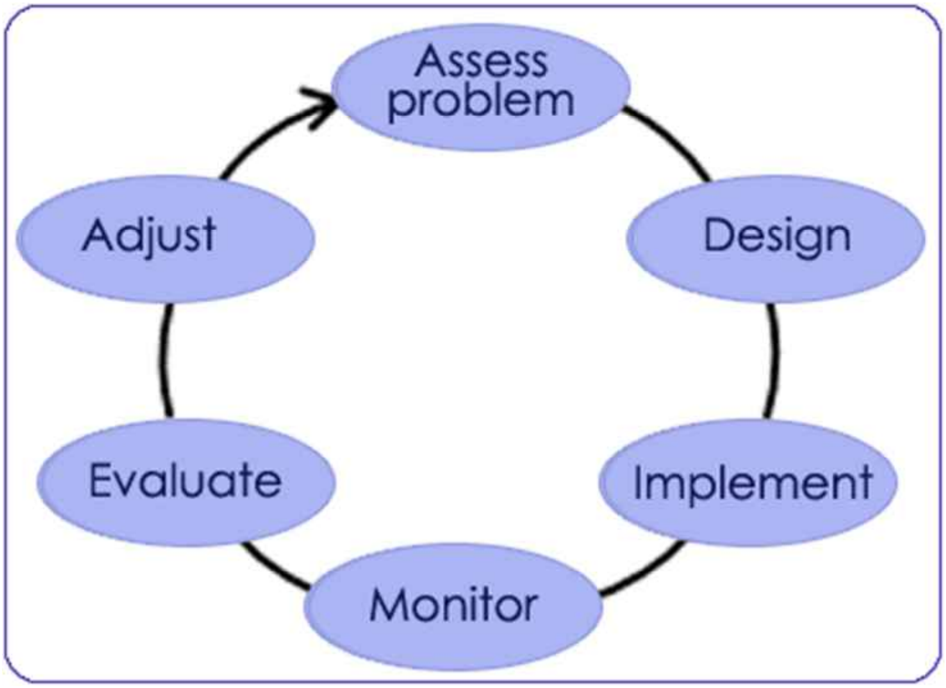

Figure 1. Adaptive Management cycle.

For this first round of the AM cycle, the GSA Team focused on subsets of the *Assessment* and *Design* steps of the cycle (Figure 1). We say "subsets" because there are other essential aspects of the first-round *Assessment* and *Design* steps not addressed in this project, including clearly defining Collaborative Program management objectives and quantitative performance measures, developing conceptual models illustrating hypothesized ecological/biological responses to specific management actions, and designing statistically robust studies to test those hypotheses. As addressed below in Section 2, there are some fundamental scientific data gaps on aspects of biology and life-history of three of the four species (RGSM, YBCU, NMMJM). Thus, the GSA team focused on documenting which scientific gaps regional or independent scientists recommend should be addressed to strengthen the eventual design and evaluation of AM experiments. As a result, work associated with the *Assessment* step of this contract concentrated on developing and implementing formal, structured processes with Collaborative Program signatories and regional scientists to identify critical scientific uncertainties and associated study questions. The *Design* step activities focused on identifying study design considerations to guide the Collaborative Program in developing and/or soliciting detailed study design proposals from the scientific community.

Throughout the process, the GSA team was cognizant of the regulatory and legislative obligations and limitations of the Collaborative Program signatories. There exist multiple Biological Opinions (BiOps) in the Middle Rio Grande. Three signatories are partners to the 2016 *Final Biological and Conference Opinion for Bureau of Reclamation, Bureau of Indian Affairs, and Non-Federal Water Management and Maintenance Activities on the Middle Rio Grande, New Mexico* (U.S. Fish and Wildlife Service [USFWS] 2016), which specifies conservation measures for the listed species in the MRG. Additionally, other signatories have their own programmatic or project-specific BiOps for their activities. Each agency and organization has its own authorizations and responsibilities it must meet, which limits the types of scientific studies and experiments that may be undertaken (for example, experiments that would impact the ability of the state of New Mexico to meet Rio Grande Compact water delivery obligations).

1.2 The Middle Rio Grande Endangered Species Collaborative Program

The MRGESCP, formed in 2000, is a partnership of the following 16 signatories:

- Albuquerque-Bernalillo County Water Utility Authority
- Assessment Payers Association of the Middle Rio Grande Conservancy District (APA)
- Bosque Ecosystem Monitoring Program (BEMP)
- City of Albuquerque Open Space Division (COA OSD)
- Middle Rio Grande Conservancy District (MRGCD)
- New Mexico Attorney General's Office
- New Mexico Department of Game and Fish (NMDGF)
- New Mexico Interstate Stream Commission (NMISC)
- Pueblo of Isleta
- Pueblo of Sandia
- Pueblo of Santa Ana
- University of New Mexico (UNM)
- U.S. Army Corps of Engineers (USACE)
- U.S. Bureau of Indian Affairs
- U.S. Bureau of Reclamation (USBR)
- U.S. Fish and Wildlife Service (USFWS)

The Collaborative Program area is defined as the Colorado-New Mexico border down to just north of Elephant Butte Reservoir, and between the levees on either side of the Rio Grande. As described in the 2012 MRGESCP By-Laws, the Collaborative Program's goals are:

> "[F]irst, to prevent extinction, preserve reproductive integrity, improve habitat, support scientific analysis, and promote recovery of the listed species within the Program area in a manner that benefits the ecological integrity, where feasible, of the Middle Rio Grande riverine and riparian ecosystem; and, second, to exercise creative and flexible options so that existing water uses

> continue and future water development proceeds in compliance with applicable federal and state laws."

The role of the Collaborative Program is to form a space for the different agencies and organizations to work together on projects and scientific research, share information that would inform management activities, and coordinate on projects and management actions. The Collaborative Program does not have any management authority itself, nor can it direct individual signatories or their budgets. The MRGESCP Executive Committee (EC) agreed to have science be the focal point of the Collaborative Program, and to move toward using AM as the main component of its activities.

2 PROCESS FOR IDENTIFYING CRITICAL SCIENTIFIC UNCERTAINTIES

Figure 2 illustrates the general process that the GSA team followed. Sections 2.1 and 2.2 discuss the details on each step of the process.

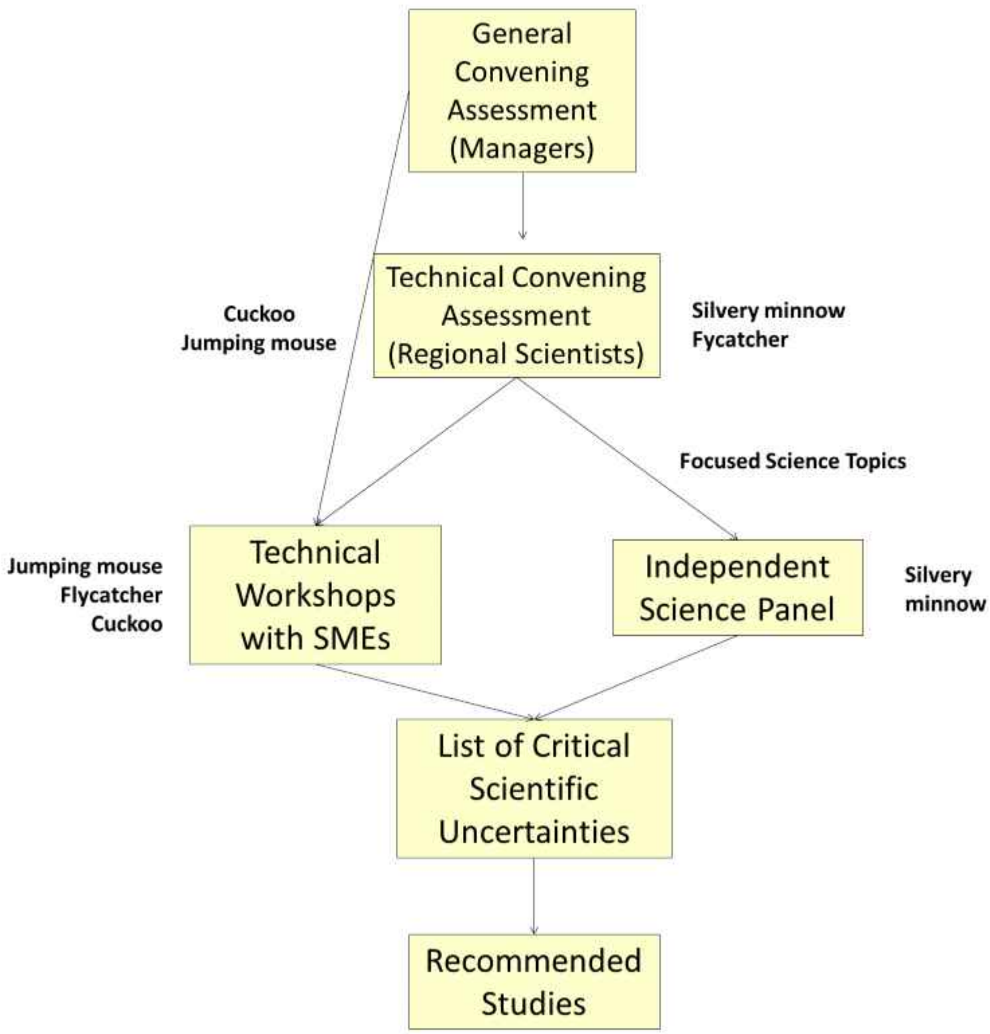

Figure 2. Flow diagram illustrating the process for identifying critical scientific uncertainties.

The progression of each different stage of elicitation (convening assessment *to* Technical Convening Assessment [TCA] *to* a technical workshop or science panel) allowed the GSA team to further refine issues and better identify the scientific gaps and uncertainties for each species. The convening model is accepted practice in the mediation field as a tool which helps the mediator identify the issues among stakeholders and develop an appropriate process that takes those issues into account (Spangler 2003). For scientific mediation, the convening model is further refined to allow for a forum to assess the state of the knowledge—in this case, the technical workshop or a panel (Moore et al. 2005).

2.1 Understanding Collaborative Program "Decision Space" Regarding Science Integration into Decision Making

At the project onset, the GSA Team conducted a "General Convening Assessment" (Figure 2) with the Collaborative Program signatories in August and September 2015. The General Convening Assessment took the form of a questionnaire, followed by interviews with EC members and their staff. This assessment included questions to gain insight into each organization's management goals, objectives, and their perspectives centered on current Collaborative Program functionality. The questions focused on what the participants believe is working well, where improvements are needed, the state of knowledge on the critical science for the four federally listed species, existing processes for identifying and resolving scientific uncertainties, and how well the Collaborative Program integrates scientific study results into decisions on water management, habitat restoration and other actions designed to advance Collaborative Program goals and objectives.

The General Convening Assessment sought to document the range of opinions, concerns and areas of optimism expressed by each signatory. One of the principle goals was to establish the boundaries of the current and future operating environment in which AM can function within the Collaborative Program. This is vital information to ensure that the results from this process are meaningful and relevant to the evolving organizational structure and procedures of the Collaborative Program.

The General Convening Assessment and candid interviews with the participating signatories were useful in establishing managers' perspectives on the current understanding of science and management concerns on the MRG. The discussions provided the foundation to design an informed, structured and transparent process for identifying and addressing critical scientific uncertainties. While Appendix A contains the complete General Convening Assessment questionnaire and a results summary of responses, some clear and consistent responses included:

- A strong commitment to the AM process was expressed, in addition to a willingness for significant investment in developing a successful AM Plan.
- The water management agencies all work well together addressing day-to-day operations, particularly to keep drying river segments wetted during low-flow periods (i.e., most notably during summer and early fall months).

- The Collaborative Program currently lacks a structured process for integrating scientific information regarding species life-history and habitat requirements into water management decisions or for improving habitat restoration designs.
- The biology and habitat associations for the YBCU and the NMMJM in the MRG are relatively poorly understood.
- The biology and habitat requirements of the SWFL are relatively well understood.
- For the NMMJM, SWFL, and YBCU, there are significant scientific uncertainties that warrant investigation, and agency technical experts could work productively together towards identifying and prioritizing critical uncertainties.
- Differences in scientific opinion regarding aspects of RGSM biology and habitat relationships have not yet been resolved. Individual signatories expressed trust in the scientific opinions of their own staff scientists, but felt and observed widespread skepticism or dismissal of alternate scientific perspectives expressed by other signatory scientists.
- There is difficulty in obtaining permits to implement certain RGSM research or monitoring studies, and concern that the current permitting process constrains advancement of scientific understanding of critical aspects of the RGSM life-history and the complex interactions between the fish and environmental factors central to an effective AM Plan.
- The high degree of scientific uncertainty, including disagreement on key life-history questions surrounding RGSM, coupled with conflicting mandates and past difficulties in reaching agreement, all suggest that for this species, a more rigorous and structured process would be necessary for identifying, prioritizing and testing alternative hypotheses most relevant to advancing management decisions.
- An administrative structure that allows for the efficient resolution of differences is lacking; also holds true for scientific issues, leading to several participants calling for more independent party involvement, both in administration of the Collaborative Program and with independent science review.

2.2 Identifying Species-Specific Scientific Uncertainties

For this project, the process for identifying critical scientific uncertainties and determining study priorities was driven by results of the General Convening Assessment regarding the relative degree of scientific agreement amongst the Collaborative Program participants and upon the experiences and process expertise of GSA Team members. Accordingly, it was determined that facilitated technical workshops attended by regional scientists representing each Collaborative Program signatory would be sufficient to identify and prioritize critical scientific uncertainties for the NMMJM, YBCU, and SWFL, respectively. For the RGSM, however, it was determined that an ISP should be convened to review the available science and objectively identify and prioritize critical scientific uncertainties (Figure 2).

To ensure active involvement by the Collaborative Program signatories through critical stages of the project, the GSA Team worked with the signatories to develop a management team and to identify regional scientists for reviewing species-specific scientific issues and topics. This began with a presentation and follow up email correspondence to the EC, where each EC representative was given the opportunity to nominate a representative to participate on an Adaptive Management Team (AMT). The purpose of the AMT was to ensure managers representing each signatory were informed about the goals and objectives of the project, were regularly updated regarding project steps and progress, and were provided opportunities to provide input into each step of the science assessment process. The AMT members, in turn, were given the opportunity to appoint scientific experts to represent their organizations through each scientific workshop and the ISP review process. These scientific representatives were referred to as Subject Matter Experts (SMEs). In the end, not every EC member chose to appoint an AMT representative, and not every AMT member identified an SME to represent their organization for each species. Table 1 presents a list of the AMT members and designated SMEs.

The GSA Team met with the AMT six times throughout the course of the project. Communication with the SMEs was concentrated around preparation, implementation and follow up associated with each technical workshop and the ISP review. All meeting agendas, slide presentations, attendee lists, and meeting summary notes were uploaded promptly to a project Wiki page available online at: (https://webapps.usgs.gov/MRGESCP/Wiki/). The Wiki was developed as a publicly accessible platform to host all information generated by the GSA Project Team throughout the course of the project.

Technical workshops for the NMMJM, SWFL, and YBCU were held in September and October 2016. The ISP meeting for the RGSM was held in February 2017. The details regarding how each workshop and the ISP review process were implemented are described in the following sections.

Table 1. Middle Rio Grande Endangered Species Collaborative Program Designated Adaptive Management Team and Subject Matter Expert Members.

		Identified Subject Matter Expert(S)		
Agency	**Identified AM Team Representative**	**RGSM**	**SWFL/YBCU**	**NMMJM**
Albuquerque- Bernalillo County Water Utility Authority	Rick Billings	Rick Billings	no designee	no designee
Bureau of Reclamation	Ann DeMint, Jennifer Bachus	Jennifer Bachus, Brian Hobbs	Darrell Ahlers, David Moore, Lori Walton	Lori Walton
NM Attorney General	no response to invitation to participate			
U.S. Army Corps of Engineers	Danielle Galloway, Michael Porter (Alt)	Michael Porter	Steven Ryan	Andrew Wastell
Assessment Payers of the MRGCD	Janet Jarratt, Mike Marcus (Alt)	Mike Marcus	Mike Marcus	no designee
City of Albuquerque	Matt Schmader	no designee	no designee	no designee
NM Interstate Stream Commission	Grace Haggerty	Rich Valdez, Eric Gonzales	Jean-Luc Cartron, Julie Kutz	no designee
Middle Rio Grande Conservancy District	Yasmeen Najmi	Bill Pine	no designee	no designee
U.S. Fish and Wildlife Service	David Campbell, Joel Lusk (Alt)	Thomas Archdeacon, Joel Lusk	Vicky Ryan	Jeffrey Sanchez, Jodie Smithem, Megan Goyette
Pueblo of Sandia	Michael Scialdone	Scott Bulgrin	no designee	no designee
Pueblo of Santa Ana	no designee	Nathan Schroeder	Cathy Nishida	no designee
Pueblo of Isleta	Cody Walker	no designee	no designee	no designee
University of New Mexico NM Dept. of Biology & Museum of Southwestern Biology	Megan Osbourne, Evan Carson (Alt)	David Propst	no designee	no designee
Bosque Ecosystem Monitoring Program	Kimberly Eichorst	no designee	no designee	no designee
Bureau of Indian Affairs	Joe Jojola	no designee	no designee	no designee
NM Department of Agriculture	declined invitation			
State of New Mexico Department of Game & Fish; Conservation Services Division	Matt Wunder	no designee	no designee	James Stewart

2.2.1 New Mexico Meadow Jumping Mouse

The NMMJM technical workshop was held September 7, 2016, at Sevilleta National Wildlife Refuge and included SMEs from the USBR, USACE, USFWS, NMDGF and the U.S. Forest Service (USFS). Appendix B-1 lists the individual participants.

The technical workshop was structured around presentations developed by GSA Team member Dr. Jennifer Frey (New Mexico State University) and organized by discreet topic sections as follows:

- Evolutionary history
- Life-history
- Range-wide distribution
- Habitat
- Survey methods

Dr. Frey's presentations were designed to be a starting point for discussions amongst the SMEs present. Following each presentation section, workshop participants were led through a facilitated discussion to vet questions and comments, and through an interactive process for identifying and prioritizing critical scientific uncertainties. The meeting summary of the NMMJM technical workshop was distributed to the SMEs for input and the final summary notes were posted to the project Wiki page (https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/NMMJM%20Technical%20Workshop.html). The workshop summary notes are also attached to this report as Appendix B-1. Section 3 of this report contains results and recommendations that emerged from the workshop.

2.2.2 Southwestern Willow Flycatcher

The SWFL technical workshop was held on October 25, 2016, at the Artichoke Cafe in Albuquerque and included SMEs from the USACE, USFWS, USBR, NMISC, Santa Ana Pueblo, Sandia Pueblo, COA OSD, APA, and USFS. Appendix C-1 contains a list of the individual participants.

A technical questionnaire was developed and disseminated to the SMEs prior to the workshop to gauge the level of agreement between scientists on the species biology, life-history, habitat requirements, and data gaps. This information was used to structure the workshop and provide insight as to which topics may require more significant discussion time than others.

Following the model of the NMMJM workshop, the GSA team invited Darrell Ahlers to speak at the SWFL technical workshop. Mr Ahlers (USBR Denver Technical Service Center) is a technical expert who has worked extensively with the SWFL and has led annual field trainings for SWFL surveys. He presented diverse scientific topics pertaining to the species generally (i.e., range-wide), and to the MRG population specifically, focusing on the following topics:

- Taxonomy and Endangered Species Act (ESA [1973]) listing
- Description and identification
- Survey methods
- Breeding biology and life-history
- Habitat associations
- Status, trends, and threats

Following each presentation section, workshop participants were led through a facilitated discussion to vet questions and comments and through an interactive process for identifying and prioritizing critical scientific uncertainties. The meeting summary of the SWFL technical workshop was distributed to the SMEs for input and the final summary notes were posted to the project Wiki page (https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/SWFL%20and%20YBCU%20Technical%20Workshop.html) and are attached to this report as Appendix C-1. Section 4 of this report includes results and recommendations that emerged from the workshop.

2.2.3 Yellow-Billed Cuckoo

The YBCU technical workshop was held at the Artichoke Cafe in Albuquerque after the SWFL workshop on October 26, 2016, and included SMEs from the USACE, USFWS, USBR, NMISC, Santa Ana Pueblo, Sandia Pueblo, COA OSD, APA and USFS. Appendix D-1 provides a list of the individual participants.

Results from the General Convening Assessment indicated that, as a newly listed species, the science associated with biology and habitat requirements for the YBCU along the MRG were relatively poorly understood. The GSA Team determined, therefore, that a pre-workshop questionnaire would not be disseminated to the SMEs prior to the workshop.

The GSA Team invited Dave Moore, a YBCU researcher with the USBR Denver Technical Service Center, to present diverse scientific topics pertaining to the YBCU generally (i.e., range-wide), and to the MRG population specifically, and focused on the following topics:

- Species description
- Taxonomy and ESA listing
- Breeding biology and life-history
- Habitat requirements
- Survey methodology
- Status, trends, and threats

Mr. Moore's presentation provided a starting point for discussion. The SMEs were led through a facilitated discussion and a prioritization exercise, culminating in identification of critical scientific uncertainties. The meeting summary notes from the technical workshop were distributed to the SMEs for input and the final summary notes were posted to the project Wiki page (https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/SWFL%20and%20YBCU%20Technical%20Workshop.html) and are attached to this report as Appendix D-1. Section 5 of this report includes the results and recommendations that emerged from the workshop.

2.2.4 Rio Grande Silvery Minnow

Results from the General Convening Assessment (Section 2.1) led the GSA Team to implement a more rigorous, multi-step process for identifying critical scientific uncertainties for the RGSM. Figure 3 illustrates the process and a description of the process follows.

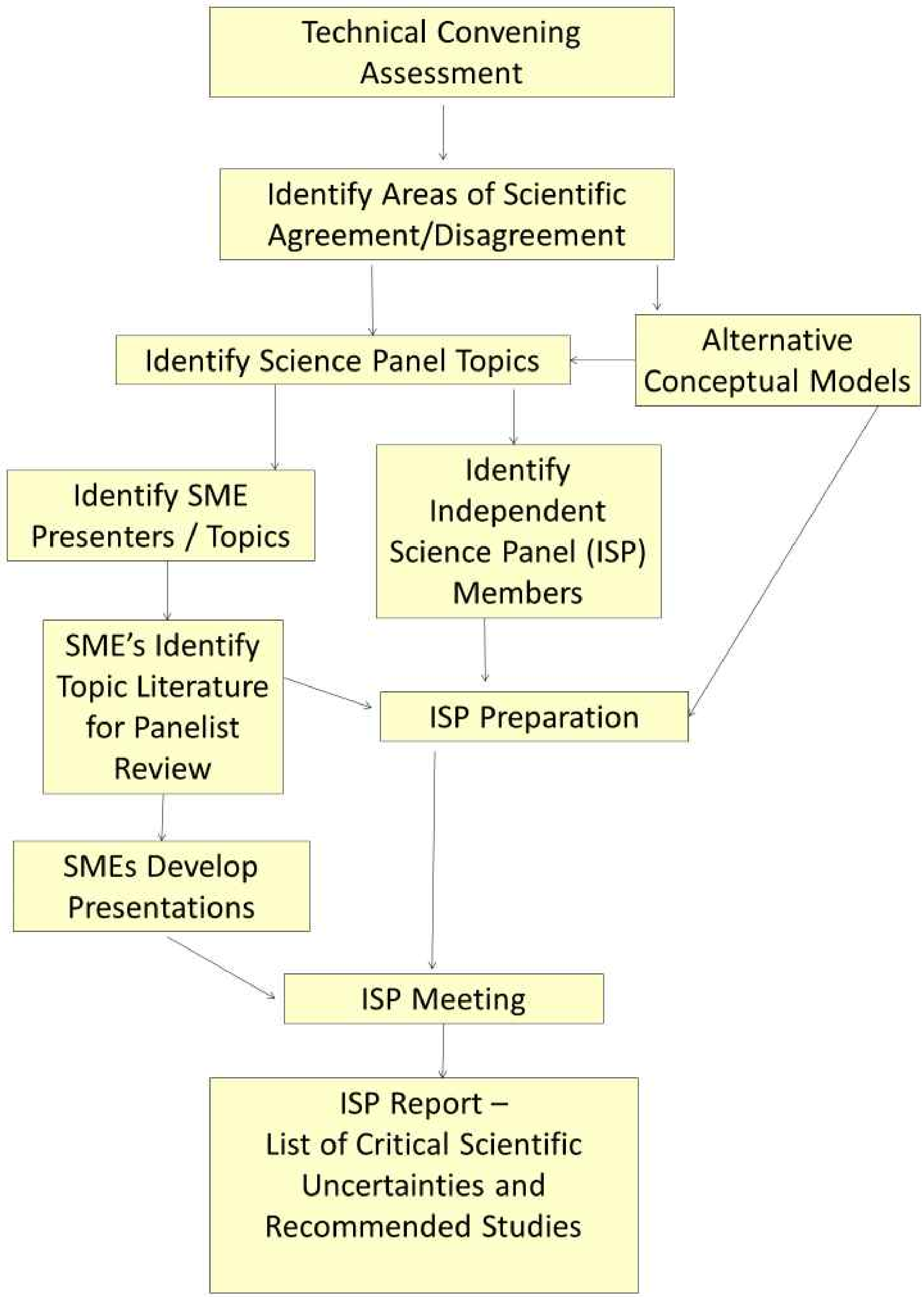

Figure 3. Independent Science Panel Process.

Technical Convening Assessment

The GSA Team developed a TCA (Appendix E-1) that included both a written questionnaire and one-on-one follow up telephone interviews with each of the designated RGSM SMEs. Each of the SMEs completed the TCA questionnaire between February and March 2016. The TCA questionnaire included several questions based on the following five broad topic areas:

- Life-history
- Snowmelt hydrograph
- River base-flow
- Habitat restoration
- Longitudinal connectivity

The GSA Team reviewed and analyzed the TCA questionnaire results to identify areas of agreement, diverging opinion, and outliers. Once compiled, GSA Team members interviewed each of the SMEs about their questionnaire responses. Interview questions were of two types:

(1) Areas of potential miscommunication in the responses to the questionnaire: where the GSA Team suspected the SME may have misinterpreted the question or identified the need to clarify the intended meaning of the SME response. In these instances, SMEs were able to amend their responses to applicable questions.

(2) Areas where the SME held a minority opinion, particularly if he or she was a clear outlier. The interview questions focused on eliciting the rationale and scientific basis behind the SME's responses, including asking for citations when available. SMEs were not allowed to amend their responses for these questions.

Over the course of interviewing the SMEs, the GSA Team determined that there were scientific perspectives of other regional scientists outside of the SMEs nominated by the AMT that were considered important to a thorough vetting process; most notably including Dr. Robert Dudley (UNM) and Dr. David Cowley (New Mexico State University [NMSU]). The GSA Team contacted Dr. Dudley and Dr. Cowley to solicit their participation in the TCA process. Dr. Cowley was able to participate, but for various reasons Dr. Dudley was unable to participate.

The TCA results (Appendix E-1) revealed the following areas of strong scientific agreement among participants:

- Spawn is cued by the ascending limb of the hydrograph.
- Peak magnitude and duration are important for promoting larval development.
- Larval development and food sources are controlled, in part, by water temperature.

- The rate of decline in the descending limb is likely important to reduce larval stranding in nursery habitat.
- Lateral floodplain connectivity is highly important.
- Better understanding the details of the larval life-stage and the attributes of rearing habitat is a high priority.

The TCA results revealed the following topics for which there were diverging scientific perspectives among participants:

- Time frame when ascending limb will trigger meaningful spawn.
- Minimum magnitude and duration of peak flow needed to optimize larval development.
- The functional role of inundated floodplain in the early life-stages of the fish.
- Importance of inundated floodplain for post-spawn adult food/energy demand.
- Causal factors driving flow-recruitment relationships.
- Adult life span.
- Benefits of isolated wetted refugia vs. extensive contiguous perennial flow during summer drought.
- Importance of improving longitudinal connectivity.
- Monitoring methods and scale to evaluate species use/response to wetted refugia restoration and management.
- Monitoring approach to evaluate species response to management actions (e.g., monitoring scale, life-stage, existing vs. new methods, etc.).

The full TCA report and individual TCA questionnaire responses were posted to the project Wiki page (https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/Technical%20Convening%20Assessments.html).

Independent Science Panel Meeting Topics and Preparation

The TCA and associated SME interviews were used to identify scientific topic areas where alternative hypotheses and all relevant supporting information should be provided and summarized in presentations to an ISP. The TCA results also were used to solicit participation by a subset of the SMEs in the ISP process (Figure 3). The SMEs selected were asked to participate in the ISP process based upon either their strong positions on specific topics or because these individuals were clear outliers in their responses to the TCA questionnaire. The GSA Team goal was to work with these SMEs to present the full range of perspectives on specific scientific topics considered relevant to AM of the MRG. Table 2 lists the selected topics and SME presenters.

The GSA Team collaborated with each SME presenter to clarify the topics and to provide feedback on talking points and presentation slides (Figure 3). To be clear, the intent was not to change their messages, but to provide advice and guidance to the presenters on how to most effectively present their points. Based on conversations with SMEs about the topics to present to the panel, the presenting SMEs included one scientist (Michael Hatch, NMSU – see Table 2) who was not part of the TCA process. All SME presenters were asked to compile and provide agency reports, peer-reviewed publications, data, and other information they considered to be directly relevant to their topics. This information was provided to the ISP members to review prior to the panel meeting (Figure 3).

Table 2. Independent Science Panel Presentation Topics and Subject Matter Expert Presenters.

Topic	SME Presenters
Scientific Perspectives on Spawn Timing	Thomas Archdeacon (USFWS) David Cowley (NMSU)
Scientific Perspectives on Spawning and Larval Development	David Propst (UNM) Richard Valdez (NMISC)
Scientific Perspectives on Relationships between Hydro-Geomorphic Attributes and Silvery Minnow Population Response	Joel Lusk (USFWS) Richard Valdez (NMISC)
Scientific Perspectives on Adult Survivorship	Thomas Archdeacon (USFWS) David Cowley (NMSU)
Scientific Perspectives on Intermittency of Flow for Adult Survivorship	Joel Lusk (USFWS) Michael Hatch (NMSU)
Scientific Perspectives on Connectivity and Fish Passage	Michael Porter (USACE) David Propst (UNM)

Independent Science Panel Selection and Management Process

The GSA Team served as a third-party neutral manager for the ISP process, including process design, panel member selection, ISP management and implementation, and coordination of the ISP final report. Regarding ISP member selection, the GSA Team followed best practices consistent with procedures addressed in a number published documents, including those developed by the NRC (2002, 2004) and the Office of Management and Budget (OMB 2004). Accordingly, ISP member selection utilized the following criteria:

- Expertise:
  - Acknowledged leaders in their fields
  - Experience serving on ISP review teams

- Independence:
  - ISP members do not represent agency or stakeholder positions
  - ISP members reside and work outside the MRG basin
  - Collaborative Program signatories (including the USACE) are not involved in ISP member selection
- Balance:
  - ISP members represent diverse areas of relevant scientific expertise
- Conflicts of Interest
  - ISP members have no financial interests, consulting arrangements, employer affiliations or grants/contracts with MRGESCP signatories

Following these standards, the GSA Team recruited and subcontracted four panelists with expertise in the areas of fisheries science, hydrology/fluvial geomorphology, population dynamics/quantitative ecology, and AM (Figure 3). The selected panelists included:

- Dr. Barry Noon, Colorado State University (chair), https://sites.warnercnr.colostate.edu/brnoon/
- Dr. Tom Dunne, University of California Santa Barbara, http://www.bren.ucsb.edu/people/Faculty/thomas_dunne.htm
- Dr. Gary Grossman, University of Georgia, https://www.warnell.uga.edu/people/faculty/dr-gary-grossman
- Dr. David Hankin, Humboldt State University, http://www2.humboldt.edu/fisheries/faculty/hankin.html

The GSA Team developed a "panel charge" that was attached to each ISP member subcontract, along with a Conflict of Interest agreement. The panel charge language was as follows:

> "The silvery minnow Science Panel is charged with a review of current science that addresses how population state variables relevant to silvery minnow recovery (e.g. abundance, density, and occupancy) vary over space and time and what environmental factors best explain this variation. Those environmental factors that significantly affect population state and are amenable to change by management actions will be highlighted."
>
> "Specifically, the Panel is charged with identifying areas of sufficient scientific certainty concerning aspects of the species' life-history needed to inform management decisions as well as areas still characterized by significant uncertainties. The panel also is charged with making specific recommendations concerning priority studies to address critical uncertainties relevant to management decisions, either within an AM Framework or supplemental to it. As appropriate, the

Panel will describe how changing environmental conditions (e.g., climate change, land use, groundwater pumping) may affect the species' response to management actions."

"The ISP tasks include:

1. Reviewing and evaluating relevant scientific literature and viewing pre-recorded presentations,
2. Participating in a workshop at which SMEs will make presentations concerning the life-history of the RGSM, and documented population-level responses to environmental drivers (e.g., peak flow events, summer/fall low flow regimes),
3. Assessing these presentations in terms of their management implications and degree of certainty both at the workshop and in follow up communications amongst panel members, and
4. Preparing a final report which will summarize what is known, what is agreed upon, and what additional studies may need to be conducted to resolve contentious issues and reduce uncertainty."

Although Collaborative Program signatories were not involved in the ISP member selection, the GSA Team kept both the AMT and the RGSM SMEs apprised of the ISP meeting procedures and process during a joint AMT-SME meeting and with email correspondence. One critical recommendation from the meeting by the AMT was to take steps to ensure ISP members were informed regarding legal, management, and other operational constraints associated with MRG water operations. To that end, GSA coordinated several pre-recorded, narrated slide presentations by regional experts on a range of water management topics and background on physical attributes of the MRG. The pre-recorded presentations were uploaded to the project Wiki page (https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/RGSM%20Pre-Recorded%20Presentations.html) for view by the ISP members, Collaborative Program stakeholders, and the general public. The presentations included:

- Middle Rio Grande Geomorphology – Cochiti to Elephant Butte: Then and Now *(presented by Mike Harvey, Tetra Tech)*
- Overview of the Rio Grande Compact (*presented by Rolf Schmidt-Peterson, NMISC*)
- Middle Rio Grande Water Operations Summary (*presented by Carolyn Donnelly, USBR*)
- Climate Change and its Potential Impact on Water Supply and Demand in the Middle Rio Grande *(presented by Dagmar Llewellyn, USBR)*
- The Middle Rio Grande Conservancy District: Keeping the Valley Green *(presented by David Gensler, MRGCD)*

In addition to reviewing the materials provided by SME presenters and reviewing the pre-recorded presentations, the ISP members participated in a pre-panel webinar presentation led by GSA Team member Dr. Gene Wilde, laying out different conceptual models for the RGSM life-history developed using results of the TCA (Figure 3). These conceptual models illustrate the alternate hypotheses and perspectives on RGSM early life-history captured through the TCA questionnaires and individual interviews. These conceptual models are available online at: https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/files/RGSM%20Conceptual%20Model%20Slides.pdf

Independent Science Panel Meeting and Report

A two-day ISP meeting was held at the Tamaya Hotel and Resort on the Pueblo of Santa Ana. The facilitated meeting involved presentations by each SME speaker followed by question and answer sessions between the ISP and each SME presenter. Following the two-day meeting, there was a half-day closed-door executive session between the ISP and the GSA Team to debrief and to discuss the process for developing the ISP report.

The GSA Team provided administrative support to the ISP as they formulated their conclusions and recommendations. The final report, *Independent Science Panel Findings Report: Rio Grande Silvery Minnow Key Scientific Uncertainties and Study Recommendations* (Noon et al. 2017), was completed in late May 2017. The ISP chair, Dr. Barry Noon, traveled to Albuquerque and provided a presentation of the ISP report conclusions and recommendations to the AMT and the SMEs on June 8, 2017. The final ISP report and other supporting documentation from the panel meeting can be found online at: https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/RGSM%20Panel%20Workshop.html. Section 6 of this report addresses the central elements, including a subset of critical scientific uncertainties and study recommendations, from the ISP report.

3 CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE NEW MEXICO MEADOW JUMPING MOUSE

This section addresses critical scientific uncertainties identified by agency SMEs during the September 2016 technical workshop (see Appendix B-1 for workshop notes). The following narrative presents *brief overviews* of the scientific relevance, management application, and recovery application for each critical scientific uncertainty. *In-depth discussions of each scientific uncertainty, along with listing history, recovery efforts, population status, MRG management actions, and additional reference citations are provided in* Appendix B-2**.** Study plan considerations also are offered in this section for each critical scientific uncertainty to guide Collaborative Program signatories with internally developing study plans or soliciting detailed technical proposals from the scientific community.

3.1 Identified Critical Scientific Uncertainties

Workshop participants prioritized the following five critical scientific uncertainties for the NMMJM:

1) Where are NMMJM populations located?
2) What is the genetic variation within and between NMMJM populations?
3) How do non-invasive survey methods compare to trapping?
4) What are the attributes for foraging, day nesting, maternal nesting, and hibernation habitats in the MRG?
5) What are the population dynamics for the NMMJM?

3.2 Connectivity Among Critical Scientific Uncertainties

The five critical scientific uncertainties identified for the NMMJM are connected. Information pertaining to one uncertainty may be necessary to inform research on another uncertainty. In this context, information regarding critical uncertainty #1 (distribution) is central to studying the other four critical uncertainties (Figure 4). Specifically, information about distribution is necessary to inform understanding of genetic status and relationships among populations. Samples for genetic analyses also may be obtained during field studies of distribution. Second, information about distribution is necessary to identify populations of NMMJM suitable for study. Currently, the only population of NMMJM known to exist in the MRG is that occurring at the Bosque del Apache National Wildlife Refuge (BdANWR; USFWS 2014a). The population of NMMJM at BdANWR is thought to be very small (approximately 25 – 50 individuals) and it occupies only a small area of suitable habitat (Wright and Frey 2015; unpublished data). Risk of extinction of the BdANWR population is high. Studies on this population using invasive methods such as trapping (e.g., to test non-invasive survey methods), or that require large sample sizes (e.g., studies of habitat or population dynamics) are likely not appropriate. Further, there are critical differences in habitat use and population demography between low elevation sites (e.g., MRG) and montane sites (Frey 2015a). Consequently, comprehensive surveys are necessary to identify any additional populations of NMMJM that may be suitable for study to inform management in the MRG.

Because of the central role of critical uncertainty #1 (distribution), it was assigned priority *Level 1* (highest). Critical uncertainty #2 (genetic variation) was also assigned priority *Level 1* because of the urgent need for information on the genetic health of the BdANWR population. Although more thorough distribution data would improve insight gained from a genetic study, the need for genetic information on the BdANWR population is so critical that it should not wait for completion of distribution studies.

Given the generally small and isolated populations and that the USFWS survey guidelines are based on invasive trapping methods, which can pose substantial risk to populations (USFWS 2015; Frey 2013b), critical uncertainty #3 (investigating non-invasive survey methods) has a priority *Level 2* (important, but of less immediate concern). Development of non-invasive survey methods would reduce risk to populations and may allow additional types of studies to occur (e.g., habitat attributes and population dynamics), particularly on more vulnerable populations. Lastly, habitat studies are necessary to inform studies of population dynamics because many demographic attributes, such as survival, may be linked to habitat quality.

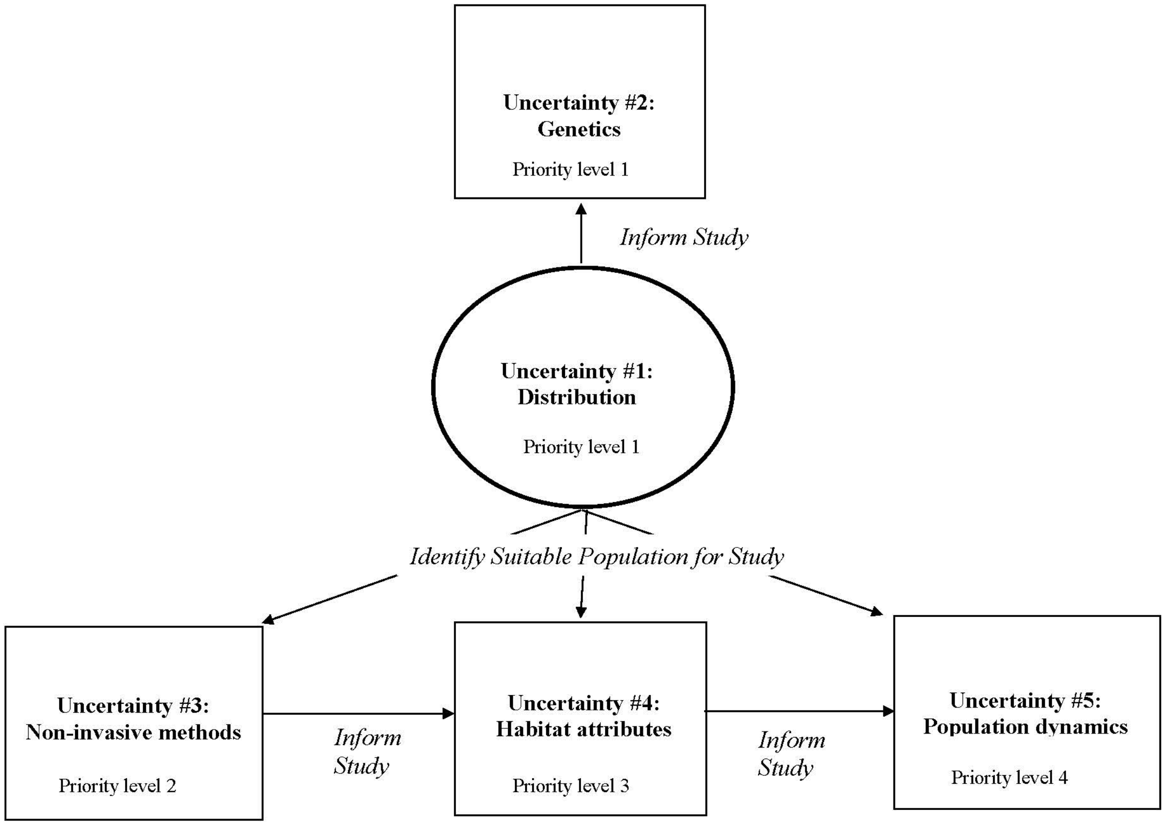

Figure 4. Relationships among critical scientific uncertainties influencing management and recovery of the New Mexico Meadow Jumping Mouse in the Middle Rio Grande, New Mexico.

3.3 Critical Scientific Uncertainty #1: Middle Rio Grande Populations Distribution

Study Question: Where are NMMJM populations located?

3.3.1 Scientific Relevance

The current state of knowledge regarding distribution of the NMMJM in the MRG can be summarized as follows:

1) The NMMJM is thought to have been widespread in the MRG based on historical habitat availability,
2) There are few historical records of NMMJM in the MRG because it is difficult to survey (absence of a record does not imply species did or does not occur),
3) The only recent surveys for the NMMJM in the MRG have occurred at BdANWR (present) and Casa Colorada State Wildlife Area (SWA; not found),
4) Geographic Information System (GIS) models constructed thus far have been largely inadequate in predicting current distribution of NMMJM in the MRG, and
5) The only location where NMMJM are known to persist in MRG is BdANWR.

For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #1: MRG Populations Distribution*.

3.3.2 Management Application

Currently, the only known population of NMMJM in the MRG is located at BdANWR. However, the NMMJM is thought to have had a wide historical distribution in the MRG prior to widespread modification of the river's hydrology (Hink and Ohmart 1984). Further, based on studies in other regions, it is known that populations of NMMJM have persisted in often small, isolated areas that have been more or less protected from threats (e.g., Frey and Malaney 2009, Frey 2017, USFWS 2014b). There have been no apparent major alterations in habitat at some historical locations in the MRG (e.g., Isleta). Reliable surveys (using specialized methods) have only occurred at two locations in the MRG since 1987 (see Appendix B-2 for detail). In addition, at no time have surveys been conducted in the active floodplain of the Rio Grande. Thus, it seems likely that additional populations of NMMJM exist in the MRG but have been undetected. Knowledge about where the NMMJM occurs is necessary to focus population safeguards on occupied areas. Conversely, knowledge about where the NMMJM does not occur can prevent needless expenditure of resources.

3.3.3 Recovery Application

A recovery plan has not yet been approved for the NMMJM. However, a recovery outline (USFWS 2014c) concluded that the NMMJM currently lacks what is known as the "3 Rs": *resiliency, redundancy*, and *representation*. The 3 Rs describe viability of a taxon, which is the ability of a taxon to sustain populations in the wild beyond a defined period. A taxon can only be considered viable if it meets all 3 Rs:

- *Resiliency* is the ability to withstand annual environmental variation and stochastic events such as extreme weather events.
- *Redundancy* is the ability to withstand catastrophic events such as long-term droughts or large-scale high-intensity wildfires.
- *Representation* is the ability to adapt to changing environmental conditions, such as via occurrence in different environments or possession of genetic variation.

Becasuse the only population of NMMJM currently known in the MRG is at BdANWR, the discovery of other populations in the MRG would increase redundancy and may contribute to enhanced resiliency and representation. Discovery of other populations of NMMJM in the MRG, or elsewhere in the watershed (e.g., Espanola, Chama River), may allow some research to occur if the population was deemed large enough (the current population at BdANWR is too small to support research using invasive methods).

3.3.4 Study Plan Considerations

The distribution of NMMJM in the MRG is best evaluated using several approaches, which would likely form separate, but interrelated, studies. The most basic way to begin to understand current distribution is to conduct field surveys at sites where the NMMJM was historically documented. Although this step is warranted, one difficulty is that locations for some historical records are not precisely known. Thus, additional research may be necessary to determine where specimens were collected, and judgment will be necessary to determine appropriate habitat to sample at sites. NMMJM are associated with early successional herbaceous wetland communities that undergo natural spatio-temporal shifts. Consequently, loss of habitat at a specific point through time does not necessarily equate with loss of a population. Further, there are few historical locations for the NMMJM in the MRG and so resampling these sites provides only limited information about distribution.

The second necessary approach is to develop spatial GIS models that can be used as screening criteria to identify areas of potential habitat and prioritize areas for field surveys. To be most useful, models should be developed that focus on different scales, in a nested hierarchy (likely as separate, but interrelated, studies). The NMMJM is an extreme habitat specialist at multiple scales and can only occur where all habitat features are met (Wright and Frey 2015). For instance, its geographic range is associated with perennial streams and rivers, while at the landscape scale it selects certain early successional riparian vegetation communities, and at the microhabitat scale it requires tall, dense herbaceous communities on moist soil (Wright and Frey 2015, Frey 2017). Consequently, a spatial model developed based on 1-kilometer (km) pixel can only predict geographic range and would be incapable of predicting specific locations where the species currently occurs (since 1-km pixel cannot provide information on microhabitat). Conversely, a fine scale spatial model developed based on 5-meter pixel data (e.g., Light

Detection and Ranging [LIDAR], National Agricultural Imagery Program), which can predict suitable microhabitat, could not be developed for the entire MRG due to data and computational limitations. Coarser scale models based on current hydrology or vegetation condition are necessary to identify areas of potential habitat, while finer scale models that can predict microhabitat are necessary to predict local areas of occurrence. Models should be developed by a team that includes a taxon expert who can ensure that appropriate variables and design are considered, and a modeling expert who can insure adherence to currently accepted methodologies, given that the field is rapidly changing.

The third necessary approach is to conduct field surveys at priority areas identified by the screening criteria. Surveys require land access permission and must be conducted following USFWS permitting requirements and survey guidelines (USFWS 2015, 2017). Surveys and field research studies on NMMJM can impose a risk to populations and to the specialized habitat upon which populations depend. The NMMJM is restricted to a small number of isolated populations that may consist of a small number of individuals. Non-invasive detection methods for this species are being developed, but they have not been fully tested and vetted for purposes of surveys (see Section 3.5 and Appendix B-2). Consequently, surveys depend on investigators capturing and handling animals. Surveys conducted by investigators with a high level of training and experience will have reduced risk of injury or death to animals, reduced damage to habitat, and higher detection rates (Frey 2013b, Perkins-Taylor and Frey 2016). Consequently, a NMMJM survey training class was developed in partnership between the USFWS and NMDGF (Frey 2015b) to provide permittees with specific knowledge necessary to increase capture rates, prevent injury to NMMJM and their habitat, and to prevent false negative or false positive results while following the Service's survey guidelines.

3.3.5 Priority Ranking

This study is considered a *Level 1* priority (Table 3) because accurate information about distribution is essential for management and recovery, and because this information is necessary to inform studies on the other critical uncertainties.

3.4 Critical Scientific Uncertainty #2: Genetics

Study Question: What is the genetic variation within and between NMMJM populations?

3.4.1 Scientific Relevance

The current state of knowledge about genetics of the jumping mouse is limited, but can be summarized as follows:

1) The taxon "*luteus,*" which was formerly regarded as a subspecies of *Zapus hudsonius* (meadow jumping mouse), is a distinct species *Zapus luteus* (yellow jumping mouse), which includes the central Great Plains form "*pallidus*";
2) The form of jumping mouse found in the MRG is *Zapus luteus luteus* (USFWS does not currently recognize these taxonomic changes);

3) There is little genetic structure within *Zapus l. luteus*; and
4) Specimens from the MRG share unique genetic characteristics not found in other populations of *Z. l. luteus*.

Currently, there is little population genetic information for the NMMJM such as estimates of inbreeding and gene flow. In addition, the methods that have been applied thus far (single locus mitochondrial deoxyribonucleic acid [mtDNA]) lack refinement that may better elucidate important genetic characteristics of populations. For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #2: Genetics*.

3.4.2 Management Application

Information on the genetic health of the population of NMMJM at BdANWR is necessary to inform need for active management to reduce any inbreeding that might be contributing to decline of this population. Such management would require genetic knowledge of appropriate source populations for infusing new genetic variation into the BdANWR population. For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #2: Genetics*.

3.4.3 Recovery Application

The only population of NMMJM currently known in the MRG is at BdANWR and this population is small and declining (Wright and Frey 2015; see Appendix B-2 for additional detail). Genetic inbreeding due to the small, isolated nature of this population could be contributing to this decline, but genetic status of the population is poorly understood. Genetic data are needed to understand the degree to which inbreeding might be compromising the population and to inform management actions that could increase resiliency of this population. Increased resiliency would improve representation. For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #2: Genetics*.

3.4.4 Study Plan Considerations

Although the goal of this study is to understand the extent of inbreeding depression in the BdANWR population (or any other populations of NMMJM that might be discovered in the MRG in the future) and to evaluate the relationship of the MRG populations with others, this question should ideally be addressed within the context of all populations of the NMMJM to understand range-wide patterns of variation. Study methods should focus on multiple loci, particularly within the nuclear genome (e.g., single nucleotide polymorphisms; whole genome sequencing), to provide fine grained information, including: bottlenecking and loss of diversity (such as through inbreeding), gene flow, signals of selection, changes in allele frequencies through time and space (landscape genomics), relative divergence, and relatedness with other populations. One difficulty with implementing this study may be obtaining adequate samples for analysis, both in terms of populations and numbers of individuals per population. Whole genome sequencing methods provide more information from smaller numbers of samples per population. For many populations, the only samples are historical museum specimens. Further, surveys have not been conducted to identify all current populations. Since the only population of NMMJM currently known to occur in the MRG (BdANWR) is very small, it might not be prudent to trap individuals to obtain tissue samples; benefits should be weighed against the risk of injury or death of individuals because of trapping. Any such trapping should be conducted with extreme care in accordance with USFWS permitting requirements and survey guidelines, to help prevent any trapping injuries or deaths.

3.4.5 Priority Ranking

Addressing this critical uncertainty is considered a *Level 1* priority (Table 3) because the sole known population of NMMJM in the MRG continues to decline and is at high risk of extinction due to small size and isolation (Wright and Frey 2015; see Appendix B-2 for additional detail). The technical workshop participants considered this study to have the highest urgency because results could be instrumental in preventing extinction of the BdANWR population. Although additional samples gained from distribution surveys would benefit a genetic study, the panel determined that a genetic study focused on the health of the BdANWR population was so important that it should not be delayed while surveys occur.

3.5 Critical Scientific Uncertainty #3: Non-Invasive Survey Methods

Study Question: How do non-invasive survey methods compare to trapping?

3.5.1 Scientific Relevance

Current USFWS survey guidelines are based on invasive trapping methods that can pose risk to populations and their habitat (USFWS 2015; Frey 2013b). Other commonly employed field methods to study small mammals (e.g., radio-telemetry) are also highly invasive. Many populations of NMMJM, including the only currently known in MRG, are likely currently too small to warrant use of invasive methods. Thus, there is an urgent need for effective non-invasive methods that can be used to survey for NMMJM and address other research on the critical uncertainties. Two non-invasive detection methods are currently being developed in research contexts, including track plates (Chambers 2017) and remote cameras (Lehnen et al. 2017), while other methods are also possible (e.g., environmental DNA [eDNA]). For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #3: Non-invasive Survey Methods*.

3.5.2 Management Application

Development of effective non-invasive methods would allow for surveys and research studies on NMMJM that eliminate many of the threats posed by traditional invasive methods. Many populations of the NMMJM, including the sole currently known population in the MRG (BdANWR), may be too small and isolated to warrant use of invasive methods to study the populations due to the serious risk imposed by live-trapping methods. However, because there have been so few surveys for the NMMJM in the MRG and so little research on the natural history of the NMMJM, there remains an urgent need to study the taxon to inform management. Consequently, development of an array of different non-invasive methods could allow for surveys and research, while minimizing risk to populations.

3.5.3 Recovery Application

Given the recent listing for the NMMJM, no recovery plan has been developed. Development of a scientifically defensible recovery plan will require research that addresses critical scientific uncertainties. For instance, the recovery outline (USFWS 2014c) concluded that conservation management will require research on critical aspects of NMMJM life-history (e.g., reproduction, abundance, survival, movement behavior), and to determine the ideal spatial configuration of restored suitable habitat along linear waterways such as canals or streams. However, conducting this research may not be prudent on many populations, including the sole currently known population in the MRG (BdANWR), because available methods are invasive and can pose a threat to population persistence. Consequently, development of non-invasive methods may provide the only avenue to obtain needed information to address the critical scientific uncertainties necessary to manage and recover the species (Figure 4).

3.5.4 Study Plan Considerations

Because the current survey guidelines are based on live-trapping, a study to develop survey methods based on non-invasive detection methods should ideally directly compare the non-invasive method with accepted live-trapping methods. Such comparisons should include detection rate, effort required to document NMMJM at a site if present; biological (e.g., non-target species, competitors, predators), environmental (e.g., habitat quality), and surveyor factors (e.g., expertise) that influence detection; and flexibility and efficacy of method for different situations. A distinction should be made between non-invasive detection methods (i.e., methods that detect the target species) and valid non-invasive survey methods (i.e., a complete program for documenting presence/absence of the target species at survey sites). Survey methods should evaluate sources of bias as well as false positive and false negative errors. Ideally, non-invasive methods should be developed and then tested in multiple populations representing an array of situations. Thus, most studies will require multiple years. The only population of NMMJM currently known to occur in the MRG (BdANWR) is very small. It is likely not prudent to use invasive methods (trapping) to study this population given its small size and elevated risk of extinction. Therefore, in most instances, non-invasive methods should be compared with conventional trapping methods in other populations that are large and have relatively lower threats.

3.5.5 Priority Ranking

Addressing this critical uncertainty is considered a *Level 2* priority (Table 3) because the sole known population of NMMJM in the MRG is small and use of invasive methods to survey and study this population is likely inappropriate in most instances due to the risk these methods pose to animals and their habitat. However, additional studies are needed to inform management and recovery actions.

3.6 Critical Scientific Uncertainty #4: Middle Rio Grande Population Habitat Attributes

Study Question: What are the attributes for foraging, day nesting, maternal nesting, and hibernation habitats in the MRG?

3.6.1 Scientific Relevance

The current state of knowledge about habitat associations of the NMMJM in the MRG is limited. Most studies have been conducted on montane populations. Only one study (Wright and Frey 2015) rigorously analyzed habitat selection on basis of quantitative data collected at three spatial scales. However, that study was conducted on one population (BdANWR) composed of few individuals. Consequently, sample sizes were small and the range of variation in available habitats was limited. Very little information is available about habitats associated with maternal nests and hibernation sites. Management actions by agencies to improve habitat for NMMJM have been conducted based on best available information (see Appendix B-2 *MRG Past and Current Management Activities*), but no research has been conducted to determine the efficacy of habitat restoration strategies for increasing occupied habitat. For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #4: MRG Populations Habitat Attributes*.

3.6.2 Management Application

Knowledge about habitats used by the NMMJM is necessary to identify and safeguard potentially occupied sites. Conversely, knowledge about habitats that are not used by the NMMJM can prevent needless expenditure of resources. For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #4: MRG Populations Habitat Attributes*.

3.6.3 Recovery Application

The recovery outline considers the NMMJM to currently lack resiliency and redundancy and has low representation. Availability of suitable habitat is a requirement for existence of a population. Information on habitat associations will help prevent curtailment of habitat and will allow for protection and restoration of suitable habitat to increase resiliency, redundancy, and representation. For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #4: MRG Populations Habitat Attributes.*

3.6.4 Study Plan Considerations

Studies designed to better understand the habitat relations of the NMMJM should be field based and should be conducted on populations within the MRG. Such field studies would likely need to occur over multiple years and include several MRG reaches to better understand the range of variation in use of habitat attributes. Habitat selection studies are usually done using telemetry to obtain fine-scale information on habitats selected by animals for different aspects of their life-history. However, the only currently known population of NMMJM in the MRG (BdANWR) is very small. It is questionable that adequate sample sizes could be obtained by studying this population at this time. In addition, it is likely not prudent to use invasive methods (trapping; telemetry) to study this population given its small size and high risk of extinction. Telemetry studies are considered particularly hazardous to small populations of NMMJM due to the relatively high potential that animals fitted with a radio collar will have reduced survival as a result. If the BdANWR population remains too small to safely conduct a telemetry study, or if no other populations of NMMJM are found within the MRG, then information gained from other select populations outside the MRG might provide some relevant information that can be applied to the MRG. However, such populations should be selected with care and should be located on a floodplain of a large order river in a non-montane, low elevation location, especially where the hydrology of the valley floor has been altered by irrigation works. However, studies conducted in other non-montane, low elevation locations that are not irrigated may also provide useful information about habitat use. Further, methods based on non-invasive detection methods should be explored as a means for studying habitat use at BdANWR.

Several study designs are available to evaluate habitat requirements. The simplest approach is description of habitat features at locations where the species is detected. However, a superior method is evaluation of used sites versus available sites as a resources selection function (Manly et al. 2002). Resource selection studies are recommended because they can determine the relative importance of habitat features (either selected or avoided by the species) and habitat selection can be evaluated at different scales (e.g., within geographic range, within home range). Habitat is usually investigated on basis of animal occurrences. Ideally, these occurrences should be corrected for detection probability to reduce sample bias. Critical independent variables should include those that have been found to be important for NMMJM in prior studies, including soil moisture; herbaceous layer composition, density and height; shrub layer composition, density and height; tree canopy cover, woody debris, soil type, hydrology, and vegetation type. However, other variables also might be appropriate.

3.6.5 Priority Ranking

Addressing this critical uncertainty is considered a *Level 3* priority (Table 3). Information on habitat associations is vital for managing and recovering species. However, the main reason this critical uncertainty ranks as a lower priority is because some information on selection of foraging habitat already exists for the MRG (BdANWR), as well as for montane populations. However, the existing data for the MRG represents a single study site of a small population and may not represent the range of variation that the species may occupy. In addition, there is relatively little information, range-wide, about selection for other habitat components including day nests, maternal nests, hibernation burrows, and travel corridors.

3.7 Critical Scientific Uncertainty #5: Population Dynamics

Study Question: What are the population dynamics for the NMMJM?

3.7.1 Scientific Relevance

There is very little information on population dynamics of the NMMJM. Existing data are limited to basic information about timing of emergence/immergence from hibernation by sex and basic information about timing of reproduction and litter size. No data exist on critical population vital rates such as survival, fecundity, and immigration/emigration. For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #5: Population Dynamics*.

3.7.2 Management Application

Lack of information about population dynamics increases uncertainty in predicting population viability and impacts of management or other actions on populations. For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #5: Population Dynamics*.

3.7.3 Recovery Application

Lack of information about population dynamics precludes ability to understand causes of population decline, which limits ability to devise recovery plans that can be assured of addressing factors that will result in resiliency. For more detailed technical information, see Appendix B-2, *Critical Scientific Uncertainty #5: Population Dynamics*.

3.7.4 Study Plan Considerations

Evidence suggests that there is considerable variation in critical population attributes (e.g., emergence dates, number of possible litters) between populations of NMMJM in montane locations and the MRG (Frey 2015a). Thus, information about population demographics drawn from other species or montane populations of the NMMJM may not apply to populations of the NMMJM in the MRG. Consequently, population demographic studies should be conducted on a population in the MRG. However, the only currently known population of NMMJM in the MRG (BdANWR) is very small and it is unlikely that adequate sample sizes could be obtained by studying this population. In addition, it is likely not prudent to use invasive methods (trapping) to study this population given its small size and high risk of extinction. Population demography studies must be long-term (multi-year) to understand the range of variation in environmental factors and how NMMJM respond to them. Estimating critical vital rates, including natality, mortality, immigration, and emigration, likely requires regular capturing and marking of individuals although there have been recent advances in models based on unmarked animals which should be considered. Survival rates should be evaluated relative to season, sex, age, body condition, habitat composition, and other environmental factors. Of particular interest is the number and timing of litters based on age, body condition, emergence date, and environmental factors and overwinter survival as function of sex, age, body condition, emergence/immergence dates, and environmental factors.

3.7.5 Priority Ranking

Addressing critical uncertainty #5: Population Dynamics, is considered a *Level 4* priority (Table 3). Information on population dynamics is vital for managing and recovering species. However, the main reason this critical uncertainty ranks as a relatively low priority is because there exists very little basic information on the NMMJM and the only currently known population of NMMJM in the MRG (BdANWR) is likely too small to be the focus of a study on population dynamics, which must occur on large numbers of animals over many years. Therefore, currently, the other critical uncertainties rank higher in importance simply because they are more feasible to implement.

Table 3. Study framework attributes for critical scientific uncertainties for the New Mexico Meadow Jumping Mouse.

Uncertainty Statement/Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Priority
Where are MRG populations located?	• Few reliable surveys done • Essential for population identification and protection • Opportunity to research habitat selection and population dynamics if a large, sustainable population is discovered	Field surveys: • Historical sites (where there is potential habitat) • Priority potential habitat Model development: • Inform screening criteria to map potential habitat at different scales • Prioritize field survey areas	Field studies: • Detection/Non-Detection with habitat data (soil moisture; herbaceous/shrub layer composition, density, height; tree canopy cover) Modeling: • Probability of Occurrence • Relative Occurrence Rate • Habitat Suitability Index (HSI)	• Multi-year • All MRG reaches	• Access/landownership issues • Permitting requirements • Distribution and habitat difficult to model • Vegetation type and microhabitat dependent • Need info on spatial habitat requirements for modeling	Level 1
What is the genetic variation within and between populations?	Level of inbreeding due to: • Isolation • Small population size Relationships among persisting populations to manage: • Inbreeding depression • Translocations • Captive breeding program • Habitat restoration for population connectivity and gene flow	Genetic analysis: • Fine-grained evaluation of genetic health (inbreeding) • Estimate contemporary gene flow among populations • Estimate evolutionary divergence of populations	• Inbreeding • Gene flow • Divergence • Relatedness	Range-wide: • Population comparisons • Identify potential source populations for translocation/captive breeding programs	• Difficult to obtain adequate sample sizes • Need surveys to identify all current populations • Invasive methods discouraged given small population size • Weigh risks/benefits of invasive methods	Level 1
How do *Invasive survey methods* (trapping, telemetry) compare to *Non-invasive methods* (e.g., models, remote cameras, track plates)?	Invasive: • Serious risk to the health of captured animals • Damage to sampled habitats • Some populations too small Non-invasive: • Develop reliable detection methods • Other uses (population trend monitoring and size estimation, habitat selection)	• Field surveys	• Detection rate • Effort required to document at a site if present • Biological (non-target species, competitors, predators), Environmental (habitat quality), and Surveyor (expertise) factors that influence detection • Sources of bias and error rates • Flexibility and efficacy of method	• Multi-year Non-invasive: • Develop different techniques • Different studies for each technique • Test in multiple populations • Represent array of situations	• The only currently known population in the MRG (BdANWR) is very small • Difficult to obtain adequate sample sizes • Invasive methods discouraged per small size and high risk of extinction • Conduct in other, larger populations with low threats	Level 2
What are the attributes for foraging, day nesting, maternal nesting, and hibernation habitats in the MRG?	• Very little known • Current habitat selection info (use vs availability) based on a single study of radio-collared individuals at BdANWR • Specific habitat uses and relations vary within and across ecotypes • Must fully understand habitat relations to understand threats, or develop conservation/mitigation measures	• Resource selection study design • Field study using telemetry • Explore non-invasive detection methods (e.g., combo of fine scale spatial models and using detections from remote cameras)	Dependent variable: • Occurrence: preferably as corrected by detection probability Independent variables: • Soil moisture, type • Herbaceous/Shrub layer composition, density, height • Tree canopy cover, woody debris, hydrology, vegetation community	• Multi-year • Include several reaches • Different, discrete studies in each area to better understand the range of variation in habitat attributes	• Only currently known population in the MRG (BdANWR) is very small • Difficult to obtain adequate sample sizes • Invasive methods discouraged given small population, high risk of extinction	Level 3
What are the population dynamics?	• No population dynamics studies done • Essential for determining population decline causal factors • Info from other species may not apply	• Long-term field monitoring of vital rates such as natality and mortality rates, im-/emigration • Regular capturing, individual marking; consider models based on unmarked animals	Survival rates based on: • Season, sex, age, body condition, habitat composition, environ factors Number/Timing of litters based on: • age, body condition, emergence date, environ factors • Overwinter survival as function of sex, age, body condition, im-/emergence dates, environ factors	• Long-term • Multi-year • MRG-focused • Large variation in key attributes (emergence dates, litter number) across ecotypes	• The only currently known population in the MRG (BdANWR) is very small. • Difficult to obtain adequate sample sizes • Invasive methods discouraged given small population, high risk of extinction	Level 4

4 CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE SOUTHWESTERN WILLOW FLYCATCHER

During a review of the current state of scientific knowledge on the SWFL at the October 2016 technical workshop (see Appendix C-1 for workshop notes), there was general consensus among the agency SMEs that extensive survey and substantive research efforts over the past few decades along the MRG and across the SWFL's range have elucidated the SWFL's natural history requirements, population status, threats, and response to recovery efforts. Nonetheless, the SMEs delineated approximately 15 (later combined into 11) scientific topics that were less studied and less understood, and they identified the top five scientific uncertainties that affect management decisions for the SWFL and, thus, should be the focus of future scientific efforts (see Appendix C-1).

The following narrative presents *brief overviews* of the scientific relevance, management application, and recovery application for each critical scientific uncertainty. *In-depth reviews of these topics, along with listing history, recovery efforts, population status, MRG management actions, and additional reference citations are provided in* Appendix C-2. Study plan considerations also are offered in this section for each critical scientific uncertainty to guide Collaborative Program signatories with internally developing study plans or soliciting detailed technical proposals from the scientific community.

4.1 Critical Scientific Uncertainties

The agency SMEs prioritized the following four critical scientific uncertainties for scientific study (ranked 1 = Highest to 4 = Lowest):

1) The strategy for prioritizing sites for SWFL breeding habitat restoration in the MRG.
2) The impact of the tamarisk beetle (*Diorhabda*) on SWFL breeding habitats in the MRG.
3) SWFL breeding population sizes, distributions, and trends along the Angostura Reach.
4) SWFL metapopulation structure and dynamics in the MRG.

Ranked fifth was "The abiotic and biotic variables that predict suitable and unsuitable SWFL habitats across multiple spatial and temporal scales in the MRG." However, this topic does not receive expanded review and consideration in this section because it was ranked as a significantly lower priority than the four critical scientific uncertainties listed above.

4.2 Connectivity Among Critical Scientific Uncertainties

The top four critical scientific uncertainties for the SWFL are interconnected; research on one informs research (e.g., provides similar or baseline data) on the other (Figure 5). More specifically, all four critical scientific uncertainties relate in some degree to identifying the following:

- Where SWFLs and/or their habitats are located along the river (critical scientific uncertainties #1-4);
- Threats to SWFL populations (critical scientific uncertainties #2-4);
- Which and where management and recovery actions, particularly SWFL habitat restoration, should be implemented to benefit or avoid jeopardy to the SWFL (critical scientific uncertainties #1-4); and
- The effects of management and recovery actions on SWFL populations (critical scientific uncertainties #1-4).

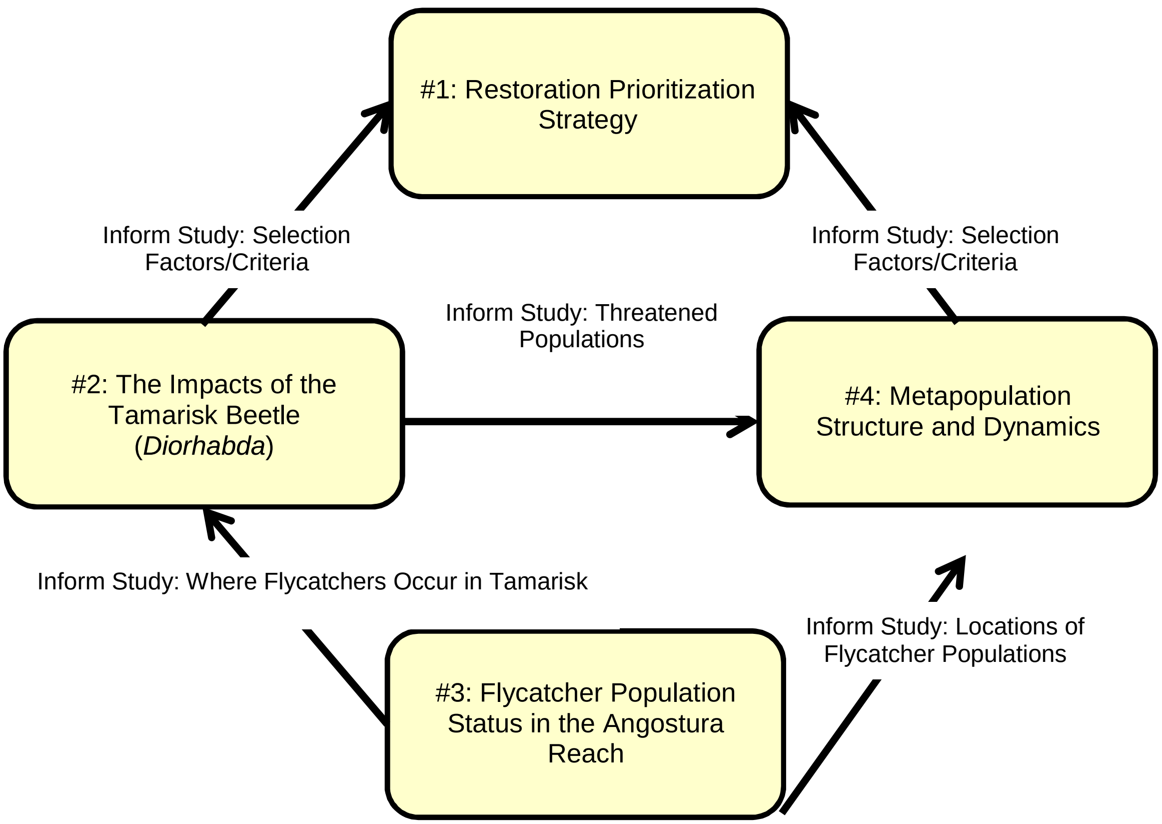

Figure 5. Relationships among critical scientific uncertainties for the Southwestern Willow Flycatcher in the Middle Rio Grande, New Mexico.

4.3 Critical Scientific Uncertainty #1: Restoration Prioritization Strategy

Study Question: What site selection and prioritization procedures contribute to the successful restoration of SWFL breeding habitats along the MRG?

4.3.1 Scientific Relevance

Although restoration projects in the MRG have resulted in the successful creation of native riparian habitats, less than a handful of restoration sites in the MRG support breeding SWFLs (e.g., Moore and Ahlers 2017, USFWS unpubl. data). Furthermore, there is no evidence that there has been sufficient creation of suitable SWFL breeding habitats to offset impacts of management actions and/or protect and stabilize SWFL populations (Moore 2009, SWCA Environmental Consultants [SWCA] 2014, Siegle et al. 2016). It is difficult to pinpoint the reason for such limited success in creating suitable SWFL breeding habitats; restoration success is contingent upon a number of interrelated factors, such as adequate funding, strong working partnerships and coordination among stakeholders, and well-designed and well-implemented restoration actions. Nonetheless, the SMEs who participated in the SWFL workshop determined that future success of the Collaborative Program's habitat restoration program is, in part, dependent upon the development of a scientifically-based habitat restoration prioritization strategy that provides managers with guidance on how best to 1) evaluate the contemporary conditions (hydrology, soils, vegetation, etc.) of potential SWFL restoration sites across the MRG and 2) consistently prioritize for restoration those sites where management efforts have the highest likelihood of successfully creating suitable SWFL breeding habitats. Scientific inquiry will be required to determine which selection factors and criteria pertaining to the SWFL's life-history requirements and recovery needs should be included in such a strategy.

4.3.2 Management Application

Currently, managers lack a MRG-wide decision-making tool for consistently selecting those sites for restoration that have the highest SWFL breeding habitat restoration potential. Results of studies addressing the critical scientific uncertainty will help managers develop a science-based MRG-wide habitat restoration prioritization strategy that 1) facilitates coordinated and repeatable selection for restoration those sites that support the conditions necessary for successful creation of suitable SWFL breeding habitats, 2) reduces factors limiting restoration success, and 3) supports Collaborative Program partners' efforts to effectively offset the impacts of management actions on the SWFL (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #1:Management Application*).

4.3.3 Recovery Application

Research addressing the critical scientific uncertainty will help managers implement recovery actions outlined in the SWFL Recovery Plan (USFWS 2002; hereafter, "Recovery Plan"). Specifically, research results will help managers develop science-driven methods (Recovery Action 6) to identify and prioritize for restoration those sites with existing conditions (hydrology, soils, vegetation) that can be cost-effectively manipulated to create or improve SWFL breeding habitats (Recovery Action 1: *Increase and improve occupied, suitable, and potential breeding habitat*). When developed and if effectively implemented across the MRG, a SWFL habitat restoration prioritization strategy can reduce or remove any influence of poor site-selection on restoration success and, thus, should lead to increased creation of suitable SWFL breeding habitats conducive to occupancy by and maintenance of breeding SWFLs (Recovery Action 2: *Increase Metapopulation Stability* and Recovery Action 3: *Improve Demographic Parameters*).

By assisting managers in implementing recovery actions 1, 2, 3, and 6, studies on the critical scientific uncertainty will help managers implement BiOps resulting from ESA §7(a)(2) consultations (Recovery Action 8.2; e.g., USFWS 2016) and support conservation efforts in compliance with ESA §7(a)(1) of the ESA (Recovery Action 8.3.1). Furthermore, if the SWFL habitat restoration prioritization strategy can be integrated into a comprehensive habitat restoration prioritization strategy that addresses all or other needs of the Collaborative Program (e.g., addresses both the needs of the SWFL and the YBCU), then the strategy also will help managers implement Recovery Action 8.4: *Integrate recovery efforts with those for other species*.

4.3.4 Study Plan Considerations

The process detailed below and illustrated in Figure 6 addresses the primary study question, "What site selection and prioritization procedures contribute to the successful restoration of SWFL breeding habitats along the MRG?"

Step 1: Define Restoration Goals and Targeted Outcomes. Although some broad goals for SWFL breeding habitat restoration are provided in the Middle Rio Grande Adaptive Management Plan (Murray et al. 2011:12), no targeted outcomes (i.e., management objectives and performance measures) have been defined that clearly articulate the desired future conditions for the SWFL or its habitats in the MRG. As clearly defined goals and objectives are "key requirements for all ecosystem-based management approaches" (Lower Columbia Estuary Partnership [LCEP] 2012:vi), a necessary first step is to develop these outcomes for the MRG. To evaluate if restoration targeted outcomes are achieved, it is crucial that the outcomes be specific and measurable. Possible outcomes include 1) occupancy of a specified proportion of restoration sites by a quantifiable number of SWFLs (e.g., a single territorial SWFL, a breeding pair of SWFLs, 10 breeding pairs), and 2) a specified proportion of restoration sites or a specified geographic extent supporting quantifiable SWFL breeding habitat types and attributes that confer suitability (e.g., USFWS 2002, Moore 2009, SWCA 2014, Siegle et al. 2016, USFWS 2016).

Step 2: Identify and Evaluate Previously Developed and Utilized Restoration Prioritization Strategies. Several restoration prioritization strategies have been proposed in MRG restoration planning reports (e.g., Parametrix 2011, USBR 2012, Tetra Tech 2015), but it is unclear whether and to what degree these strategies have been employed in the implementation of actual restoration projects. This step should involve inventorying existing restoration prioritization strategies, evaluating the line of scientific evidence for which selection factors (i.e., those elements considered when making a decision) and criteria (i.e., the priority range or threshold of values for each selection factor) are included in each strategy (Figure 7), and documenting which restoration projects, if any, have utilized restoration prioritization strategies in the planning phase.

Step 3: Explore Relationships Between Restoration Prioritization Strategies and Successful Restoration Outcomes. For those restoration projects that have employed restoration prioritization strategies during the project planning phase, it is useful to determine if the strategies were correlated with successful creation and restoration of suitable SWFL breeding habitats, as well as other defined goals and objectives for the SWFL. A number of statistical tests, modelling approaches, and software programs are available to analyze the relationships between restoration outcomes and utilized strategies. Prior to conducting these analyses, standardized methods should be developed to assess the effectiveness of restoration projects in achieving the targeted outcomes for both the SWFL and its habitats established above in Step 1 (SWCA 2014). SWFL outcomes at restoration sites can be ascertained from completed and on-going standardized surveys and monitoring efforts (e.g., Moore and Ahlers 2017; Appendix C-2, *Flycatcher Critical Scientific Uncertainty #3*); however, additional surveys and nest monitoring studies likely are necessary to obtain sufficient data on SWFL presence, reproductive success, and survivorship. Similar to habitat assessments described in Appendix D-2, *Cuckoo Critical Scientific Uncertainty #1: Study Plan Considerations*, quantifying habitat outcomes should involve both field-based assessments and remote sensing monitoring (e.g., LIDAR, Landsat Thematic Mapper) of key ecosystem attributes at restoration sites, such as vegetation composition and structure, patch size, and surface water and groundwater dynamics. Wherever possible, data on habitat conditions at restoration sites should be obtained from completed and on-going restoration assessments (e.g. Moore 2009, SWCA 2014, Siegle et al. 2016); however, habitat conditions at some restoration sites will need to be reassessed to obtain accurate and current data as vegetation characteristics (e.g., vegetation structure, plant species composition, distribution, geographic extent) change over time. It is essential that data on habitat outcomes be contemporary to data on SWFL outcomes (e.g., occupancy by breeding SWFLs).

Step 4: Conduct Efficacy Analyses of Restoration Prioritization Strategy Elements. To help identify which selection factors and criteria contribute most or least to a successful restoration prioritization strategy, the selection factors and criteria included in strategies utilized in successful restoration projects should be compared and contrasted with those of strategies utilized in less or unsuccessful projects.

Step 5: Improve Restoration Prioritization Strategy. Step 5 involves identifying how existing restoration prioritization strategies can be improved to yield the maximum benefits for the SWFL. Specifically, constructing a final SWFL habitat restoration prioritization strategy for the MRG requires:

- Building upon the results of Step 4 and identifying those selection factors and criteria of existing prioritization strategies that should be excluded or retained;
- Determining if criteria in existing prioritization strategies should be adjusted; and
- Determining if additional selection factors and criteria should be included (Figure 7).

The last two bullets above likely will involve literature review, data mining, and original quantitative research studies. Valuable sources for literature review and data mining efforts include scientific and gray literature on SWFL life-history requirements and recovery needs (e.g., USFWS 2002, 2013a), existing SWFL HSIs (e.g., Siegle et al. 2013, Hatten 2016), and habitat restoration prioritization strategies currently implemented in other large ecosystem-level restoration programs (e.g., the Lower Colorado Multi-Species Conservation Program [2006]). There is much flexibility and variety in the types of research studies undertaken and methods employed to investigate which selection factors and criteria should be included in a restoration prioritization strategy for the MRG; studies can be empirical (i.e., collection of observational data, field-based AM experiments), theoretical (i.e., involve modelling), or both.

To illustrate the types of research studies that could be conducted, an investigation of the question, "Does inclusion of the section factor *distance of restoration sites to existing SWFL breeding populations* in a SWFL habitat restoration prioritization strategy increase probability of occupation by breeding SWFLs?" could involve:

- Analyzing correlations between successful SWFL occupancy of completed restoration projects and distance to existing breeding populations; and/or
- Completing an AM experiment that entails 1) gleaning from the scientific literature the maximum and optimal distances between metapopulations to promote metapopulation dynamics, as well as the optimal distance that restoration should be completed away from existing breeding SWFLs to avoid take of SWFLs or their eggs, 2) using the results of the literature review to design and implement restoration at variable distances from existing SWFL breeding populations and, then, 3) assessing SWFL occupancy and other population metrics over a predetermined timeframe (e.g., 1, 5, and 10 years after restoration).

Aspects such as logistics, cost, study duration, and training and permit requirements will depend on the types of studies conducted and methods employed. Field-based research likely will require specialized training and permits (e.g., SWFL survey, detection, and nest monitoring training and ESA Section 10a permits), and data collection over multiple years.

Step 6: Finalize Restoration Prioritization Strategy. A formal MRG-wide SWFL habitat restoration prioritization strategy should be constructed using the information from Step 5 on which selection factors and criteria ought to comprise the strategy. Once finalized, the restoration prioritization strategy, along with all instructions and tools necessary for implementing the strategy, should be made available to all managers in the MRG.

Step 7: Apply Restoration Prioritization Strategy to MRG. After completing Step 6, potential restoration sites along the MRG should be assessed using the finalized restoration prioritization strategy to determine pre-existing conditions and then those sites with the most favorable conditions should be selected and prioritized for restoration efforts, such as habitat enhancements or creation. Sites also can be assessed to determine if actions other than restoration, such as protection, should be implemented. Generated products useful to managers should include GIS databases of sites, their pre-existing conditions, and their restoration attributes (e.g., high priority for restoration, low restoration potential).

<u>Next Steps: Complete Restoration, Monitoring, Evaluation, and Adjustment</u>. In order to determine whether the restoration prioritization strategy designed through the above described process effectively promotes restoration and achievement of targeted outcomes of the SWFL and its habitats, we recommend managers:

1) Design and implement restoration at the priority sites based on the best available science;
2) Monitor, using standardized protocols, the status and trends of the SWFL and ecosystem conditions;
3) Evaluate whether targeted outcomes are met; and
4) Determine if and how future management actions should be adjusted through the AM process.

Because water resources and funding are limited and managers must balance the habitat needs for multiple species of conservation concern, managers also might want to evaluate whether the SWFL habitat restoration prioritization strategy acts as an “umbrella” for other species of concern, promoting restoration successes for such species as the YBCU and the RGSM, or if it is strategically advantageous to integrate the SWFL habitat restoration prioritization strategy into a comprehensive habitat restoration prioritization strategy for the MRG.

4.3.5 Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 1* priority (Table 4) and was ranked #1 of the top four SWFL critical scientific uncertainties identified by the SMEs.

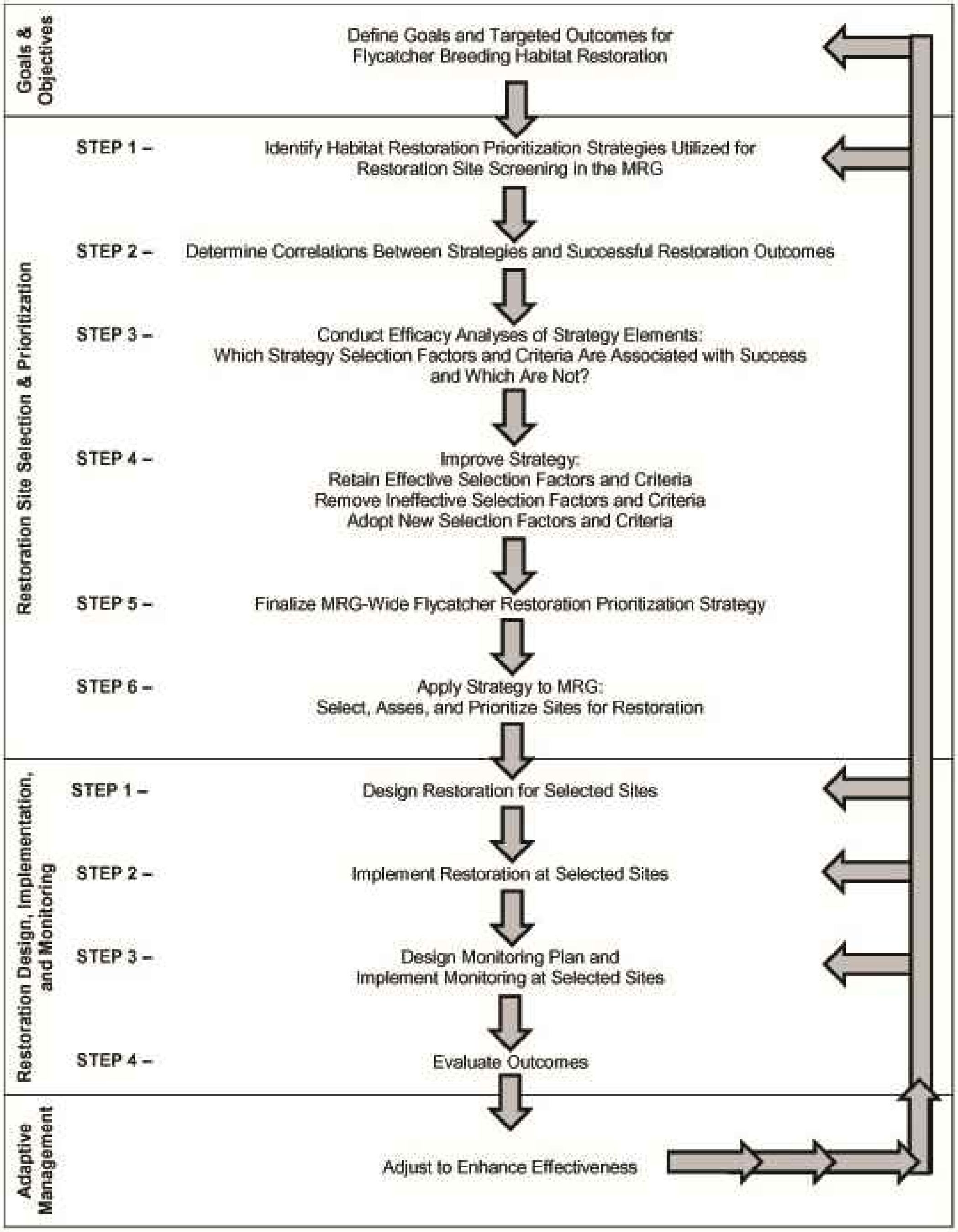

Figure 6. Middle Rio Grande-wide Southwestern Willow Flycatcher restoration prioritization strategy development process.

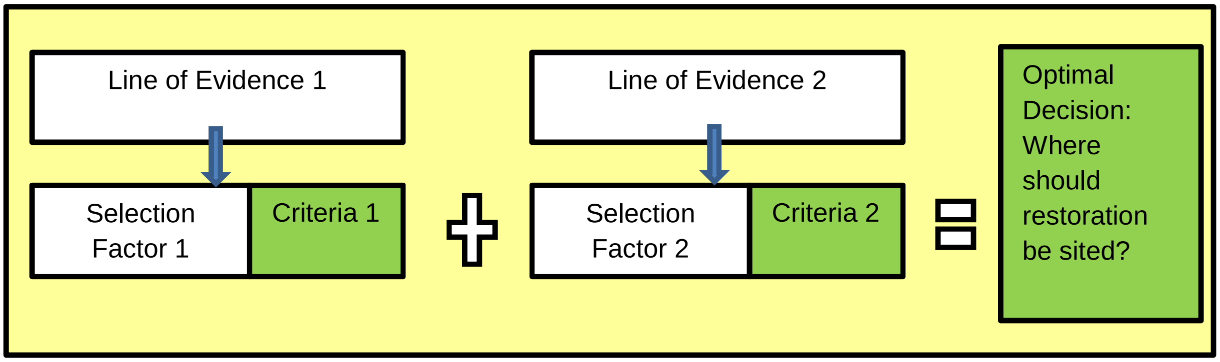

Figure 7. Multi-criteria habitat restoration priority strategy.*

*Model (adapted from the Lower Columbia Estuary Partnership [2012]) showing how optimal decisions regarding evaluation and prioritization of restoration projects are based on inclusion of selection factors and criteria that are derived from rigorous scientific information about the life-history requirements and recovery needs of the southwestern willow flycatcher (Line of Evidence).

4.4 Critical Scientific Uncertainty #2: The Impacts of the Tamarisk Beetle

Study Question 1: What are the impacts of the tamarisk beetle (*Diorhabda*) on SWFLs and suitable SWFL breeding habitats in the MRG?

Study Question 2: Which unoccupied and occupied suitable SWFL breeding habitats in the MRG are most threatened by *Diorhabda* in the near- and long-term?

4.4.1 Scientific Relevance

In an effort to control the spread of exotic tamarisk (*Tamarix*) in the Southwest, a chrysomelid leaf beetle, *Diorhabda spp.*, was released beginning in 2001 in Colorado, Nevada, California, Utah and other states, with the restriction that release sites be more than 200 miles from any known SWFL breeding territory (Dudley et al. 2001, Dudley and Bean 2012). In New Mexico, *Diorhabda* was released only in the eastern part of the state. However, *Diorhabda* populations originally established in 2001 in the Four Corners region of Utah and Colorado spread into northwestern New Mexico beginning in 2009 and, as a result of subsequent rapid southeastward dispersal, *Diorhabda* is now considered to be present throughout the MRG (Johnson and Jamison 2015, Tamarisk Coalition 2016, BEMP 2016). As *Diorhabda* is now firmly established in the MRG and its spread is unchecked, it can have substantial impacts on tamarisk vegetation used by SWFLs, as well as SWFLs themselves (Figure 8). Research efforts are underway to determine the distribution of *Diorhabda* in the MRG, and the timing and impacts of *Diorhabda* herbivory on tamarisk; however, the actual impacts of *Diorhabda* on the SWFL and its breeding habitats are largely unknown and little studied (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #2: Scientific Relevance*). As a large proportion of SWFLs nesting in the MRG could be negatively impacted by *Diorhabda* defoliation and resultant die-offs of tamarisk, the SMEs recommend that scientific studies be completed to improve our understanding of the ecological impacts of *Diorhabda* on the SWFL, including whether

Diorhabda alters the composition and abundance of the SWFL's arthropod prey community, impacts SWFL nest success, and affects the availability and suitability of SWFL nesting substrates and habitats.

4.4.2 Management Application

Studies investigating this critical scientific uncertainty will meet the Collaborative Program's needs for science-based advancements in our knowledge of the impacts of *Diorhabda* on the SWFL and its habitats. Data from such studies can inform management decision-making approaches to tamarisk removal, native habitat restoration, and other mitigation actions to minimize *Diorhabda* threats to the SWFL. Principally, rigorous quantitative scientific information on how and where *Diorhabda* affects the SWFL and its habitats currently or in the near-future will be useful for developing a strategy for selecting and prioritizing for restoration suitable flycatcher breeding habitats that are most at risk of potentially large-scale negative impacts from *Diorhabda* defoliation and resultant die-offs of tamarisk (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #2: Management Application*). Collaborative Program partners implementing such proactive restoration is essential to minimizing *Diorhabda* threats to the SWFL.

4.4.3 Recovery Application

Research on the impacts of *Diorhabda* on both the SWFL and tamarisk-dominated vegetation suitable to the SWFL falls within a priority research topic identified in the Recovery Plan (USFWS 2002), *Identify factors that may be limiting population stability* (Recovery Action 6.7.2). Results of this research will assist managers in implementing recovery actions to 1) increase and improve suitable and potentially suitable[1] SWFL breeding habitats by managing exotic plant species (Recovery Action 1.1.3.2), and 2) improve demographic parameters (Recovery Action 3). Specifically, the research will provide information useful in designing and implementing tamarisk removal and native habitat restoration efforts aimed at preventing or mitigating potentially large-scale negative impacts to the SWFL (e.g., reduced survival, reduced nesting success) resulting from *Diorhabda* defoliation and resultant tamarisk die-offs. Furthermore, study results will help to ensure that managers implement laws, policies, and agreements that benefit the SWFL (Recovery Action 8), including *implementing Biological Opinions resulting from ESA §7(a)(2) consultations* (Recovery Action 8.2; e.g., USFWS 2016) and *supporting compliance with ESA §7(a)(1) of the ESA* (Recovery Action 8.3.1).

[1] From USFWS (2002:16), potentially suitable habitat (= "potential habitat") is defined as a riparian system that does not currently have all the components needed to provide conditions suitable for nesting flycatchers (as described above), but which could – if managed appropriately – develop these components over time.

4.4.4 Study Plan Considerations

The critical scientific uncertainty is a complex topic and it, along with the two study questions, should be addressed by adopting an integrative research strategy that involves answering a number of interrelated questions. Specifically, it is necessary to ascertain where *Diorhabda* are and where they will be, how *Diorhabda* alter their environment, and what vegetation will remain after *Diorhabda*-caused tamarisk defoliation and mortality. The geographic distribution and abundance of *Diorhabda* and the timing and extent of tamarisk defoliation by *Diorhabda* and refoliation currently are being tracked in the MRG (e.g., Johnson and Jamison 2015, BEMP 2016, Tamarisk Coalition 2016, Dillon and Ahlers 2017) and are incidentally recorded during standardized SWFL surveys (USFWS unpubl. data). However, these efforts should be expanded to encompass the entire MRG and to address questions specific to the critical scientific uncertainty, such as:

- What proportions of unoccupied and occupied suitable SWFL breeding habitats in the MRG are currently, or will be in the near future, infested with *Diorhabda*?
- Does the timing of tamarisk defoliation by *Diorhabda* in the MRG coincide with SWFL nesting?

Concurrent or consecutive to *Diorhabda*-specific studies, the impacts of *Diorhabda* on the SWFL and its required habitats should be evaluated where *Diorhabda* occurs in unoccupied and occupied habitats suitable to breeding SWFLs. This evaluation likely is best accomplished by conducting separate, but complimentary, rigorous quantitative studies investigating interactions of multiple trophic levels and multiple ecosystem components across multiple temporal and spatial scales. Priority questions for study include:

- What are the relationships of *Diorhabda* abundance and tamarisk defoliation with SWFL nest success in the MRG?
- How does *Diorhabda* defoliation and resultant die-offs of tamarisk alter prey composition and availability in SWFL breeding habitats in the MRG?
- How does *Diorhabda* defoliation and resultant die-offs of tamarisk alter microhabitat and patch characteristics of unoccupied and occupied suitable SWFL breeding habitats in the MRG?
- Is passive revegetation of native vegetation occurring in areas where *Diorhabda* defoliation has resulted in tamarisk die-offs and, if so, is this vegetation suitable or projected to become (i.e., potentially) suitable for breeding SWFLs?
- Does *Diorhabda* significantly reduce SWFL breeding habitat suitability and availability in the MRG?

Studies addressing the critical scientific uncertainty should utilize existing datasets, as well as build on and augment completed and on-going work (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #3*). For example, data on the distribution of suitable SWFL habitats and SWFL populations in the MRG can be compiled from existing literature (e.g., Siegle et al. 2013, Tetra Tech 2015, Hatten 2016, Tracy et al. *in prep*) and standardized SWFL survey reports (e.g., Moore and Ahlers 2017) and databases (e.g., USFWS unpubl. data).

The integrative research strategy required for answering the critical scientific uncertainty necessitates knowledge of a diversity of disciplines (e.g., ornithology, entomology, botany, demography, community ecology), sampling techniques and technologies (e.g., nest monitoring, arthropod collection, vegetation sampling), data analysis and modelling methods (e.g., analyzing large, multivariate datasets), collection and management of large ecological datasets, and data collection over multiple years. Aspects such as logistics, cost, study duration, and training and permit requirements will depend on the types of studies conducted and methods employed.

4.4.5 Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 2* priority (Table 4) and was ranked #2 of the top four SWFL critical scientific uncertainties identified by the SMEs.

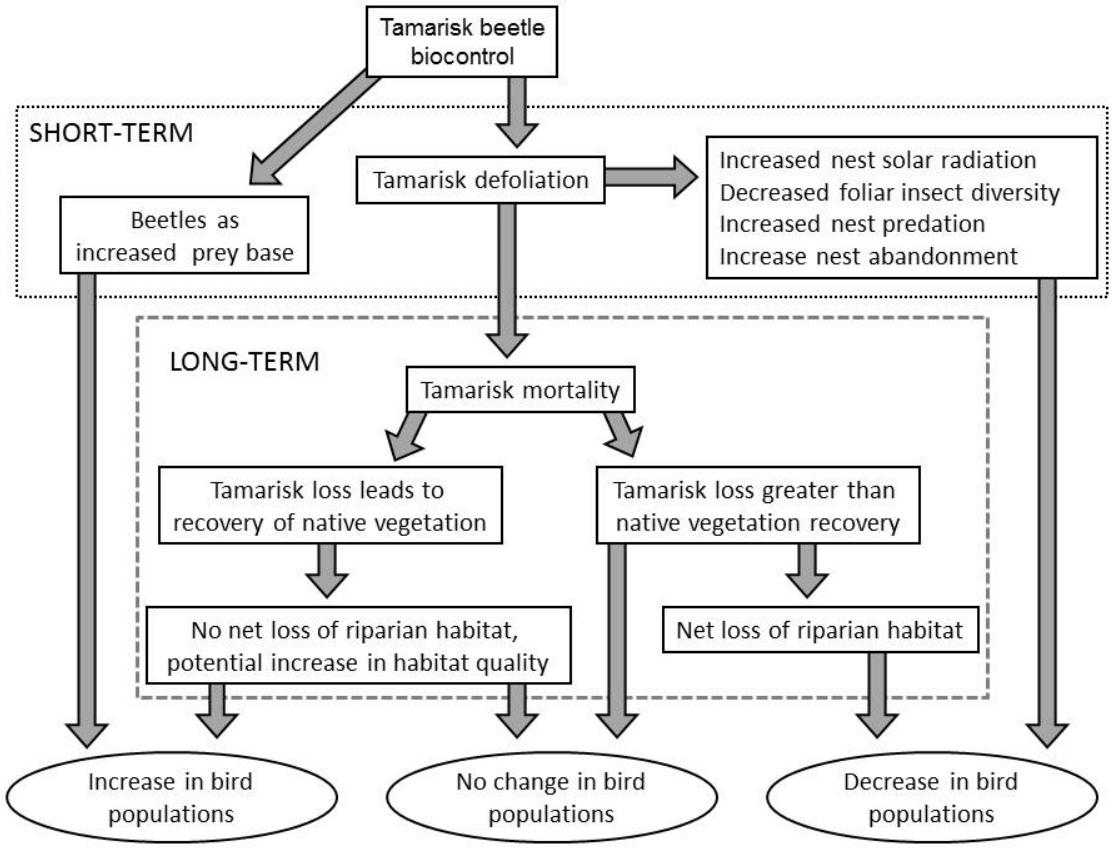

Figure 8. Hypothesized model of effects on tamarisk beetle on birds*.

*Hypothesized model of three primary ways that biocontrol of tamarisk trees by the tamarisk beetle can affect avian populations in riparian systems (reproduced with permission from Paxton et al. [2011:258]). In the short term, prior to the trees' death, tamarisk beetles could provide a food source for insectivorous birds as beetle populations expand. Defoliation and mortality of tamarisk, however, will eventually reduce habitat quality by reducing abundance of other insect prey dependent on foliage and by removing canopy cover critical for reducing exposure of nests to predators, brood parasites and the extreme temperatures typical of the southwestern United States. The long-term consequences of tamarisk mortality will depend on the rate of vegetation recovery after the tamarisk dies; these consequences might range from no net loss of habitat if native vegetation recovers at the same rate as tamarisk dies to net loss of habitat when tamarisk mortality is not followed by regrowth of other riparian vegetation.

4.5 Critical Scientific Uncertainty #3: Flycatcher Population Status in the Angostura Reach

Study Question: What are the sizes, distributions, and trends of SWFL breeding populations along the Angostura Reach?

4.5.1 Scientific Relevance

SWFL survey and monitoring efforts are extensive in the MRG (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #3: Scientific Relevance*). However, suitable SWFL breeding habitats in some areas along the Rio Grande have never been surveyed, have not been surveyed recently, or have been surveyed inconsistently (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #3: Scientific Relevance*). Thus, it is challenging to compute an accurate MRG-wide population estimate. To improve population estimates for the MRG, the SMEs recommend that surveys be completed where efforts are outdated, inconsistent, minimal, or absent. Specifically, the SMEs recommend that concurrent and repeated standardized SWFL surveys be conducted within all suitable SWFL breeding habitats along the Angostura Reach, which extends approximately 41 miles from the Angostura Diversion Dam downstream to the Isleta Diversion Dam. Results of these surveys will help to determine with better accuracy if and where the SWFL is present in the reach, as well as the sizes and trends of any located SWFL breeding populations. To identify which factors affect SWFL breeding populations in the reach, the SMEs also recommend that survey efforts be augmented by scientific investigations on potential limiting factors, such as those on habitat availability, prey composition and availability, and nest success.

4.5.2 Management Application

Concurrent and repeated standardized SWFL surveys within all suitable SWFL breeding habitats along the Angostura Reach, particularly those proposed for biotic, geomorphologic, and hydrologic alterations, will provide managers with the data necessary for effectively mitigating and assessing the effects of their actions on SWFLs in the reach (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #3: Management Application*). Principally, collected data on locations of breeding SWFLs and their nests will inform siting of management actions:

- Projects that benefit the SWFL (e.g., planting native vegetation) can be sited near existing SWFL populations, and
- Projects that jeopardize the SWFL (e.g., vegetation removal) can be sited away (e.g., greater than 0.4 km [0.25 mi]) from breeding territories and nest sites.

Furthermore, data on where SWFL populations are declining, and which factors are limiting or threatening SWFL populations can help managers determine which and where management actions should be implemented to improve the status of the SWFL. Finally, survey data collected before, during, and after implementation of management actions can help managers evaluate the effects of their actions on SWFLs and implementing AM.

4.5.3 Recovery Application

The Recovery Plan (USFWS 2002) recommends that SWFL breeding populations and suitable SWFL breeding habitats in the Southwest be surveyed and monitored to assess population status and trends, and track recovery progress (Recovery Action 5: *Survey and Monitor*). Completing comprehensive SWFL surveys in the Angostura Reach can contribute to these recovery efforts by helping to determine with greater accuracy if recovery criteria are being met for the Middle Rio Grande Management Unit, the Rio Grande Recovery Unit, the state, and range-wide (Recovery Action 5.1.3). Furthermore, when the surveys are repeated in the reach over multiple years, they can help to document dispersal movements, colonization events, and population changes (Recovery Action 5.3). In addition, surveys conducted before and after implementation of recovery actions can be used to assess the efficacy of such actions (recovery actions 5.2, 5.2.1).

As described above in Management Application, survey results, such as locations of breeding SWFLs and their nests, also can inform siting of recovery actions. In particular, survey results can help to ensure that recovery actions, such as habitat restoration, are sited sufficiently near existing SWFL breeding populations to benefit the SWFL (Recovery Action 1: *Increase and improve currently suitable and potentially suitable habitat*), but are not sited too close to existing SWFL breeding populations that they jeopardize SWFLs or their nests (Recovery Action 3.1.2: *Reduce direct impacts that topple or otherwise destroy nests*). Similarly, studies on which factors are limiting or threatening SWFL populations in the reach—a priority research topic identified in the Recovery Plan (Recovery Action 6.7.2: *Identify factors that may be limiting population stability*)—will provide data essential for determining where and which recovery actions should be implemented to improve the status of the SWFL.

By assisting managers in implementing recovery actions 1, 3, 5, and 6, studies on the critical scientific uncertainty will help managers implement Recovery Action 8: *Assure implementation of laws, policies and agreements that benefit the SWFL*, including *implementing Biological Opinions resulting from ESA §7(a)(2) consultations* (Recovery Action 8.2; e.g., USFWS 2016) and *supporting compliance with ESA §7(a)(1) of the ESA* (Recovery Action 8.3.1).

4.5.4 Study Plan Considerations

Addressing the critical scientific uncertainty involves data mining, standardized protocol surveys (e.g., Sogge et al. 2010), nest searching and monitoring, and, possibly scientific research. Specifically, determination of historical and recent SWFL population sizes and distributions along the Angostura Reach requires extensive data mining of hardcopies of survey forms dating back at least 20 years, as well as cross-checking survey form entries with corresponding information in the USFWS database (unpubl. data). Investigation of current SWFL population sizes and distributions entails 1) verifying and mapping locations of previous survey routes to ensure consistency in site-naming and to establish and name new survey routes, 2) coordinating standardized protocol surveys and data reporting among any and all agencies and organizations involved in on-going surveys of the reach, and 3) completing standardized protocol surveys (e.g., Sogge et al. 2010) in those areas not covered by existing surveys. All sites along the reach should be surveyed concurrently within each year of the study to ensure that survey results are comparable within and among years. In addition, multiple years of surveys are necessary to assess SWFL population trends in the Angostura reach and whether population sizes are increasing, decreasing, or remaining stable.

To identify which factors affect SWFL breeding populations in the reach, it is essential that survey efforts be augmented by scientific investigations on potential limiting factors, such as those on habitat availability, prey composition and availability, and nest success. These investigations likely involve time- and labor-intensive fieldwork conducted over multiple years. Therefore, separate studies likely will be necessary to investigate each factor. Wherever possible, data should be obtained from completed and on-going complimentary studies (e.g., see Appendix C-2, *Flycatcher Critical Scientific Uncertainties #2 and #4*). If resources are limited, surveys are a priority over investigations on potential limiting factors.

Field studies will require permission to access survey sites from a multitude of landowners (municipal, county, state, federal, and tribal) and any work entailing SWFL surveys, monitoring, and handling will necessitate obtaining specialized training and permits (e.g., SWFL survey, detection, and nest monitoring training and ESA Section 10a permits).

4.5.5 Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 2* priority (Table 4). It was ranked #3 of the top four SWFL critical scientific uncertainties identified by the SMEs, but the ranking was nearly tied for second place with the Critical Scientific Uncertainty #2 *The Impacts of the Tamarisk Beetle*.

4.6 Critical Scientific Uncertainty #4: Flycatcher Metapopulation Structure and Dynamics

Study Question: What is the connectivity among SWFL populations in the MRG?

4.6.1 Scientific Relevance

No SWFL metapopulation studies have been completed in New Mexico. Existing SWFL survey and monitoring efforts in New Mexico primarily document territory locations and do not provide data on connectivity and stability of populations (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #4: Scientific Relevance*). Information gained from studies conducted outside of the state, such as those in Arizona, cannot be directly applied to the MRG as both metapopulation structure (i.e., the number, size, and distribution of metapopulations) and dynamics (i.e., the processes that connect and effect metapopulations, such as extinction and colonization through immigration and emigration) are influenced by local population sizes and the spatial arrangement of SWFL breeding habitats at local and landscape scales (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #4: Scientific Relevance*). Thus, the SMEs concluded that MRG-specific information is needed as to whether populations in the MRG function as metapopulations, which populations are sources and which are sinks, and how changes in one population affect other populations. In addition, the SMEs concluded that information specific to the MRG is needed to determine if and how SWFL metapopulation structure and dynamics will be affected by any future loss, fragmentation, degradation, and restoration of riparian woodlands.

4.6.2 Management Application

To offset the effects of water management actions on the SWFL and its habitat, managers must protect, restore, and create riparian vegetation that is occupied by breeding SWFLs and promotes flourishing and stable SWFL metapopulations in the MRG. To this end, managers require, in part, effective and MRG-specific restoration siting criteria (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #1*). Such criteria can be crafted, to some extent, based on the results of studies on SWFL metapopulation structure and dynamics; these studies yield useful data on 1) at what distance efforts to establish, develop, and maintain suitable SWFL breeding habitats in the MRG should be sited from existing SWFL breeding populations to ensure successful colonization of restoration sites, and 2) how best to geographically distribute restoration efforts across the MRG to connect spatially separate SWFL breeding populations and promote metapopulation dynamics (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #4: Management Application*). In addition to informing management decision-making approaches to siting habitat restoration efforts, SWFL metapopulation studies should help to determine where and which management actions should be implemented and the effects of these actions on the status of the SWFL in the MRG by providing data on SWFL population responses to landscape changes and management actions, respectively.

4.6.3 Recovery Application

Research on SWFL metapopulation structure and dynamics, particularly on dispersal, is identified as a priority in the Recovery Plan (Recovery Action 6: USFWS 2002). Results from this priority research can assist managers in implementing the Recovery Plan's (USFWS 2002) spatially explicit approach to recovery, which involves increasing metapopulation stability rather than simply maximizing the number of individuals throughout the SWFL's range (Recovery Action 2; USFWS 2002:100) (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty #4: Recovery Application*). For example, results of metapopulation research in the MRG can provide local managers with information (e.g., the critical amount and configuration of SWFL habitat that is necessary for long-term metapopulation persistence) useful for promoting SWFL occupation of restoration sites and achieving stable SWFL metapopulations within the MRG Management Unit. In addition, collected data on SWFL population responses to landscape changes and recovery actions can help managers determine where and which recovery actions should be implemented and the effects of these actions on the status of the SWFL in the MRG. By helping managers recover the SWFL, study results also can assist managers in their efforts to implement BiOps resulting from ESA §7(a)(2) consultations (Recovery Action 8.2; e.g., USFWS 2016) and comply with ESA §7(a)(1) of the ESA (Recovery Action 8.3.1).

4.6.4 Study Plan Considerations

Definitions for metapopulation vary, but they all are in agreement that metapopulations are composed of geographically discrete subpopulations that are connected by dispersing individuals (e.g., Levins 1970, Hanski and Gilpin 1997, Morris and Doak 2002, Newton 2004). Thus, as movement of organisms among habitat patches is a key aspect of metapopulation structure and dynamics, metapopulation study generally involves quantifying dispersal patterns and dynamics. This is true for the SWFL, where metapopulation structure and dynamics have been documented primarily by tracking movements and site fidelity in color-banded and radio-telemetered birds along the Gila, San Pedro, Colorado, and Salt rivers in Arizona—as well as elsewhere in Arizona, California, Nevada, and southeast Oregon (Cardinal et al. 2006; Koronkiewicz et al. 2004, 2006; McLeod et al. 2008; Paxton et al. 2007; Sedgwick 2004). Data on the age and sex of tracked birds (from blood samples and morphological data collected from banded birds), habitat characteristics of source and dispersal populations, availability and distribution of suitable habitats, and nest success provide evidence as to which factors influence movement and site fidelity (e.g., Paxton et al. 2007).

Although substantial information on metapopulation structure and dynamics has been gained from SWFL dispersal studies in Arizona, such efforts have involved labor-intensive fieldwork to obtain sufficient sample sizes; for example, Paxton et al. (2007) banded and tracked 1,080 adults and 498 nestlings from 1996 to 2005. Because collecting movement data is both time- and money-intensive, models addressing dispersal can provide vital alternatives to fieldwork that are more time- and cost-effective (Akcakaya et al. 2007). Modelling can be used to look at the following:

- Patterns of SWFL population synchrony and rates of extinction and recolonization, and the extent to which the populations operate as metapopulations.
- How SWFL inhabit networks of habitat patches in fragmented landscapes, and the relationship among population dynamics, movement, and landscape features.
- Possible SWFL population responses to landscape changes and management actions at multiple spatial scales.
- The critical amount and configuration of SWFL habitat that is necessary for long-term metapopulation persistence.
- How SWFL populations can persist over a network of habitat patches of specified sizes and distances.
- The dependence of SWFL extinction risk on subpopulation sizes and the degree of connectivity among subpopulations.

In the MRG, the primary study question is “What is the connectivity among SWFL populations in the MRG?” In addition, there are at least three sub-questions of interest: 1) At what minimum and maximum distances are SWFL breeding populations connected by metapopulations dynamics?; 2) Which SWFL populations in the MRG are sources and which are sinks, and how do changes in one population affect other populations?; and 3) How does loss, fragmentation, and degradation of riparian habitats—and, conversely, restoration and creation of habitats—affect metapopulation structure and dynamics in the MRG? Given the different approaches available to understanding metapopulation structure and dynamics, there is much flexibility and variety in the types of studies undertaken and methods employed to address the study questions. Studies can be empirical (i.e., collection of observational data, field-based AM experiments), theoretical (i.e., modelling), or both. In addition, studies can use a multitude of methods to assess dispersal and factors influencing movement (e.g., tracking individuals, genetic analyses, isotope analyses, satellite models, etc.). Aspects such as logistics, cost, study duration, and training and permit requirements will depend on the types of studies conducted and methods employed. Any work entailing SWFL surveys, monitoring, and handling will necessitate obtaining specialized training and permits (e.g., SWFL survey, detection, and nest monitoring training and ESA Section 10a permits).

4.6.5 Priority Ranking

Addressing this critical scientific uncertainty was ranked #4 of the top four SWFL critical scientific uncertainties identified by the SMEs, and is considered a *Level 3* priority (Table 4).

Table 4. Study framework attributes for critical scientific uncertainties for the Southwestern Willow Flycatcher.

Uncertainty Statement/ Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Priority
The strategy for prioritizing sites for SWFL habitat restoration in the MRG. • What site selection and prioritization procedures contribute to the successful restoration of SWFL breeding habitats along the MRG?	• Promote successful occupancy by/maintenance of breeding populations on restoration sites • Ensure Collaborative Program cost-effectively and successfully offsets effects of water management actions in compliance with the ESA	Data mining: • Scientific and gray literature on SWFL life-history requirements and recovery needs • Existing SWFL habitat suitability models • Strategies currently implemented in MRG and other large ecosystem-level restoration programs Original quantitative field-based and remote sensing scientific studies: • Strategies currently being utilized in MRG • Efficacy of MRG strategies • Selection factors and criteria that should be included in SWFL strategy	• Efficacy of MRG strategies • Selection factors and criteria: o Landownership o Land use o Habitat features including vegetation floristics and structure, o Geographic extent of habitat o Proximity/connectivity to existing high quality riparian habitat o Presence/proximity to existing SWFL populations o Processes that promote PCEs, e.g., hydrogeomorphic elements, groundwater depth, and river flows o Threats to SWFL populations	• Multi-year • MRG	• Collecting large datasets • Qualified and permitted personnel • Integrative research strategy that synthesizes results of a number of interrelated studies	Level 1
The impact of the tamarisk beetle (*Diorhabda*) on SWFL breeding habitats in the MRG. • What are the impacts of the tamarisk beetle (*Diorhabda*) on SWFLs and SWFL breeding habitats in the MRG? • Which unoccupied and occupied suitable SWFL breeding habitats in the MRG are most threatened by *Diorhabda* in the near- and long-term?	• Minimize threats and create/restore SWFL breeding habitats	• Data mining • Literature reviews • Modelling • Field surveys and observations	*Diorhabda*: • Distribution and abundance • Direction and rate of spread • Timing of defoliation • Presence in suitable SWFL habitat SWFL: • Availability and distribution of suitable breeding habitats • Prey composition and availability • Nest success Habitat where *Diorhabda* absent and present: • Vegetation floristics, structure, and other features • Microclimate and other microhabitat features • Occurrence of passive native revegetation suitable for SWFLs	• Multi-year • MRG	• Land access and permission • Qualified and permitted personnel • Collecting large datasets • Investigating interactions of multiple trophic levels and ecosystem components across multiple temporal and spatial scales • Integrative research strategy that synthesizes results of a number of interrelated studies	Level 2
SWFL presence, population size, and population status along the Angostura Reach. • What are the sizes, distributions, and status of SWFL populations along the Angostura Reach?	• Assess and monitor effects of management actions • Ensure Collaborative Program cost-effectively and successfully offsets effects of water management actions in compliance with the ESA o Site beneficial projects (e.g., planting native vegetation) near existing SWFL populations o Site jeopardizing projects (e.g., vegetation removal) away from SWFL breeding territories and nest sites to avoid take	Data mining: • Forms of previous SWFL surveys submitted to USFWS Literature Review: • Recent reports on SWFL population size, distribution, and status/trends Field Surveys: • Current distribution • Population size • Population status/tends • Nest monitoring	• Distribution • Population sizes • Population trends • Nest success	• Multi-year • Angostura Reach	• Land access and permission • Qualified and permitted personnel • Obtaining hardcopies and electronic copies of previous (>20 years) surveys • Ensuring continuity and consistency in data collection over multiple years • Ensuring all survey sites are completed concurrently within each year of the study	Level 2

Table 4. Study framework attributes for critical scientific uncertainties for the Southwestern Willow Flycatcher.

Uncertainty Statement/ Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Priority
SWFL metapopulation structure and dynamics in the MRG. • What is the connectivity among SWFL populations in the MRG?	• Identify at what distance to site habitat restoration projects from existing SWFL breeding populations: o Increase successful near-term occupancy o Achieve long-term metapopulation stability • Assess success of habitat creation/restoration efforts to increase metapopulation stability • Develop a coordinated restoration strategy to promote/maintain flourishing and stable SWFL metapopulations	Much flexibility and variety in study types and methods: • Adaptive Management experiments • Tracking of individuals Genetic analyses Isotope analyses Satellite models	• Distances among breeding populations • Dispersal distances and rates • Age and sex • Breeding site connectivity • Reproductive success • Suitable habitat distribution • Population size • Annual population changes • Population longevity	• Multi-year • MRG	• Considerations, including logistics, cost, study duration, and training and permit requirements, depend on the types of studies conducted and methods employed	Level 3

5 CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE YELLOW-BILLED CUCKOO

During a review of the current state of scientific knowledge on the YBCUat the October 2016 technical workshop (see Appendix D-1 for workshop notes), there was general consensus among the agency SMEs that increased scientific inquiry on the YBCU in the past two decades, as well as more recent extensive surveys along the MRG and across the YBCU's range, have advanced our knowledge of the YBCU's natural history requirements, breeding population status, threats, and response to management efforts. However, the SMEs concluded that there remains much about the YBCU that is not well understood. Specifically, the SMEs delineated approximately 15 scientific topics that were less studied and less understood, and they identified the top five scientific uncertainties that affect management decisions for the YBCU and, thus, should be the focus of future scientific efforts (see Appendix D-1).

The following narrative presents *brief overviews* of the scientific relevance, management application, and recovery application for each critical scientific uncertainty. *In-depth reviews of these topics, along with listing history, recovery efforts, population status, MRG management actions, and additional reference citations are provided in* Appendix D-2. Study plan considerations also are offered in this section for each critical scientific uncertainty to guide Collaborative Program signatories with internally developing study plans or soliciting detailed technical proposals from the scientific community.

5.1 Identified Critical Scientific Uncertainties

The agency SMEs prioritized the following four critical scientific uncertainties for scientific study (ranked 1 = Highest to 4 = Lowest):

1) The abiotic and biotic variables that predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales.
2) YBCU breeding population sizes, distributions, and trends in the MRG.
3) Similarity in YBCU and SWFL breeding habitat requirements in the MRG.
4) Spatial behavior patterns of YBCUs that breed in the MRG within and among years, and drivers.

Ranked fifth was "the timing and availability of YBCU prey in the MRG and which factors influence both." However, this topic does not receive expanded review and consideration in the following sections because it was ranked as a significantly lower priority than the four critical scientific uncertainties listed above.

5.2 Connectivity Among Critical Scientific Uncertainties

The top four critical scientific uncertainties for the YBCU are interconnected; research on one uncertainty informs research (e.g., provides similar or baseline data) on other uncertainties (Figure 9).

More specifically, all four critical scientific uncertainties relate in some degree to where YBCUs are on the landscape, the sizes and trends of YBCU breeding populations, YBCU breeding habitat requirements, and YBCU spatial behavior patterns.

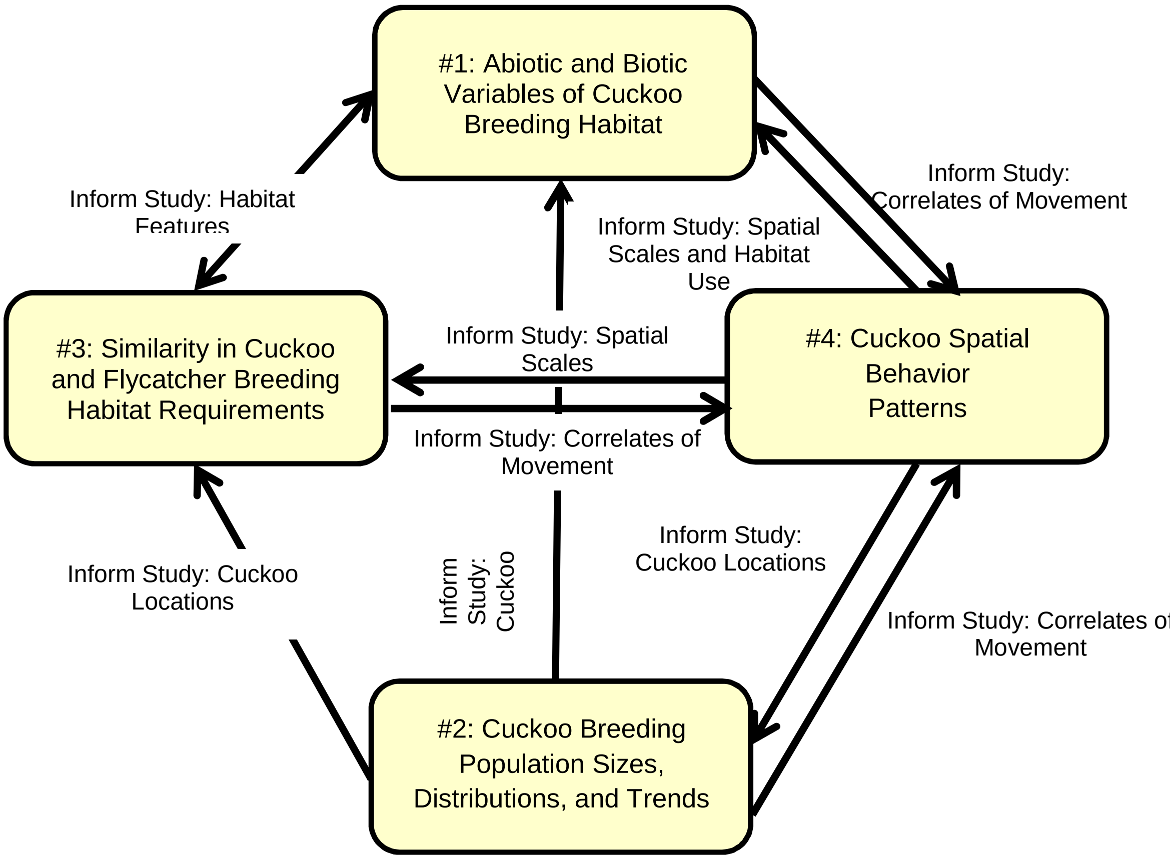

Figure 9. Relationships among critical scientific uncertainties of the Yellow-billed Cuckoo in the Middle Rio Grande, New Mexico.

5.3 Critical Scientific Uncertainty #1: Abiotic and Biotic Variables of Yellow-Billed Cuckoo Breeding Habitats

Study Question: Which abiotic and biotic variables predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales?

5.3.1 Scientific Relevance

YBCUs make decisions about where to breed at multiple spatial scales. As they migrate north, they make decisions on where they stop to breed (the landscape or breeding site), where within the landscape they regularly travel to meet life-history requirements (the patch, also termed "territory" or "home range and core use area[2]"), and where they build their nests (the nest site). Required breeding habitat attributes, such as geographic extent of vegetation, vegetation floristics (species composition) and physiognomy (structure), and distance to surface water, all can differ among these different spatial scales. In addition, the geographic distribution and the abiotic and biotic features of YBCU breeding habitats can vary temporally due to within- and between-year variation in river flows and precipitation, disturbance events (e.g., fluctuating reservoir levels, fire, or high magnitude floods that result in scouring), and natural succession, maturation, and degradation of riparian vegetation. In the MRG, no rigorous scientific inquiry has been completed to determine landscape requirements (e.g., elevation, geographic extent, topographic diversity), only limited data exist on patch requirements (e.g., size, vegetation floristics, vegetation physiognomy of patches), and very limited data exist on nest site requirements (e.g., nest substrate and height) (see Appendix D-2, *Cuckoo Critical Scientific Uncertainty #1:Scientific Relevance*). Furthermore, although information exists as to the seral stage of vegetation in YBCU breeding patches (e.g., the maturity of the cottonwood overstory), studies have not been completed to determine how YBCU breeding habitats change temporally. Therefore, the SMEs determined that further scientific research is essential to accurately characterize YBCU breeding habitats in the MRG; studies are needed to determine which spatial and temporal scales are biologically relevant to the YBCU and which abiotic and biotic variables predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales.

5.3.2 Management Application

Managers can offset threats to YBCU breeding habitats in the MRG by controlling exotic vegetation, planting native vegetation, improving geomorphological conditions, and adaptively managing water flows to create the conditions necessary for YBCU breeding habitat establishment, development, maintenance, and recycling. Unfortunately, the successful design and implementation of YBCU breeding

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[2] *Home range* is defined as the area regularly travelled to meet life-history requirements) and *core use area* is defined as a portion of the home range that is utilized more thoroughly and frequently (Hughes 1999).

habitat restoration has been limited by the lack of information on multi-scale YBCU breeding habitat requirements (see Appendix D-2, *Cuckoo Critical Scientific Uncertainty #1: Scientific Relevance*). Therefore, to improve the success of YBCU breeding habitat restoration efforts, managers require more accurate data on 1) restoration targets, such as patch size, configuration, and vegetation composition and structure; 2) which habitats are unsuitable or marginally suitable (e.g., monotypic tamarisk stands) for breeding YBCUs and, thus, a priority for restoration; and 3) which river processes and active and passive management actions promote YBCU breeding habitats. If conducted in both naturally-occurring habitats and restoration sites in the MRG, research on which spatial and temporal scales are biologically-relevant to the YBCU and how abiotic and biotic variables of suitable YBCU breeding habitat differ across multiple scales will provide managers with the required scientific data. Furthermore, research results (e.g., a YBCU breeding habitat suitability model) will be useful to formulating and standardizing conservation measures necessary to effectively offset short-term decreases in available YBCU breeding habitats resulting from water management and river maintenance activities in the MRG.

5.3.3 Recovery Application

Results of studies characterizing multi-scale YBCU breeding habitat requirements will provide information useful in accurately identifying the primary constituent elements of critical habitat, determining which and where habitats in the MRG should be designated as critical, and making a final ruling on critical habitat. In addition, study results will provide information vital to YBCU recovery efforts, such as on potential threats to YBCU breeding habitats (e.g., invasion of exotic plant species), and on which habitats should be a priority for protection and restoration.

5.3.4 Study Plan Considerations

The first step in addressing the critical scientific uncertainty is to define suitable YBCU breeding habitat. Although occupancy by breeding YBCUs generally infers that the habitat is suitable (e.g., Johnson et al. 2017), YBCUs can occupy unsuitable, low quality habitat. Thus, metrics other than occupancy likely are more biologically meaningful in defining suitability, such as high reproductive success, high survivorship, and high use (USFWS 2002). Once it is determined which YBCU metrics indicate suitability, occupied suitable YBCU breeding habitats in the MRG should be delineated and mapped. Existing literature (e.g., Sechrist et al. 2013, Dillon et al. 2017) and standardized YBCU survey forms for the MRG submitted to the USFWS (USFWS unpubl. data) can provide useful data on YBCU detection and nest site locations during the breeding season, but additional surveys and nest monitoring studies likely are necessary to obtain sufficient data on YBCU presence, reproductive success, and survivorship in the MRG (see Appendix D-2, *Cuckoo Critical Scientific Uncertainty #2*).

The next step to addressing the critical scientific uncertainty is to quantify the abiotic and biotic habitat variables that predict occupied suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales. There is some evidence that three spatial scales are of biological importance to the YBCU: the landscape (also termed the "breeding site"), the patch (also termed the "territory," or the "home range and core use area"), and the nest site (e.g., Girvetz and Greco 2009, Johnson et al. 2017). Nonetheless, definitions of these spatial scales vary among studies and are largely lacking for the MRG (e.g., Sechrist et al. 2013, Johnson et al. 2017). The spatial scale of habitat measurements should match the spatial scale at which organisms use habitat as habitat features exhibit changing patterns when measured at different scales (Meyer and Thuiller 2006, Girvetz and Greco 2009, Seavy et al. 2009). Furthermore, the more vagile a species is, the more important it is to measure habitat at multiple spatial scales (Meyer and Thuiller 2006). Therefore, it is essential that the following two questions be answered prior to conducting habitat assessments:

1. What are biologically relevant definitions of spatial habitat terms, such as landscape, patch, home range, core use area, territory, and nest site?
2. Which spatial scales are biologically relevant to the YBCU in the MRG?

Our increasing understanding of YBCU spatial behavior patterns (see Appendix D-2, *Cuckoo Critical Scientific Uncertainty #4*) should refine spatial-scale definitions for the YBCU for the MRG specifically and range-wide.

Once the geographic units of measurement are identified and standardized, those habitat features considered most predictive of suitable YBCU breeding habitats must be identified. Determining which abiotic and biotic variables predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales likely will require an iterative process of collecting habitat data at a subset of occupied YBCU sites, modelling habitat suitability, and testing the predictability of habitat suitability models across all occupied sites in the MRG. After the appropriate compliment of habitat variables are selected for measurement, habitat quantification and characterization of occupied suitable habitats can be completed in a variety of ways. Due to the YBCU's large home range, it can be logistically difficult to obtain detailed field-based measurements of habitat features—such as vegetation structure, floristic composition, geographic extent of the floodplain and vegetation communities, and proximity to surface water—at scales considered biologically meaningful for the YBCU. To avoid the constraints of fieldwork or to compliment field-based habitat assessments, it is valuable to explore the predictive power of complex multi-scale habitat suitability models based on remote sensing data (e.g., LIDAR, Landsat Thematic Mapper, aerial photographs), statistical models, or a combination of both (Girvetz and Greco 2009, Johnson et al. 2017). Whether habitat data are collected in the field or remotely, it is essential that data on habitat features be contemporary to data on suitability (e.g., occupancy by breeding YBCUs) because both change over time. Furthermore, to quantify the temporal changes, data should be collected over multiple years.

The collected YBCU suitability (e.g., occupancy) and habitat data should be analyzed to address the primary study question associated with the critical scientific uncertainty, "Which abiotic and biotic variables predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales?" In addition, data should be analyzed to answer the following five sub-questions:

1) Where are unoccupied and occupied suitable YBCU breeding habitats located in the MRG?

2) Which vegetation community types provided suitable habitat for the YBCU?
3) How are key features of naturally-occurring suitable YBCU breeding habitats similar and/or different from those of occupied restoration sites in the MRG?
4) In the MRG, to what degree do breeding YBCUs use exotic vegetation, particularly tamarisk, for foraging and nesting?
5) How do features (e.g., hydrologic conditions, vegetation structure) of YBCU breeding habitats in the MRG vary temporally and what is the longevity/persistence of YBCU breeding habitats in the MRG?

Knowledge of a diversity of disciplines, sampling techniques and technologies, and data analysis and modelling methods are required as successfully addressing the critical scientific uncertainty involves adopting an integrative research strategy that investigates multiple ecosystem components across multiple temporal and spatial scales. Any work entailing YBCU surveys or monitoring will necessitate obtaining specialized training and permits (e.g., YBCU survey, detection, and nest monitoring training and ESA Section 10a permits).

5.3.5 Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 1* priority (Table 5) and was ranked #1 of the top four YBCU scientific uncertainties identified by the SMEs.

5.4 Critical Scientific Uncertainty #2: Yellow-Billed Cuckoo Breeding Population Sizes, Distributions, and Trends

***Study Question*:** What are YBCU breeding population sizes, distributions, and trends in the MRG?

5.4.1 Scientific Relevance

In the past two decades, formal YBCU survey efforts have provided estimates of YBCU breeding population sizes, distributions, and trends in the MRG (see Appendix D-2, *Cuckoo Critical Scientific Uncertainty #2: Scientific Relevance*). However, evaluation of survey results from this period has been complicated by the fact that survey areas and methods have not been consistent within and among survey efforts. In addition, despite consistent and comparable surveys by the USBR since 2009 south of the Pueblo of Isleta, there has been limited survey data from the Cochiti Reach (which extends approximately 22 miles from Cochiti Dam to the Angostura Diversion Dam) and Angostura Reach (which extends approximately 41 miles from Angostura Diversion Dam south to the Isleta Diversion Dam) (Dillon et al. 2017) (see Appendix D-2, *Cuckoo Critical Scientific Uncertainty #2: Scientific Relevance*). Therefore, to obtain accurate YBCU breeding population estimates for the MRG, the SMEs recommend that standardized YBCU surveys be conducted concurrently and repeatedly within all suitable YBCU breeding habitats along the entire length of the MRG. Furthermore, scientific investigation is needed to identify which factors (e.g., availability of suitable habitat, nest predation, human disturbance, livestock grazing, river flows) affect YBCU breeding population sizes, distributions, and trends in the MRG.

5.4.2 Management Application

Concurrent, repeated, and comprehensive standardized YBCU surveys in the MRG conducted before and after implementation of management actions will provide managers with the data necessary for effectively assessing and offsetting the effects of their actions on YBCUs in the MRG. Principally, collected data on locations of breeding YBCUs and their nests will inform siting of management actions, ensuring that those projects that might benefit the YBCU (e.g., planting native vegetation) are sited near existing YBCU breeding populations and those projects that might jeopardize the YBCU (e.g., vegetation removal) are sited away (e.g., greater than 0.4 km [0.25 mi]) from breeding territories and nest sites. Studies conducted complementary to surveys status will provide information to managers on where YBCU breeding populations are declining, and which factors (e.g., availability of suitable habitat, nest predation, human disturbance, livestock grazing, river flows) are limiting or threatening YBCU breeding populations, which is essential for determining where and which management actions could be implemented to improve the status of the YBCU in the MRG.

5.4.3 Recovery Application

Information on sizes, distributions, and trends of YBCU breeding populations and which factors contribute to population trends (e.g., availability of suitable habitat, nest predation, human disturbance, livestock grazing, river flows) will assist managers in identifying the threats to YBCU breeding populations, ascertaining if and where recovery efforts are required, and assessing the effects of recovery actions on YBCU breeding populations. Once a recovery plan is finalized, collected data will be useful in determining if recovery criteria are being met.

5.4.4 Study Plan Considerations

Addressing the critical scientific uncertainty involves data mining, standardized protocol surveys (e.g., Halterman et al. 2016), nest searching and monitoring, field-based research, and, possibly, modeling studies. The first step to understanding YBCU breeding populations in the MRG is to analyze the results of previous survey efforts (e.g., Dillon et al. 2017) to determine historical and recent YBCU breeding population sizes, distributions, and trends in the MRG. Once these baseline data are analyzed, current YBCU breeding population sizes and distributions in the MRG should be investigated by:

1) Verifying and mapping locations of established YBCU survey routes to ensure consistency in site-naming, as well as establish and name new survey routes,
2) Acquiring data from any and all agencies and organizations involved in on-going standardized YBCU protocol surveys in the MRG,
3) Completing standardized YBCU protocol surveys (Halterman et al. 2016) in those areas not covered by existing surveys,
4) Obtaining multiple years of survey data to assess if and where YBCU breeding population sizes are increasing, decreasing, or remaining stable,

5) Securing permission to access survey sites from a multitude of landowners and managers (municipal, county, state, federal, and tribal), and
6) Hiring sufficient ESA Section 10a-permitted personnel to ensure that all survey sites along the MRG are completed concurrently within each year of the study.

All survey data, whether obtained from partners or from efforts to specifically address the critical scientific uncertainty, should be analyzed using the appropriate statistical tests and software to determine YBCU breeding population sizes, distributions, and trends in the MRG. As part of these analyses, a rigorous evaluation of the most biologically accurate method for delineating breeding populations should be completed. River reach was used by both Dillon et al. (2017) and the USFWS (2016) as a spatial unit of measurement to evaluate YBCU breeding populations and make determinations regarding stability of breeding populations; however, river reach likely does not reflect how YBCU breeding populations are spatially distributed across the MRG.

Although obtaining and analyzing data on YBCU breeding population sizes, distributions, and trends should be the primary focus of efforts to address the critical uncertainty, it is also valuable to complete scientific investigations to identify which factors affect YBCU breeding populations in the MRG, such as habitat availability, prey composition and availability, and nest success. These investigations likely will involve time- and labor-intensive fieldwork conducted over multiple years. Therefore, separate studies likely will be necessary to investigate each factor. Wherever possible, data should be obtained from completed and on-going complimentary studies (e.g., see Appendix D-2, *Cuckoo Critical Scientific Uncertainties #1 and 3*).

5.4.5 Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 2* priority (Table 5) and was ranked #2 of the top four YBCU scientific uncertainties identified by the SMEs.

5.5 Critical Scientific Uncertainty #3: Similarity in Yellow-Billed Cuckoo and Southwestern Willow Flycatcher Breeding Habitat Requirements

Study Question: How similar are the YBCU and the SWFL in their breeding habitat requirements in the MRG?

5.5.1 Scientific Relevance

Both the YBCU and the SWFL are migratory landbirds of conservation concern that breed in the Southwest in dense woody riparian vegetation. Despite overlap in YBCU proposed critical habitat and SWFL designated critical habitat, the two species are not always found in similar habitats or locales as a result of differing life-history requirements. Little scientific work has been completed to determine similarity in breeding habitat requirements between the two bird species and any comparisons of habitat requirements are hampered by the fact that less is known for the YBCU. To determine how similar the YBCU and the SWFL are in their breeding habitat requirements in the MRG, the SMEs recommend that scientific research be completed to determine which abiotic and biotic breeding habitat features at multiple spatial scales (e.g., landscape, patch, nest site) predict where the YBCU and SWFL co-occur, occur individually, and are absent within the MRG.

5.5.2 Management Application

There is no quantitative scientific information available regarding which breeding habitat requirements the YBCU and SWFL share in common and which are species-specific. Therefore, it is unclear whether offsetting and conservation measures developed for the SWFL benefit the YBCU. Studies characterizing the similarity between YBCU and SWFL breeding habitat requirements in the MRG will provide information needed to effectively design and implement offsetting measures for, as well as accurately evaluate the impacts of management actions on, both the YBCU and the SWFL and for each species individually.

5.5.3 Recovery Application

Lacking vital YBCU life-history information and formal guidance from a recovery plan or a federal designation of critical habitat, managers involved in recovery efforts for the SWFL are attempting to implement the same efforts for the YBCU based on the assumption that the two riparian obligate bird species are similar in their breeding habitat requirements. However, there is no scientific evidence to support the deduction that recovery actions and conservation measures for the SWFL benefit either the YBCU or its habitats (USFWS 2014d). Studies investigating the critical scientific uncertainty not only would provide information on YBCU-specific breeding habitat requirements at multiple spatial and temporal scales, but also would provide a comparison and contrast with that of the SWFL. Therefore, such studies will provide information necessary for species-specific, dual-species, and multi-species recovery planning and implementation efforts in the MRG.

5.5.4 Study Plan Considerations

Addressing the primary question, "How similar are the YBCU and the SWFL in their breeding habitat requirements in the MRG?" involves answering the following three sub-questions:

1) What is the degree of YBCU and SWFL co-occurrence in the MRG? Specifically, at what frequency do YBCUs and SWFLs breed in the same riparian patches in the MRG?
2) Which abiotic and biotic breeding habitat features at multiple spatial scales predict where the YBCU and SWFL co-occur, occur individually, and are absent in the MRG?
3) Which abiotic and biotic breeding habitat features at multiple spatial scales (e.g., landscape, patch, nest site) are similar or dissimilar between suitable YBCU and suitable SWFL breeding habitats? Specifically, which habitat attributes are specific to the YBCU, specific to the SWFL, and shared by both bird species?

Each sub-question can be investigated in separate studies, but they should be addressed in a sequential manner so that study results build upon and augment each other. Determining the degree of YBCU and SWFL co-occurrence in the MRG (*Sub-question 1*) requires first obtaining previously-collected data on occurrences of both the YBCU and the SWFL from either targeted surveys and studies or from incidental reports (e.g., YBCU incidentally detected during formal SWFL surveys) to estimate historical and recent co-occurrence. Answering *Sub-question 1* also requires obtaining current YBCU and SWFL co-occurrence data from both on-going work and new survey efforts. Similar to addressing *SWFL Critical Scientific Uncertainty #3 and the YBCU Critical Scientific Uncertainty #2*, this entails:

1) Verifying and mapping locations of established YBCU and SWFL survey routes to ensure consistency in site-naming, as well as establish and name new survey routes,
2) Acquiring data from any and all agencies and organizations involved in on-going standardized YBCU and SWFL protocol surveys in the MRG,
3) Completing standardized protocol surveys for the YBCU (Halterman et al. 2016) and the SWFL (Sogge et al. 2010) in those areas not covered by existing surveys,
4) Securing permission to access survey sites from a multitude of landowners and managers (municipal, county, state, federal, and tribal), and
5) Hiring sufficient ESA Section 10a-permitted personnel to ensure that all survey sites along the MRG are completed concurrently within each year of the study.

Similar to addressing YBCU Critical Scientific Uncertainty #1, accurately answering *sub-questions 2* and *3* requires the completion of original scientific studies to determine which habitat features are associated with landscapes, habitat patches, and nest sites supporting only breeding YBCUs, only breeding SWFLs, and both bird species. These studies likely will involve fieldwork to collect multi-spatial-scale habitat data; however, mining scientific and gray literature on YBCU and SWFL life-history requirements might be a more time- and cost-effective method of obtaining at least some of the required information. Literature useful for data mining efforts includes federal recovery plans and listing documents (e.g., USFWS 2002, 2013a, 2014e), YBCU and SWFL monitoring reports (e.g., Dillon et al. 2017, Moore and Ahlers 2017), peer-reviewed publications (e.g., Hughes 1999, Paxton et al. 2007), and the results of studies addressing YBCU critical scientific uncertainties #1 and #4. Statistical and remote sensing models also can supplement or provide informative alternatives to fieldwork, such as the range-wide satellite model for suitable SWFL breeding habitat developed by Hatten (2016), the SWFL habitat suitability model for the MRG developed by Siegle et al. (2013), and aerial-photo and satellite models for the Lower Colorado River (LCR) developed by Johnson et al. (2017).

5.5.5 Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 2* priority (Table 5). It was ranked #3 of the top four YBCU scientific uncertainties identified by the SMEs, but the ranking was nearly tied for second place with Critical Scientific Uncertainty #2 *Cuckoo breeding population sizes, distributions, and trends in the MRG*.

5.6 Critical Scientific Uncertainty #4: Yellow-Billed Cuckoo Spatial Behavior Patterns

***Study Question*:** What are the spatial behavior patterns of YBCUs that breed in the MRG within and among years?

5.6.1 Scientific Relevance

The vagile YBCU moves within and among breeding sites within and among years in response to local conditions (e.g., availability of preferred prey) and travels complex, long-distance migration routes between breeding sites in the Southwest and wintering sites in South America. Studies employing color banding, radio telemetry, light-level geolocators, and Global Positioning System (GPS) tags conducted in the Southwest over the past two decades have yielded important information on YBCU migration routes, wintering locations, dispersal from natal and breeding areas, site fidelity, and territory use. However, information on spatial behavior patterns of YBCUs that breed in the MRG is derived primarily from tracking 10 individual YBCUs in two different studies conducted from 2007-2010 (Sechrist et al. 2012, 2013). Therefore, the SMEs recommend additional scientific research to elucidate spatial behavior patterns of YBCUs that breed in the MRG.

5.6.2 Management Application

In the absence of sufficient information on YBCU breeding habitat requirements at multiple spatial and temporal scales, managers are attempting to implement habitat restoration for the YBCU based on the assumption that restoration techniques developed for the SWFL will create suitable YBCU breeding habitats. Although using the SWFL as a surrogate for the YBCU is valuable as a temporary measure, successfully protecting and promoting YBCU breeding populations through habitat restoration require obtaining scientific information specific to the YBCU on restoration targets, such as patch size, configuration, and vegetation composition and structure, and where in the MRG habitat protection and restoration are needed. Researching YBCU spatial behavior patterns is a useful means for obtaining such information.

5.6.3 Recovery Application

In order to develop a YBCU recovery plan, designate critical habitat, and plan and implement effective YBCU recovery efforts that address threats during all phases of the YBCU's annual cycle, it is essential that research be completed on YBCU spatial behavior patterns (USFWS 2014e). Such research can inform which and where recovery actions (e.g., habitat restoration) are necessary by elucidating the habitats and geographic locations used by YBCUs in the MRG and, possibly, elsewhere. Specifically, YBCU spatial behavior pattern studies provide the following information useful to recovery efforts: 1) YBCU breeding habitat requirements, such as size and vegetation characteristics, of home ranges and core use areas; 2) habitat requirements during pre- and post-breeding movements (and, possibly, migration and wintering); 3) locations of breeding sites in the MRG and, possibly elsewhere; and, depending on the tracking methods employed (e.g., radio telemetry versus GPS tags), 4) migratory routes, stopover sites, and wintering grounds. Research results also can be useful in assessing connectivity between YBCU populations (e.g., to what degree the range of the western and eastern Distinct Population Segments (DPSs) overlap during the breeding and nonbreeding seasons).

5.6.4 Study Plan Considerations

Addressing the critical scientific uncertainty involves answering the question, "What are the spatial behavior patterns of YBCUs that breed in the MRG within and among years?" In addition, the following seven sub-questions should be answered:

1) What are biologically relevant definitions of spatial habitat terms, such as landscape, patch, home range, core use area, territory, and nest site?
2) What is the spatial structure of YBCU breeding home ranges and core use areas?
3) What are the breeding (and, possibly stopover and wintering) habitats used by YBCUs that breed in the MRG?
4) What are the locations of breeding sites (and, possibly, migratory routes, stopover sites, and wintering grounds) of YBCU that breed in the MRG?
5) What is the degree of YBCU site fidelity in the MRG?
6) How far do YBCU individuals move from source breeding and natal populations within and among years?
7) What is the connectivity among YBCU populations within the MRG, and between the MRG and other breeding sites along the Rio Grande and other stream drainages within and outside of New Mexico?
8) What factors are correlated with YBCU dispersal (e.g., age, sex, climate, geographic distribution of habitat)?

To date, information on YBCU movement has been derived primarily from: 1) color banding and resighting studies conducted along the Kern River in California (e.g., Stanek and Stanek 2013), the San Pedro River in Arizona (e.g., Halterman 2009), and the LCR in California, Arizona, and Nevada (Parametrix, Inc. and Southern Sierra Research Stations [SSRS] 2015, 2016a,b); 2) radio telemetry studies conducted along the Kern River in California (e.g., Stanek and Stanek 2013), in the MRG (Sechrist et al. 2013), and the LCR (McNeil et al. 2013); 3) light-level geolocator studies conducted in the MRG and Pecos River in New Mexico (Sechrist and Best 2012, Sechrist et al. 2012, Dillon et al. 2017) and in the LCR (McNeil et al. 2013); and 4) GPS tag studies in the LCR (Parametrix, Inc. and SSRS 2015, 2016a, b). In addition to tracking movements of individual birds, both colonization events of previously unoccupied YBCU breeding habitats and YBCU population fluctuations not attributable to local demographics can provide indirect evidence of dispersal (Gaines and Laymon 1984, Halterman 2003, Halterman et al. 2016, USFWS 2013b). Thus far, despite investment of significant resources, movement studies have been hampered by small sample sizes because YBCUs are difficult to detect, trap, and observe. More specifically, YBCUs have a secretive nature, often referred to as "bizarre" and "peculiar," that can thwart detection and capture efforts, and they have short legs that are often covered by body feathers that can prevent visual observations of leg bands (Hughes 1999). Study results also have been complicated by the fact that YBCU behaviors vary among individuals, populations, and years.

If sufficient sample sizes are obtained to achieve desired statistical power, radio telemetry can be effective in determining within-season and within-site spatial behavior patterns of YBCUs in the MRG and, thus, a current multi-year radio telemetry study by the USBR's Albuquerque Area Office (L. Walton, USBR, pers. comm.) should inform our knowledge of within-season movements, such as home ranges and core use areas. Although color banding (including resighting and recapturing) individuals and fitting birds with geolocators have been the traditional methods of investigating spatial behavior patterns among years and during the nonbreeding season, studies on these topics should employ newly developed technologies, such as GPS tracking units, which track YBCU movements with greater precision and accuracy, over larger geographic areas (i.e., during all phases of the YBCU's annual cycle), and require smaller sample sizes. To determine correlates of YBCU spatial behavior patterns, data should be collected on the age and sex of tracked birds (from blood samples and morphological data collected from banded birds), habitat characteristics of high use areas, availability and distribution of suitable habitats, availability and phenology of prey, and nest success. Wherever possible, results of completed and on-going habitat, prey, and nest monitoring studies (see YBCU critical scientific uncertainties #1-3) should be used to investigate correlates of YBCU spatial behavior patterns to limit redundancy and unnecessary expenditure of resources. As investigating spatial behavior patterns is complex, it requires knowledge of diverse disciplines (e.g., ornithology, entomology, botany, demography, community ecology), sampling techniques and technologies (e.g., color banding, radio telemetry, nest monitoring, arthropod collection, vegetation sampling), and data analysis and modelling methods. In addition, obtaining sufficient sample sizes will necessitate multiple years of resource- and labor-intensive fieldwork. Surveying for and handling YBCUs require obtaining specialized training and permits (e.g., ESA Section 10a permits).

5.6.5 Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 2* priority (Table 5). It was ranked #4 of the top four YBCU scientific uncertainties identified by SMEs, but the ranking was nearly tied for second place with Critical Scientific Uncertainty #2 *Cuckoo breeding population sizes, distributions, and trends in the MRG*.

Table 5. Study framework attributes for critical scientific uncertainties for the Yellow-Billed Cuckoo.

Uncertainty Statement/Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Recommended Priority
The abiotic and biotic variables that predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales. • Which abiotic and biotic variables predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales?	• Accurately evaluate impacts of management actions • Design, implement, and evaluative offsetting measures (e.g., habitat restoration)	• Data mining: o YBCU survey data submitted to USFWS • Literature Review: o Scientific and gray literature • Field-based, remote sensing, and modeling studies on abiotic and biotic features of breeding habitat: o Multi-spatial scale o Multi-temporal scale	• Landscape features: o Floodplain extent and ruggedness o Vegetation greenness indices o Connectivity, distribution, availability, and composition of vegetation community types • Patch (home range and core use area) features: o Vegetation composition and structure o Presence and proximity to surface water, and saturated/moist soils o Groundwater depth o Size and shape o Composition and availability of prey • Nest site features o Nest tree height and floristics o Surrounding vegetation composition and structure o Microclimate • Temporal changes o Seasonality and persistence of surface water and moist soils o Longevity of suitable vegetation community types	• Multi-year • MRG	• Land access and permission • Qualified and permitted personnel • Collecting large datasets • Time- and labor-intensive fieldwork • Investigating ecosystem components across multiple temporal and spatial scales	Level 1
YBCU breeding population sizes, distributions, and trends in the MRG. • What are YBCU breeding population sizes, distributions, and trends in the MRG?	• Accurately estimate YBCU breeding population sizes, distributions, and trends in the MRG Where are YBCUs breeding o Where are YBCUs declining • Ensure Collaborative Program cost-effectively and successfully offsets effects of management actions in compliance with the ESA o Proper siting of projects	• Data mining: o YBCU survey data submitted to USFWS • Literature Review: o Recent reports on YBCU population size, distribution, and status/trends • Field-based, remote sensing, and modeling studies	• Historical, recent, and current breeding population sizes and distributions • Annual variation in breeding population sizes and distributions • Breeding population trends • Survey year • Factors that affect breeding population sizes, distributions, and trends: o Im-/emigration o Habitat changes o Changes in prey composition and availability o Nesting success	• Multi-year • MRG	• Land access and permission • Qualified and permitted personnel • Obtaining hardcopies and electronic copies of previous (> 20 years) surveys • Ensuring continuity and consistency in data collection over multiple years • Ensuring all survey sites are completed concurrently within each year of the study	Level 2
Similarity in YBCU and SWFL breeding habitat requirements in the MRG. • How similar are the YBCU and the SWFL in their breeding habitat requirements in the MRG?	• Accurately evaluate and effectively offsets impacts of management actions on both the YBCU and SWFL in compliance with the ESA: o Evaluate impacts o Design, implement, and evaluate offsetting measures (e.g., habitat restoration)	• Data mining: o YBCU and SWFL survey data submitted to USFWS • Literature Review: o Recent reports on YBCU and SWFL breeding population sizes, distribution, and status/trends o Recent reports on individual species occurrence and co-occurrence o Scientific and gray literature on YBCU and SWFL life-history requirements and recovery needs o Existing YBCU and SWFL habitat suitability models • Field-based, remote sensing, and modeling studies on abiotic and biotic features of breeding habitat: o Multi-spatial scale o Multi-temporal scale	• Locations of where YBCU and SWFL occur alone and co-occur • Annual variation in occurrences of both species • Habitat features at multiple spatial and temporal scales (see above *The abiotic and biotic variables that predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales*)	• Multi-year • MRG	• Land access and permission • Qualified and permitted personnel • Collecting large datasets • Time and labor-intensive fieldwork • Obtaining hardcopies and electronic copies of previous (> 20 years) surveys • Obtaining habitat suitability models for both species • Investigating ecosystem components across multiple temporal and spatial scales • Integrative research strategy that synthesizes results of a number of interrelated studies	Level 2

Table 5. Study framework attributes for critical scientific uncertainties for the Yellow-Billed Cuckoo.

Uncertainty Statement/Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Recommended Priority
Spatial behavior patterns of YBCUs that breed in the MRG within and among years, and drivers. • What are the spatial behavior patterns of YBCUs that breed in the MRG within and among years?	• Accurately evaluate impacts of management actions • Ensure Collaborative Program cost-effectively and successfully offsets effects of management actions on the YBCU in compliance with the ESA: o Set restoration targets o Determine focus areas for protection and restoration efforts	• Much flexibility and variety in methods for tracking movements of individuals: • Radio-telemetry • GPS • Light-level geolocators • Stable isotopes • Color-banding • Much flexibility and variety in study types and methods to assess factors influencing movement: • Field-based studies • Remote sensing studies • Modeling studies	• Site fidelity • Natal and breeding dispersal distances and rates • Home range sizes • Core use area sizes • Migration distances and routes • Wintering locations • Habitat characteristics of high use areas • Prey composition and availability • Reproductive success • Connectivity among populations • Age and sex • Suitable habitat availability and distribution	• Multi-year • MRG	• Land access and permission • Qualified and permitted personnel • Collecting large datasets • Time- and labor-intensive fieldwork • Investigating ecosystem components across multiple temporal and spatial scales • Integrative research strategy that synthesizes results of a number of interrelated studies	Level 2

6 CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE RIO GRANDE SILVERY MINNOW

This section addresses several critical scientific uncertainties identified by an ISP charged with performing detailed reviews and evaluations of specific topics surrounding RGSM biology, life-history and habitat requirements (see Section 2.2.4). The narrative sections below provide *brief overviews* of the scientific relevance, management application, and recovery application for several critical scientific uncertainties identified by the ISP and documented in their final report (Noon et al. 2017). *In-depth discussions of these topics, along with listing history, recovery efforts, population status, MRG management actions, and additional reference citations are provided in* Appendix E-2**.** Study plan considerations also are offered in this section for each critical scientific uncertainty to guide Collaborative Program signatories with internally developing study plans or soliciting detailed technical proposals from the scientific community.

6.1 Identified Critical Scientific Uncertainties

The ISP identified 20 critical scientific uncertainties in five thematic areas (Population Dynamics, Reproductive Biology, Age and Growth, Physical Habitat Relations, and Sampling Methodologies). Two uncertainties, noted below, were listed in each of two thematic areas. Critical scientific uncertainties and potential studies to address them were ranked by the ISP as *Level 1* (most critical) or *Level 2* (important, but of less immediate concern), or were unranked.

Thirteen of the uncertainties were identified as *Level 1* and these are presented below. The ISP report (Noon et al. 2017) did not specifically attribute any of the uncertainties in Physical Habitat Relationships as *Level 1* or *Level 2*; however, ISP chair Barry Noon (personal communication) subsequently reported that the panel identified two uncertainties under Physical Habitat Relationships as being *Level 1*. The 13 *Level 1* uncertainties identified by the ISP were:

Population Dynamics

1. What are the key age-specific fecundity and survival rates (e.g., life-history sensitivities) that have the greatest impacts on RGSM population growth?

    - The ISP believes that managers and researchers working with the RGSM would benefit from construction and parameterization of a matrix population-dynamics model for the species. This model would allow the identification of the age-specific fecundity and survival rates (i.e., sensitivities) that have the greatest impacts on RGSM population growth and, therefore, which aspects of the RGSM life-history might be most amendable to management actions.

2. What are the age-specific survival rates, and their variances, of RGSM?

    - Age-specific survival rates are necessary to parameterize the recommended population dynamics model. The ISP reviewed the estimates of RGSM survival derived by Daniel Goodman (2010, 2011). The ISP observed that the survival estimates varied widely across years and reaches and concluded that age-specific survival rates were not adequately known, especially as this relates to parameterizing the recommended population dynamics model.

3. What are the age-specific fecundities, and their variances, of RGSM?

    - Age-specific fecundity rates are necessary to parameterize the recommended population dynamics model. The ISP reported there were no published estimates of RGSM fecundity, although fecundity estimates from a series of hatchery fish was available. The ISP concluded the fecundity and annual egg production of wild RGSM are insufficiently known to parameterize the population dynamics model. This uncertainty is similar to #8, below; they are considered in combination henceforth.

4. Can the relationship between the annual catch-per-unit-effort (CPUE) index and true population size be better characterized?

    - The ISP concluded that the relationship between the annual CPUE index and true population size has been insufficiently characterized. The CPUE index is based on fish captures made by seining, the efficiency of which varies with flow, mesohabitat, and fish size. At present, CPUE cannot be adjusted neither for variation in these factors, nor their interactions. The index, thus, is sensitive to variation in flow, habitat variability, etc., compromising its ability to track interannual trends in RGSM populations. This uncertainty is similar to #13, below; they are considered in combination, henceforth.

5. What is the relationship between RGSM demographic rates and: A) hydrologic factors; B) abiotic environmental factors; and C) biotic factors in the MRG?

    - The ISP concluded that uncertainty remains regarding the relationships between RGSM demographic rates and: A) hydrologic factors; B) abiotic environmental factors; and C) biotic factors. RGSM abundance (fall CPUE index) is correlated with several environmental factors. However, the fall CPUE-index conflates survival of different age classes and reproductive output. Further, given the limitations of CPUE described in #4 above, it is not known how hydrological, abiotic, and biotic factors affect RGSM survival and reproductive output.

Reproductive Biology

6. What is the temporal variability in RGSM spawning and its periodicity throughout the spring and summer?

    - The ISP recommends that knowledge of the temporal variation in RGSM spawning should be improved. The efficiency of Moore egg collectors (MECs), used to monitor abundance of RGSM ova in the MRG, is affected by discharge, depth, and other factors. The ISP recommends development of correction factors to allow a better understanding of the timing, location, and magnitude of RGSM reproductive activity. Also, timing of deployment of MECs limits their use in detecting potential monsoonal spawning events and the ISP recommends expanding the seasonal sampling frame to assess the presence and significance of monsoonal spawning events. This uncertainty is similar to #12, below; they are considered in combination, henceforth.

7. What are the specific environmental cues that trigger RGSM spawning?
    - The ISP concludes that although RGSMs are known to spawn on the ascending hydrograph, there is uncertainty as to the precise environmental cue(s) that trigger spawning. This uncertainty is similar to #10, below; they are considered in combination henceforth.
8. What are the size-specific fecundities of naturally-spawning RGSM and the number of (fractional) spawning events?
    - The ISP concludes that size-specific fecundities of naturally-spawning RGSM and number of (fractional) spawning events are unknown (see also uncertainty #3, above).

Physical Habitat Relations

9. What is the spatial extent and hydraulic quality of habitats used by RGSM for critical life-stages (spawning, larval rearing, juvenile, and adult)?
    - The ISP concludes there is uncertainty in the spatial extent and hydraulic quality of habitats used by RGSM for key life-stages (spawning, larval rearing, juvenile, and adult). Habitats used by some like history stages (juveniles, adults) are well known, but those used for spawning and larval stages are less well known. Also, the spatial extent and distribution of such habitats has not been determined.
10. What is the proximate trigger (e.g., flow velocity, temperature, rate of increase in flow velocity, or some combination) for spawning by the RGSM (see also uncertainty #7, above)?
    - The ISP concludes that the precise proximate trigger for spawning (e.g., flow velocity, temperature, rate of increase in flow velocity, or some combination) is not known (see also uncertainty #7, above).

Sampling Methodologies

11. What is the age structure of the RGSM population?
    - The ISP concludes there is uncertainty in the age structure of the RGSM population and the typical longevity of individuals.
12. How does the vertical and horizontal distribution of RGSM ova vary as a function of flow and location in the Middle Rio Grande channel?

- There is uncertainty in the vertical and horizontal distribution of RGSM ova, within the MRG water column, as a function of flow and location. This uncertainty is similar to #6, above; they are considered in combination, henceforth.

13. Does the CPUE index, as currently calculated, provide a valid index of RGSM population abundance?

    - The CPUE index as currently calculated is sensitive to variation in catchability due to a number of factors (discharge, depth, etc.), which limit the ability of the index to track changes in RGSM population abundance (see also uncertainty #4, above) and would benefit from studies that better describe, and allow for correction of, sampling limitations. (Note, the priority of this uncertainty was reported as Level 2 in Noon et al. [2017].)

The following seven scientific uncertainties were also identified by the ISP as important, but of less immediate concern (*Level 2*), or were unranked (Noon et al. 2017):

Population Dynamics

- Are there density-dependent factors that limit population growth in the RGSM? What is the strength of these factors?
- What effect does hatchery augmentation have on RGSM population dynamics and achievement of recovery objectives?
- What is the contribution to RGSM population dynamics of fish collected and transported during dry-season salvage operations?

Reproductive Biology

- What is the optimum reproductive habitat for RGSM?

Age and Growth

- What is the typical longevity of RGSM?

Physical Habitat Relations

- What is the role of, and relative contribution to, fish production (age-0 recruitment and survival of all age classes) channel and floodplain habitats?
- What is the management potential for fish production (recruitment and survival of age-0 fish) in each reach of the Middle Rio Grande?

6.2 Connectivity Among Critical Scientific Uncertainties

The Level 1 critical scientific uncertainties for RGSM are interconnected. In some cases, information pertaining to one uncertainty is related to, or is necessary to inform research on, other critical uncertainties. Information on RGSM age structure (uncertainty #11) is required to estimate age-specific survival (uncertainty #2) (left-hand side of Figure 10). Estimates of age-specific survival and age-specific fecundity, as informed by age structure, are necessary to determine life-history sensitivities (uncertainty #1), and all of these measures are required to develop and assess models relating demographic rates and environmental conditions (uncertainty #5). The relationship between demographic rates and the environment is related to, and informs studies of, the spatial and temporal distribution of ova (uncertainty #12) and RGSM habitat quality (uncertainty #9). CPUE is necessary, as a dependent variable, to assess models of demographic rates and environmental conditions and the quantity and quality of RGSM habitat. Finally, cues for spawning (uncertainties #7 and #10) are needed to understand the timing and periodicity of RGSM spawning (uncertainty #6), and both are needed to fully understand the spatial and temporal distribution of ova. Presentation of these interrelationships is not intended to indicate the relative importance of various uncertainties but may be useful in determining the order in which the uncertainties are addressed.

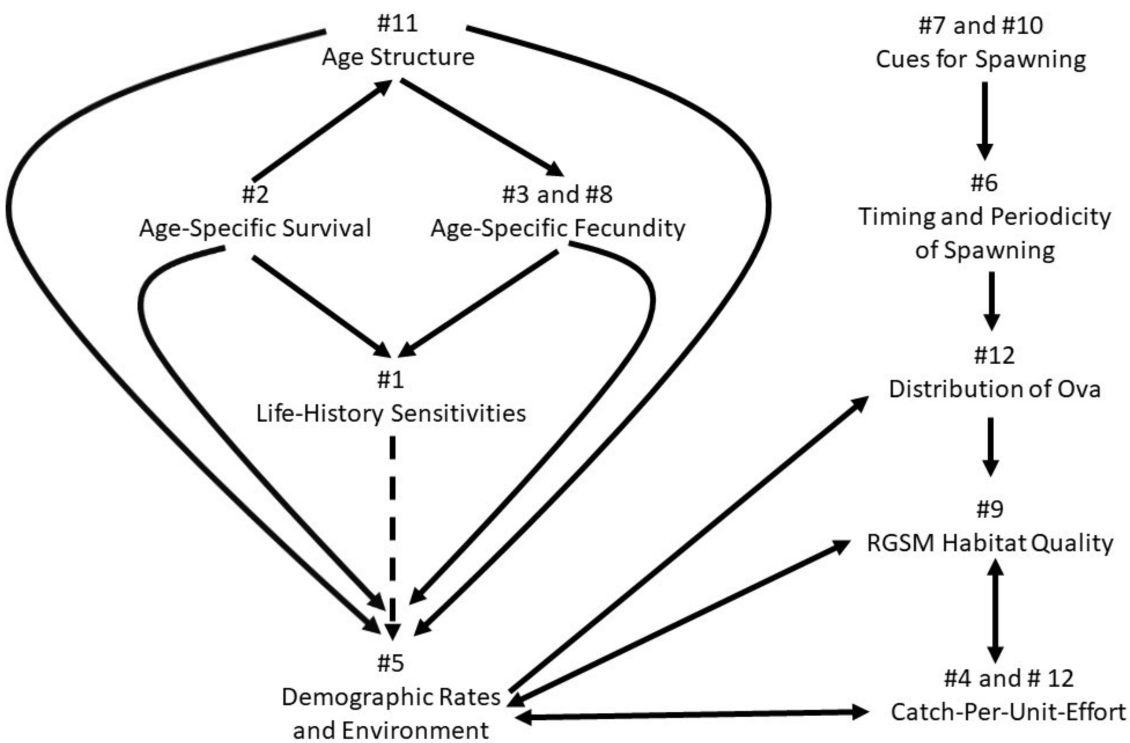

Figure 10. Interrelationships of Level 1 scientific uncertainties identified by the Independent Science Panel for the Rio Grande Silvery Minnow in the Middle Rio Grande.

6.3 Critical Scientific Uncertainty #1: Key Life History Sensitivities

Study Question: What are the key age-specific fecundity and survival rates (e.g., life-history sensitivities) that have the greatest impacts on RGSM population growth?

6.3.1 Scientific Relevance

The ISP strongly urges development and parameterization of a matrix population model for the RGSM. Estimates of age- (or size-) specific survival and fecundity rates, i.e., population vital rates, can be used to parameterize this model (Leslie 1945; Caswell 2001), which can be used to estimate the future size of a population, the relative abundance of different age (or size) classes, and the rate of population growth. Linking matrix models with environmental variables allows not only prediction of population responses, but an understanding of the mechanisms responsible for those changes. Matrix models also can be used to assess life-history sensitivities, which measure which age-specific survival and fecundity rates that have the greatest impact on population growth. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #1: Critical Life-History Sensitivities*.

6.3.2 Management Application

Sensitivity and elasticity analyses provide important management insight into which aspects (age-specific survival rates, age-specific fecundities) of RGSM life-history that have the greatest effect on rates of population change, thereby allowing improvements in design and implementation of future management and research efforts, by directing those actions and studies to the life-history stages where they would have the greatest affect. For example, a given habitat manipulation could affect several life-history stages; however, the manipulation might have little effect on RGSM populations if other, more influential stages, are not affected by the manipulation. Coupling projection matrices with (1) estimates of the natural variation in each vital rate and (2) relevant hydrologic and other environmental covariates can provide probabilistic estimates of the direction and magnitude of population responses and an understanding of the potential impact of management actions on long-term population viability. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #1: Critical Life-History Sensitivities*.

6.3.3 Recovery Application

Recovery goals for RGSM provide explicit abundance (CPUE) and reproductive success criteria for prevention of extinction and eventual downlisting. These criteria are not commonly met, particularly in dry years. Understanding which life-history sensitivities are most important to the rate of population growth and are most amenable to management will facilitate the achievement of RGSM recovery goals. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #1: Critical Life-History Sensitivities*.

6.3.4 Study Plan Considerations

Initial estimates of life-history sensitivities should focus on estimating the elasticity value of each age-specific survival and fecundity rate. Initial parameterization of the projection matrix can be based on existing data (for example, see Noon et al. 2017), although there are some limitations to those data, and there are length-based means of estimating missing parameters (e.g., Velez-Espino et al. 2006). Once a projection matrix is constructed, elasticities of age-specific survival and age-specific fecundity rates can be calculated using eigen-analysis as described by Caswell (2001). To the extent possible, age-specific survival and fecundity rates should include estimates of spatial (among mesohabitat types and reaches) and temporal (across years) variability. The projection matrix presented by Noon et al. (2017) is deterministic and was constructed for heuristic purposes and they recommended eventually including measures of parameter uncertainty. Hilborn and Mangel (1997) distinguish between two types of uncertainty: observation uncertainty and process uncertainty. Observation uncertainty is, essentially, measurement error. There are many potential sources of measurement error, for example, different members of a field crew might vary in their measures of RGSM length, or different sampling crews or gears may have different abilities to capture RGSM, which could affect estimates of survival. Process uncertainty describes temporal and spatial variation in the underlying process being studied. For example, survival of age-0 RGSM will likely vary from year to year. At a minimum, estimates of process uncertainty for each age-specific survival and fecundity rate should be incorporated into analyses of the projection matrix. Incorporating process uncertainly (i.e., stochasticity) within matrix models requires simulation solutions. Conducting these stochastic life-stage simulations will give more precise estimates of population growth rates and the vital rates most responsible for changes therein.

The projection matrix, and insights derived from it, can be greatly improved as age-specific fecundity and survival estimates (see critical uncertainties #2 and #3 below) and estimates of their variances are acquired.

6.3.5 Priority Ranking

Addressing critical scientific uncertainty #1 is considered a Level 1 Priority (Table 6) and was among the most important management-relevant scientific uncertainties identified for the RGSM by the ISP.

6.4 Critical Scientific Uncertainty #2: Age-Specific Survival Rates

Study Question: What are the age-specific survival rates, and their variances, of RGSM?

6.4.1 Scientific Relevance

RGSM abundance can vary by over two orders of abundance within a year and varies substantially among reaches within the MRG. To understand variation in the abundance and distribution of RGSM, it is essential to have estimates of the underlying demographic parameters that give rise to the observed population abundances. This requires estimates of age-specific survival rates and estimates of their variability. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #2: Age-Specific Survival Rates*.

6.4.2 Management Application

Sensitivity and elasticity analyses of age-specific survival rates can show which age class(es) or early life-history stages have the greatest effect on population growth rate. Effectiveness of management actions then could be maximized by considering actions that promote survival of those specific those ages or early life-history stages. Based on correlations between RGSM population size in October samples and hydrologic characteristics in the preceding spring, current management of RGSM is largely directed toward providing habitat and spring flows to facilitate RGSM spawning and survival of early life-history stages. These actions are based on correlation rather than on any specific mechanistic model, which could be developed though analysis of sensitivities and elasticities. An understanding of the effects of spatial and temporal variation in age-specific survival rates can allow appropriate allocation of adjustment of management actions across years and among river reaches. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #2: Age-Specific Survival Rates*.

6.4.3 Recovery Application

Recovery goals for the RGSM require self-sustaining populations that meet specific abundance, reproductive, and permanency criteria. Meeting these criteria will require manipulation of river flows and habitat restoration. The nature, timing, and magnitude of management activities will differentially affect different RGSM life-history stages and, hence, recovery of the species. Sensitivity and elasticity analyses, by identifying the most influential population vital rates, provide guidance as to which management activities will have the greatest effect and how these activities may be most profitably be varied among reaches or over time. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #2: Age-Specific Survival Rates*.

6.4.4 Study Plan Considerations

Age-specific survival rates are likely to vary temporally and spatially (among mesohabitats and reaches) in response to variation in environmental conditions. The ISP recommends making age-specific survival rates estimates in two basic ways. First, CPUE can be partitioned by age class (age 0, age 1, age 2) using, for example, October CPUE indices, from successive years. Comparing CPUE for a given cohort (i.e., RGSM spawned in a given year) with CPUE of that cohort in the following year allows the use of ratio estimators to provide an estimate of annual survival rate:

$$Survival = \frac{CPUE(t+1)}{CPUE(t)}$$

Separating CPUE by mesohabitat, river reach, and year, allows estimates of survival and its spatial and temporal variance to be obtained. The ISP notes these estimates depend on constant catchability. However, these estimates also assume there is no movement of RGSM between reaches and mesohabitats. This latter assumption is problematic for mesohabitat types and will complicate estimates of mesohabitat-specific survival rates.

Lengths of RGSM captured during CPUE sampling are recorded. These lengths are then used to assign ages to captured RGSM assuming standard growth rates (e.g., Dudley et al. 2016). The ISP recommends instead that these assignments be made using the R *mxdist* library (or a comparable package), which uses maximum likelihood methods to estimate mean lengths, and their variances, from length frequency information (MacDonald and Pitcher 1979; MacDonald 2015). Thus, rather than using a fixed relationship between length and age estimates, the length-age relationship (and variances) can be updated at any desired time step (e.g., monthly, annually). With some expansion, this effort could be expanded to incorporate one of the two studies recommended by the ISP for resolving uncertainties in RGSM age structure (Critical Scientific Uncertainty #11). The ISP recommended that small samples of RGSMs be aged each year (in October and spring) to provide estimates of mean length and variance in length at age. (Note, these fish contribute to studies estimating age-specific fecundity and ovarian histology of RGSM.) Annual estimates of the age-length relationship allow for time-dependent assignments to age-class and provide insights into how length varies over time. These estimates could be used as input for the R mxdist library (MacDonald 2015) to resolve overlapping length-frequency distributions into component age distributions. This package requires the user to specify the number of age classes present. Three age groups should be assumed (ages 0, 1, and 2 in October; ages 1, 2, and 3 in spring) and the validity of this assumption can be assessed by altering the number of age classes and assessing model fit. If aged samples cannot be collected, then current "best guesses" of means and variances of lengths at ages 0, 1, 2, and 3 (e.g., Horwitz et al. 2011) should be used, based on historic age samples.

Survival also can be estimated using regression-based estimators (e.g., Skalski et al. 2005; Goodman 2011) that follow the abundance of a cohort over time, typically in annual steps. These methods could be used for adult RGSM based on the October CPUE index, or for age-0 fish, using seine catches made over a period of weeks or months. In fisheries, the regression of ln(catch) over time, for a cohort, is referred to as a catch curve and commonly is used to estimate mortality and by manipulation, survival (Ricker 1975). Catch curves can be used to estimate annual survival using data incremented over annual periods or it can be used to estimate survival over shorted time periods, which is commonly done to estimate survival of age-0 fish (Dahlberg 1979; Quist and Guy 2001; Wilde and Durham 2008b). Smith et al. (2012) recently reviewed, and made methodological recommendations for, analyses of catch curves.

Given the large variation in length at age in age-0 fish, the most precise field estimates of survival might be derived from catch curve analyses, as above, based on numbers of fish with ages estimated from otoliths (e.g., Wilde and Durham 2008b). Given the low daily survival rates of early life-history stages, removal of fish from the wild would have no discernable population effects. Alternatively, recently dead age-0 fish could be obtained from isolated pools during periods of summer drought in tandem with ongoing salvage activities. Validation of otolith age estimates (Taubert and Coble 1977; Durham and Wilde 2008a) could be conducted with fish obtained from hatcheries or other research facilities such as Dexter National Fish Hatchery, Albuquerque BioPark, and Los Lunas.

Precise field-based estimates of survival, particularly for early life-history stages, may be difficult to make in the field. Pepin (1991) found that temperature accounted for a large proportion of the variation in ova survival rates and that temperature and size were the primary factors that influenced survival of age-0 fish. RGSM reared in hatcheries and other research facilities (Dexter National Fish Hatchery, Albuquerque BioPark, and Los Lunas) could possibly be used to measure survival rates and conduct controlled experiments that examine environmental effects on survival.

6.4.5 Priority Ranking

Addressing critical scientific uncertainty #2 is considered a Level 1 Priority (Table 6) and was among the most important management-relevant scientific uncertainties identified for the RGSM by the ISP.

6.5 Critical Scientific Uncertainty #3 (and #8): Age-Specific Fecundities

Study Question: What are the age-specific fecundities, and their variances, of RGSM?

6.5.1 Scientific Relevance

RGSM abundance can vary by over two orders of abundance within a year and varies substantially among reaches within the MRG. To understand variation in the reproductive output and success of RGSM, it is essential to have estimates of age-specific fecundities and their variability. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #3: Age-Specific Fecundities*.

6.5.2 Management Application

Sensitivity and elasticity analyses of age-specific fecundity rates can show which age class(es) make the greatest contribution to reproductive output and, hence, population growth rate. This understanding can lead to improvements in the effectiveness of management actions. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #3: Age-Specific Fecundities*.

6.5.3 Recovery Application

Recovery goals for RGSM provide explicit criteria for abundance (CPUE) and reproductive success to prevent extinction and to allow eventual down-listing. These goals also explicitly recognize the importance of RGSM populations within difference reaches of the MRG. Understanding temporal and spatial variation in age-specific fecundity rates will help direct attention and action toward age-classes that are most important to the rate of population growth and which would be most amenable to management, which will facilitate the achievement of RGSM recovery goals. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #3: Age-Specific Fecundities*.

6.5.4 Study Plan Considerations

Fecundity of RGSM in wild populations can be expected to vary among and within age classes, due to spatial and temporal variation fish size, physiological state, and other factors. To develop fecundity-size (age) relationships for wild RGSM, the ISP recommends collection of a sample of gravid females from the wild, just before initiation of peak flows in the spring. These RGSMs should span the range of sizes (i.e., age classes present in the population). Collected fish would be euthanized and aged by counts of annular rings on otoliths. Enumeration of the numbers oocytes in different stages of development can be done by macroscopic examination, by differentiating “immature” and “mature” oocytes. However, given the possibility that RGSM may spawn multiple batches of ova and may spawn over a protracted period, counts of oocytes may not yield useful estimates of fecundity (Heins and Rabito 1986; Heins and Baker 1987; Rinchard and Kestemont 1996). Therefore, oocyte counts should be supplemented with measurements of mature oocyte diameters, which when presented as histograms, would provide information on the variation in developmental stages among “mature” oocytes that would provide some insight into whether RGSM spawn multiple batches of ova, over a period of days. Variation in stages of maturity among oocytes also could be studied microscopically using histological preparations of ovarian tissue. Different preservatives generally are used for samples intended for histological analysis (Patiño and Takashima 1995), a small but important consideration. Of the two methods, histology will yield more detailed and definitive information on variation in oocyte developmental stages. It is uncertain whether RGSM is a multiple spawning species and, if so, whether later spawns are biologically important. Histological analysis of RGSM ovaries collected in spring samples will provide some insight into this question (Fernandez-Delgado and Herrera 1994; Ali and Kadir 1996; Lowerre-Barbieri et al. 1996; Rinchard and Kestemont 1996). However, to definitively determine whether fractional spawning occurs, and how substantial it is, will require collection of samples throughout the putative spawning season. It seems likely that RGSM do produce a large, synchronous spawn (Durham and Wilde 2008a) in early spring and sampling this season alone, should provide information useful in developing fecundity-size (age) relationships.

As a possible alternative to the above study, as a means of estimating fecundity, the ISP suggests capturing wild RGSM from the MRG, moving them to a breeding facility, and inducing spawning either through the use of hormones or by manipulation of environmental spawning cues. After spawning, RGSM could be released back into the wild. Counts of spawned ova and lengths of females used could then be used to estimate size-fecundity relationships, which then could be used to estimate age-specific fecundity. There are caveats to this approach. First, if fish are released, age cannot be directly assessed. Second, hormones used to induce spawning may result in the final maturation of a greater proportion of oocytes (= greater number of ova spawned) than might be expected if spawning was not hormonally induced. This would result in an over estimate of fecundity. The potential magnitude of this effect could be assessed with hatchery fish. Here, two samples of female RGSM, one injected and other not, would be used for a histological comparison of the number and stages of oocytes. Third, simply removing RGSM from the wild, as per the study outline above, results in a small decrement in population; however, capture, transport, and re-introduction post-spawn RGSM into the wild may decrease the number of fish lost, but because of the multiple stresses these fish will have experienced, this protocol risks possible introduction of disease into the wild population.

As a possible alternative to capturing RGSM and transporting them to a breeding facility for induction of spawning, Wilde and Urbanczyk (unpublished data) have had some success with capture and in situ induction, using hormones, of spawning in flow-through chambers kept within the river. Study species included Plains minnow and all fish used the in situ spawning studies were successfully released alive. This approach would allow estimation of size-fecundity relationships, without removing fish from the wild, but with not allow any direct assessment of age.

Here, as for age-specific survival, it is clear that the ISP recommends multiple estimates, not necessarily derived from multiple methods, so that estimates of spatial and temporal variation in age-specific fecundity, and their variances, are obtained.

6.5.5 Priority Ranking

Addressing critical scientific uncertainty #3 (including #8) is considered a Level 1 Priority (Table 6) and was among the most important management-relevant scientific uncertainties identified for the RGSM by the ISP.

6.6 Critical Scientific Uncertainty #4 (and #13): Catch-Per-Unit-Effort Index

Study Question: Can the relationship between the annual CPUE index and true population size be better characterized?

6.6.1 Scientific Relevance

The October CPUE-index currently used to monitor RGSM abundance and assess population responses is a count-based index of population size based on seine catches. RGSM catchability is likely to vary among size (i.e., age) classes and as a function of river flows and mesohabitat types. Consequently, the relationship between the CPUE index and the true abundance of RGSM is unknown and variable over time and across mesohabitats, which limits the usefulness of the CPUE index as a reliable measure of status and trends in the RGSM population. Reliability of the CPUE index can be improved by studies that better characterized the index and which possibly allow for adjustment for variation in catchability. Appendix E-2, *Critical Scientific Uncertainty #4: Limitations of the CPUE Index*.

6.6.2 Management Application

The framework for habitat restoration in the MRG (Tetra Tech 2004), the RGSM recovery plan (USFWS 2010), and the recent BiOp for USBR's and its BiOp Partners' water management activities in the MRG (USFWS 2016) recommend management and restoration activities, the success of which are tied to changes in RGSM abundance as measured by the fall (October) MRG basin-wide CPUE results. How the CPUE index is calculated affects its accuracy and variability and, therefore, its ability to accurately measure changes in RGSM abundance due to management and restoration. Correcting the CPUE index for catchability would enhance its accuracy and usefulness. Appendix E-2, *Critical Scientific Uncertainty #4: Limitations of the CPUE Index*.

6.6.3 Recovery Application

Recovery goals for RGSM are related to measures of population size as one of the criteria for downlisting. Thus, it is important to have measures (i.e., CPUE) of population size and response to management actions that accurately reflect the true abundance of RGSM and which have a small sampling variance. Appendix E-2, *Critical Scientific Uncertainty #4: Limitations of the CPUE Index*.

6.6.4 Study Plan Considerations

There is a growing interest within the sciences for the adoption of practices, termed reproducible research, that require, among other considerations, that data sets and computer code used in studies be made available to other researchers so that results can be verified and alternative analyses conducted (Peng 2009; Sandve et al. 2013). This matter was not addressed by the ISP, but reproducible research practices are strongly suggested here as an integral part of all studies recommended by the ISP for two reasons. First, many of the reports cited herein, as well as those cited and reviewed by the ISP, do not present sufficient descriptions of study methods or summary statistics to allow the reader to fully evaluate the data and arguments presented. Second, in trying to implement studies suggested by the ISP, basic study design considerations, such as estimating sample sizes and conducting proscriptive power analyses, are made difficult, if not impossible, because necessary measures of sample variability are not reported.

The ISP recommended two studies to assess the relationship between the CPUE index and true RGSM abundance. These studies should be conducted in the field as an extension of ongoing surveys. First, CPUE estimates obtained by seining should be collected in conjunction with estimates obtained by depletion sampling such as those presented by Dudley et al. (2012). The ISP suggests that abundance estimates obtained from depletion sampling are likely to be more accurate than those obtained from seining if the depletion sampling is thorough. This does seem likely given that RGSM population estimates based on depletion sampling were consistently twice as high as those derived from seining (Dudley et al. 2012). RGSM abundance estimates from depletion sampling can then be used to “correct” or “calibrate” the seine-based CPUE index using a ratio estimator (Cochran 1977; Thompson 2002). The ISP suggested this study should be conducted over at least two years. The study by Dudley et al. (2012) compared estimates collected during 2008-2011, which was sufficient to suggest that the (seine-based) CPUE index was indicative of general population trends; however, results of that study are applicable to the the range of habitat and flow conditions that occurred during the four years of that study. Dudley et al. (2012) presented standard errors for their estimates of capture probabilities in different mesohabitats, but did not present any information on interannual or flow-related variation in capture probabilities. At a minimum, their standard errors could be used in a prospective power analysis (Peterman 1990; Maxell 1999) to estimate the necessary number of replicates and, possibly, years of study needed.

The ISP also recommended a study that would compare catches of RGSM in the fine-mesh seines used to sample adult RGSM and the finer-mesh seines used to sample age-0 RGSM, with catches from a very fine-mesh seine that, presumably would non-selectively capture RGSM of all sizes. Catches from this latter seine then could be used calibrate RGSM catches from the seines used for adult and age-0 RGSM using ratio estimators. Comparing catches in two seines types varying in size selectivity would allow assessment of the degree to which smaller age-0 RGSM are missed in mid-summer surveys and could support current aggregation of RGSM catches from the “adult” and “age-0” seines into a single index of CPUE, the appropriateness of which was questioned by Hubert et al. (2016). The size of the study can be determined with prospective power analysis, based on the precision desired, using catch rates and estimates of their variability from existing data. Note, a relatively modest expansion of this effort could also address one of the studies recommended by the ISP to address uncertainties in RGSM age structure (Critical Scientific Uncertainly #11.) In addition to the above, the ISP recommends collecting RGSM from inundated floodplain habitats using fyke nets and seines in areas in which both gears can be effectively deployed (see Gonzales et al. 2014). Seine catches could be adjusted for size selectivity using fyke net catches, under the assumption that RGSM catches in fyke nets, which are a passive gear (they are set in place and fish enter into the net under their own effort) will more closely represent the true distribution of RGSM lengths and ages than will catches from seines, which are an active gear, catches of which will be influenced by seine operation and variation in avoidance (i.e., swimming speed differences attributable to differences in lengths and ages of RGSM). A fitted selection curve can then be used to adjust length data for gear-selection bias before these data are used to resolve length-frequency distributions into component age distributions using the R *mxdist* library or comparable statistical methods.

The ISP recommended presenting CPUE estimates for specific mesohabitats rather than combining results across mesohabitats. Further, the ISP recommends using the current CPUE metric be replaced with a mesohabitat-specific metric calculated for a single mesohabitat, characterized by high abundance of RGSM, that has substantial availability in all primary sampling reaches, they state, “The time-series of this metric should provide a more reliable indicator of trends in October abundance of RGSMs because it assumes only that catchability within this mesohabitat type are constant across years at the time of October sampling. As flows during October are probably low and have relatively little variation across years (relative to other months), we believe that this assumption is a reasonable one.” We acknowledge the potential shortcomings of the use of a single mesohabitat to monitor catches, but such an approach would eliminate among-mesohabitat variance from the metric proposed by the ISP and be used to supplement, rather than replace, the CPUE index. The potential merits of this recommendation can be studied with existing data. First, mesohabitats with the greatest catch rates in which seine results and depletion sampling are most correlated can be examined as candidate mesohabitats. Then simulation studies can be conducted to determine which measure, the currently-constructed CPUE or the mesohabitat-specific CPUE, provides the most accurate and precise estimates of trends in RGSM abundance.

6.6.5 Priority Ranking

Addressing critical scientific uncertainty #4 (and #13 from Noon et al 2017) is considered a Level 1 Priority (Table 6) and was among the most important *management-relevant* scientific uncertainties identified for the RGSM by the ISP.

6.7 Critical Scientific Uncertainty #5: Demographic Rates and Environmental Factors

Study Question: What is the relationship between RGSM demographic rates and: A) hydrologic factors; B) abiotic environmental factors; and C) biotic factors in the MRG?

6.7.1 Scientific Relevance

The relationship between RGSM CPUE, among other population characteristics, and a substantial number of environmental variables, particularly those related to aspects of the MRG hydrograph, has been studied. However, these studies have been correlative in nature and, while useful in suggesting relationships amenable to management action, do not provide an understanding of the specific mechanism(s) by which these relationships affect RGSM populations. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #5: Demographic Rates and Environmental Factors*.

6.7.2 Management Application

To manage RGSM and most effectively allocate water and other resources, it is necessary to move beyond correlational analyses of RGSM abundance, reproductive success, etc., to understanding how exactly specific actions affect abundance, survival, and reproductive success. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #5: Demographic Rates and Environmental Factors*.

6.7.3 Recovery Application

Recovery goals for RGSM provide explicit abundance (CPUE) and reproductive success criteria for prevention of extinction and eventual downlisting. These goals also explicitly recognize the importance of RGSM populations within difference reaches of the MRG and establishing additional populations elsewhere. Understanding how RGSM abundance and population vital rates respond to temporal and spatial variation in environmental conditions will facilitate recovery in the MRG and will also provide useful insight into conditions required for re-establishment of RGSM in other portions of its historic range. For more detailed technical information, see Appendix E-2, *Critical Scientific Uncertainty #5: Demographic Rates and Environmental Factors*.

6.7.4 Study Plan Considerations

The ISP recommends that population vital rates (age-specific survival and fecundity rates) as well as CPUE data should be modeled as a function of broad-scale hydrologic variables, mesohabitat type, and abiotic factors that may vary across mesohabitat types (e.g., salinity, turbidity, water depth, local flow rates, etc.). These models should explicitly explore the inclusion of mesohabitat-type and reach as covariates. If age-specific survival and fecundity rates are available to fully parameterize a stochastic population matrix model, initial modeling exercises could be conducted with existing data.

Once age-specific survival and fecundity rates have been modeled as a function of scale hydrologic variables, mesohabitat type, and abiotic factors, the ISP suggests that field studies could be used to validate and refine the models. These studies would take advantage of natural temporal and spatial variation in candidate response variables, including age-specific survival and fecundity, reproductive output, and abundance to further evaluate the effects of environmental covariates (predictor variables). These studies, primarily based on inferences drawn from regression type models, are appropriately viewed as correlational studies. The size (time frame, number of samples, etc.) of the study can be determined with prospective power analysis, based on the precision desired, using estimates of CPUE and population vital rates, as well as estimates of their variability, from existing data.

Once mechanistic relationships between environmental factors and abundance and population vital rates are understood, the ISP suggests that hypothesis-based experimental studies could be conducted under controlled conditions at the Los Lunas or Albuquerque BioPark hatchery facilities. These studies would, of necessity, be limited to those factors that can be simulated or manipulated, but the results would help elucidate exact causal mechanisms and would have greater predicative power than those obtained from observational studies.

6.7.5 Priority Ranking

Addressing critical scientific uncertainty #5 is considered a Level 1 Priority (Table 6) and was among the most important management-relevant scientific uncertainties identified for the RGSM by the ISP.

Table 6. Study framework attributes for critical scientific uncertainties identified for the Rio Grande Silvery Minnow.

Uncertainty Statement/Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Recommended Priority
What are the key life-history sensitivities of RGSM and which age-specific survival and fecundity rates most affect the rate of population change?	• Sensitivity and elasticity analyses identify aspects of RGSM life-history that have the greatest effect on rates of population change • Coupled with relevant hydrologic and environmental covariates these analyses can facilitate understanding of management actions	• From existing data, and data to be conducted in other studies, construct stochastic life-history matrices (age-specific survival and fecundity rates, and their variances) • Calculate sensitivities and elasticities	• Elasticity and sensitivity of age-specific survival and fecundity rates • Responses of sensitivities, elasticities, and population growth rate to change in hydrological and environmental covariates	• Multi-year • All MRG reaches	• Incorporate reproducible research practices • Initial parameterization, without variances, may be possible from existing data, but new data especially for fecundity are necessary • Stochastic matrix models require simulation for solution and assessment	Level 1
What are the survival rates, and estimates of their natural (process) variability, of different age classes of RGSM?	• Need to know age structure to estimate reproductive output • Survival estimates are needed to understand population responses to management • Mechanistically relate population responses to hydrologic and other environmental variables to survival of specific age classes	Field studies and existing data: • From field counts, calculate the ratio(s) of successive age classes as a measure of survival • Collect, measure, and age small number of RGSM to verify length-age relationships • Assess intra-annual (among months) mortality of RGSM • Use regression (catch curve) measures of survival within and among years Experimental studies: • Determine RGSM growth and survival rates in relation to temperature	Field studies and existing data: • Numbers and lengths of fish captured in field sampling • Length and age of fish collected for length-age verification • Collect, measure, and age small number of RGSM Experimental studies: • Length, age, growth rate, and survival	• Multi-year • All MRG reaches	• Incorporate reproducible research practices • Use R Project library mxdist, or similar method, to assess size-frequency information to be used in survival estimates • Need to verify length as indirect measure of age • Assess information separately for each mesohabitat type • Estimates of process uncertainty are necessary	Level 1
Age-specific fecundities of wild RGSM are poorly known: what is the fecundity of RGSM and how does it vary with age or size?	• Need to know fecundity and timing of reproduction to understand population responses to management • Mechanistically relate population responses to hydrologic and other environmental variables to fecundity of specific age classes	Field studies and existing data: • Collect gravid females to estimate fecundity rates • Collect, measure, and age small number of RGSM for histological analysis of ovaries Experimental studies: • Move wild-caught fish to an experimental facility to induce spawning for fecundity estimates • In situ spawning for fecundity estimates	Field studies: • Lengths and ages of collected fish • Counts of ova, measurements of ova sizes • Histological analyses of ovaries Experimental studies: • Lengths and ages of collected fish • Counts of released ova	• Multi-year • All MRG reaches	• Incorporate reproducible research practices • Initial parameterization, without variances, may be possible from existing data, but new data are necessary • Estimates of process uncertainty are necessary • Design should include measures to assess presence of fractional spawning • Samples, ideally, will spawn the length of the spawning season to determine presence and importance of fractional spawning	Level 1

Table 6. Study framework attributes for critical scientific uncertainties identified for the Rio Grande Silvery Minnow.

Uncertainty Statement/Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Recommended Priority
What is the relationship between the annual CPUE index and true RGSM population size?	• CPUE index is not a reliable measure of true RGSM abundance • Accuracy of CPUE index likely varies over time and across mesohabitats	Field studies: • Compare current CPUE index with catch estimates from depletion sampling to calibrate index • Compare RGSM catches made with seines used in the standard sampling program with catches made by a very fine-mesh seine • Compare fyke net catches with seine catches in floodplains to assess gear-size selectivity Analyses of existing data: • Calculate CPUE (and variances) separately for each mesohabitat type	Field studies: • Number of fish captured, including mean and variance of catches • Length of fish captured, including mean and variance of sizes of fish Analyses of existing data: • Mesohabitat specific indices of CPUE (plus variances) and an overall index weighted and stratified by mesohabitat type	• Multi-year • All MRG reaches	• Incorporate reproducible research practices • Use R Project library mxdist, or similar method, to assess size-frequency information • Assess information separately for each mesohabitat type	Level 1
How do key RGSM vital rates vary as a function of hydrologic factors, abiotic environmental factors, and biotic factors?	• Model RGSM (matrix model) populations as a function of key hydrologic and other variables to predict and assess population responses to management actions	Field studies: • Number and lengths of RGSM captured in standard sampling compared with model predictions based on hydrology and other environmental variables Experimental studies: • Reproduction, survival, population growth of RGSM in response to experimental manipulation of environmental variables in research facility settings	Field studies: • Number and length of RGSM captured in field sampling • Measurements of hydrologic and environmental variables believed to affect RGSM populations Experimental studies: • Number and length of RGSM and population growth rates • Measurements of manipulated environmental parameters	• Multi-year • All MRG reaches	• Incorporate reproducible research practices • Field samples are necessary to test and refine models • Once stochastic matrix models are parameterized, initial exploration of effects of environmental variables may be conducted using existing data in retrospective analyses	Level 1

7 RECOMMENDED PATH FORWARD

This project focused on organizing, holding, and facilitating several workshops and an ISP meeting to assess and document perspectives of both regional and independent scientists concerning the state-of-the-science on a range of topics related to the biology and habitat requirements of four endangered species of management interest to the Collaborative Program. The purpose for the workshops and panel meeting was to identify scientific uncertainties and data gaps considered important for supporting management decisions and informing AM experiments.

The Collaborative Program now faces the difficult challenge of determining which of the many recommended topics should be prioritized for funding. As importantly, the Collaborative Program must consider how to maximize the potential that the funded studies will yield results that improve management decisions and meet Collaborative Program goals and objectives. Addressing these challenges will require well organized and structured approaches, and this report section recommends avenues utilized by other endangered species and AM programs around the country for consideration by the Collaborative Program in moving forward. These recommendations include: (1) utilizing a Structured Decision Making (SDM) process to prioritize study recommendations based upon direct linkages to well defined management objectives and performance measures; (2) integrating management objectives, performance measures, and prioritized studies into a multi-year (3-5 year) strategic science plan (SSP), and; (3) integrating multifaceted use of independent science review and input through various stages of the AM cycle.

7.1 Study Prioritization

The GSA team acknowledges that this report is one of several recent science program evaluations (e.g., Noon et al. 2017; AMEC Foster Wheeler 2016; Hubert et al. 2016) each of which offers extensive recommendations related to strengthening scientific methods, filling management-relevant knowledge gaps and improving management decisions. The recommendations are highly diverse: some are likely to generate benefits in the short-term whereas others could require many years; some are directly linked to guiding AM experiments whereas others aim to address foundational science gaps or management practices; some recommendations are inexpensive whereas others are costly; some recommended studies are stand-alone whereas others require complementary activities to precede or follow. Further complicating matters are the different perspectives of scientists and managers within and across agencies regarding which recommendations should be prioritized and funded.

The good news is that the MRG Collaborative Program is not the first or only multi-stakeholder program faced with such challenges. Several case studies have been published describing how structured decision support strategies and tools were applied to prioritize research and management actions associated with complex natural resource and endangered species management challenges (e.g., Conroy et al. 2008; Gregory et al. 2012a; Gregory et al. 2012b; Gregory & Long 2009; Ogden & Innes 2009; Patrick & Damon-Randall 2008). The approaches utilized in these case studies are collectively referred to as SDM.

This is an approach that is advocated by the U.S. Department of the Interior as a basis for the AM of natural resources under conditions of uncertainty (Williams et al. 2009).

Rooted in decision theory, SDM involves a step-by-step approach to generating and evaluating strategies (in this case strategies for prioritizing studies) marked by multiple interests, multiple participants, conflicting information and uncertainty (Gregory et al. 2012a). According to Gregory et al. (2012b), "the main contribution of an SDM approach is that it takes information relevant to the diverse considerations involved in species recovery planning—concerns relating to ecological, legal, implementation, uncertainty, governance, or management issues—and first organizes them as part of a single decision-focused plan that addresses both factual issues and values, then asks a series of context-specific questions concerning the likely consequences of management actions in order to highlight the key factual uncertainties and value-based trade-offs: What are the underlying objectives of conservation efforts? What are the expected consequences of different management actions, and how should outcomes be measured? What confidence do scientists hold in proposed actions? Do agency affiliations result in biased predictions? To what extent should ecological initiatives be constrained by economics? Is the level of agreement among experts sufficient to implement selected actions?" (p. 33).

The case study highlighted in Gregory et al. (2012b) explains how this structured process was used to help managers and scientists from USFWS, the National Oceanographic and Atmospheric Administration and the Maine Department of Marine Resources address three complex challenges associated with Atlantic Salmon recovery. The challenges were: 1) determining the appropriate balance among the various "funding-worthy" areas of short-term recovery activities, 2) prioritizing between short-and long-term recovery activities (i.e., between management and research) and, 3) creating an outline for moving forward that would be supported by the scientists and managers from all three agencies.

From our perspective, there are several advantages to using a similar SDM approach in the MRG to prioritize a sequence of recommended studies for funding. First, the research and study recommendations identified in our report (and in Noon et al. 2017) are priorities identified by scientists. SDM is designed to engage decision makers, managers and scientists together. We believe engaging all three groups will be essential to a complete assessment of which studies to prioritize and is more likely to ensure that decision makers have a clear understanding of what they are funding and why. Secondly, we suggest it is critical that any study prioritization process is intimately linked to clearly defined management objectives and performance measures. A key step in the SDM process is working with decision makers, managers and scientists to identify management objectives, performance measures and alternative management scenarios to achieve objectives. Developing performance measures to assess whether management objectives are being achieved forms the foundation for any scientifically-based AM program (Cliff Dahm, Delta Science Program, personal communication). Recommended studies that can be clearly linked to supporting these objectives and performance measures should take a higher priority than those that cannot. Thirdly, Collaborative Program partners have dedicated considerable time and resources towards implementing workshops and ISPs to identify scientific uncertainties and improve the scientific rigor of the MRG AM program. Applying a focused SDM process geared towards helping the Collaborative Program determine which scientific recommendations should be prioritized for funding (and when) ensures those investments in workshop and ISP products continue to receive the focus and attention they deserve.

A few key considerations for applying SDM to prioritize scientific investigations include:

- The SDM process is not a "one-size fits all" approach. Rather, it should be tailored specifically towards achieving the goal of prioritizing scientific investigations that can be directly linked to supporting Collaborative Program management objectives and performance measures.
- A SDM is more likely to produce desired results if the individual(s) leading the process have experience applying different SDM techniques across a broad range of natural resource challenges. This should include expertise guiding resource management agencies with defining performance measures.
- Prioritizing scientific investigations for the four endangered species of management interest to the Collaborative Program requires an efficient way to work through the range of perspectives of the different management agencies. SDM approaches are well suited to this task because they focus deliberations on the key objectives and provide a range of tools to address the underlying biological and implementation uncertainties (e.g., Science Courts to debate the pros and cons of various competing recovery hypotheses).
- Portfolio builders, strategy tables, and other techniques (Gregory et al. 2012b) have been used as part of SDM approaches to demonstrate the advantages and disadvantages of alternative sequences of management actions. As always with an SDM approach, the tools cannot "make" any decisions but are used to provide a structure that encourages open and informed discussions among scientists and managers.
- Developing objectives and performance metrics to evaluate Collaborative Program management actions will require careful consideration of the pros and cons of different measures. For example, in some cases it may be necessary to adopt a less desirable performance metric due to data limitations (R. Gregory, University of British Columbia, personal communication).
- The Sacramento-San Joaquin River Delta Science Program (Delta Science Program) recommends following the **SMART** process for developing performance measures (Delta Science Program, Delta Stewardship Council 2016):
    - **S**pecific: clear definitions and exact expectations with standard data collection and reporting to accurately judge performance.
    - **M**easurable: Quantitative terms and numeric targets to meet performance expectations.
    - **A**ccountable: Requires reasonable targets and time frames.
    - **R**esults-Oriented: Must support core values or benefits – quantifies intermediate or final outcomes easily linked to other program goals or quantitative metrics.

- o **T**ime-bound: Must function at reasonable time steps.

We strongly encourage the Collaborative Program to fully evaluate the SDM process and carefully apply it with the end goal of prioritizing scientific investigations. The products developed through a well-executed SDM process should provide substantive information needed to develop a multi-year SSP.

7.2 Strategic Science Plan

A core component of AM is a SSP. A SSP delineates the priority research and monitoring activities necessary to inform management decisions. The SSP defines the time schedule for implementation and completion of research and monitoring projects. Developing a SSP involves a well-defined, deliberative process with full involvement of stakeholders and scientists. While science alone cannot solve the complex challenges facing the MRG Collaborative Program, science that is responsive to and integrated with management and policy processes is a key component of any solution (Delta Science Program, Delta Stewardship Council 2016).

As discussed in Section 7.1, the outcome of an effective SDM process would provide several core components of a MRG SSP, including clearly defined management objectives, performance measures, alternative management scenarios and prioritized research and monitoring activities with direct linkages to the performance measures. Additional core components should include defining a unified vision, principles, and approaches for building on existing MRG science efforts and developing new ones. Ultimately a MRG SSP would serve as a living guide for organizing, conducting, and integrating science into Collaborative Program decision making.

A few key design and implementation components of a multi-year MRG SSP include:

- The most effective organization for a SSP is on a multi-year basis, where priority research and monitoring projects are identified for implementation and ongoing actions over the full expected year(s) of evaluation. The SSP may identify a broad range of research and monitoring projects over a long (e.g., a 10-20 year) time frame, but the priority projects addressed in the SSP should be delineated on an ongoing 3- to 5-year scale (for example see Delta Science Program, Delta Stewardship Council 2016; U.S. Geological Survey [USGS] 2007b).
- The scientific rigor for each proposed project and the linkage to Collaborative Program management objectives and performance measures should be established from formal scopes of work reviewed by a panel of scientists (including regional and outside independent scientists – see Section 7.3 below) and managed by the Collaborative Program Science Coordinator. Each scope of work should identify project goals, objectives, and tasks with associated costs. The costs associated with each project and the source of funding should be identified in the triennial work plan and budget.
- Similar to other well-established AM programs (e.g., Glen Canyon, Platte River, Missouri River, Sacramento-San Joaquin River, etc.), we recommend annual scientific reporting meetings should

be held to bring together scientists (both regional and independent – see Section 7.3 below), managers, and decision makers for the purpose of reporting results and future activities, including any necessary adjustments under the AM cycle. The multi-year SSP should be reviewed annually to ensure that all information is current and to make any necessary changes or adjustments in projects or schedules.

- Key findings generated from funded studies should be documented in a Five-Year *State of the Science Report* that serves to assimilate ongoing scientific understanding and the current status of species.

While there are certainly other important considerations for developing an effective SSP for the MRG, these recommendations are intended as a starting point to aid the Collaborative Program with moving this process forward. As this process evolves, we strongly encourage the Collaborative Program to implement a variety of approaches to ensure the highest caliber science to support the MRG AM Program, including the establishment of a standing independent science committee to provide support through key stages of the SSP design and implementation. This latter recommendation is addressed in greater detail below.

7.3 Independent Science

As discussed in Section 2.1, results from the General Convening Assessment interviews with Collaborative Program signatories revealed shared interest in utilizing independent science review to help address certain scientific topics and to move towards a more structured process for integrating advances in scientific understanding into decision-making. The Collaborative Program acted on this by convening two separate ISPs in the winter of 2016 addressing the RGSM Population Monitoring Program (Hubert et al. 2016) and the RGSM Genetics Project (AMEC Foster Wheeler 2016). A third ISP was implemented through this AM Framework project in winter 2017 addressing critical scientific uncertainties surrounding RGSM life-history (Noon et al. 2017).

The ISP process for this current project was designed to address specific scientific topics over a fixed period of several months with no contractual commitment for continued involvement by the ISP either as a group or by individual members. While such "stand-alone" ISPs are utilized by other large-scale river restoration programs across the United States for addressing complex topics, most of these programs (e.g., Platte River, Grand Canyon, Missouri River, Kissimmee River, Sacramento-San Joaquin River Delta) also utilize standing Independent Science Committees or Boards to enable on-going support on a range of science-related decision support services.

As the Collaborative Program moves forward with prioritizing and addressing uncertainties and data gaps identified in this report, the GSA team recommends establishing and selectively utilizing a standing Independent Science Advisory Committee (ISAC) to support the Collaborative Program through various steps of the AM cycle (Figure 11). Advantages of a standing ISAC compared to the stand-alone ISP utilized in our project include:

- Better Understanding of MRG Science and AM Priorities: A challenge for all panel members involved in stand-alone ISP processes is that they must review and digest a voluminous number (many dozens or sometimes hundreds) of reports, articles, datasets and other background information in a very compressed timeframe (2-3 months) in preparation for a one-time panel meeting. After an initial ramp-up period, the learning curve for a standing ISAC would lessen with time, allowing members to gain greater depth of understanding of both the science and AM environment in the MRG, leading to greater value over time to Collaborative Program decision makers.
- Enhanced Review and Technical Support: We believe the Collaborative Program will benefit from a scenario where a standing ISAC assists not only with identifying critical scientific uncertainties but are available to provide technical support through the subsequent study design and proposal evaluation process. This would help ensure that study designs accurately align with the science recommendations and are scientifically and statistically robust. Science coordinators from other large-scale restoration programs have found involvement by standing independent science committee members ensures the scientific objectivity and credibility of their programs and improves stakeholder confidence that funded studies will yield unbiased and scientifically robust results (S. VanderKooi, USGS, personal communication; J. Bonneau, USACE, personal communication).
- Decision Support: There are many challenges to executing successful AM programs, including devising a structured process for evaluating study results and ensuring that conclusive results, when attained, are communicated effectively to decision makers responsible for adjusting management (Allen & Gunderson 2011; Fischman & Ruhl 2015; Gunderson & Light 2006; Liu et al. 2008; LoSchiavo et al. 2013; Martin et al. 2009; Ripley & Jaccard 2016; Thom et al. 2016; Williams et al. 2011). Other large-scale restoration programs commonly task their ISACs with reviewing and advising on program management objectives and performance measures, prioritizing scientific investigations, reviewing results from funded studies, advising decision makers regarding management implications, and recommending adaptive adjustments to the existing science program as new information is developed. We suggest the Collaborative Program science program would benefit from similar independent science support. As with other programs, the objective would not be to supplant involvement and leadership by the regional scientific community, but to strategically use and integrate peer review by independent scientists to strengthen the overall science program.

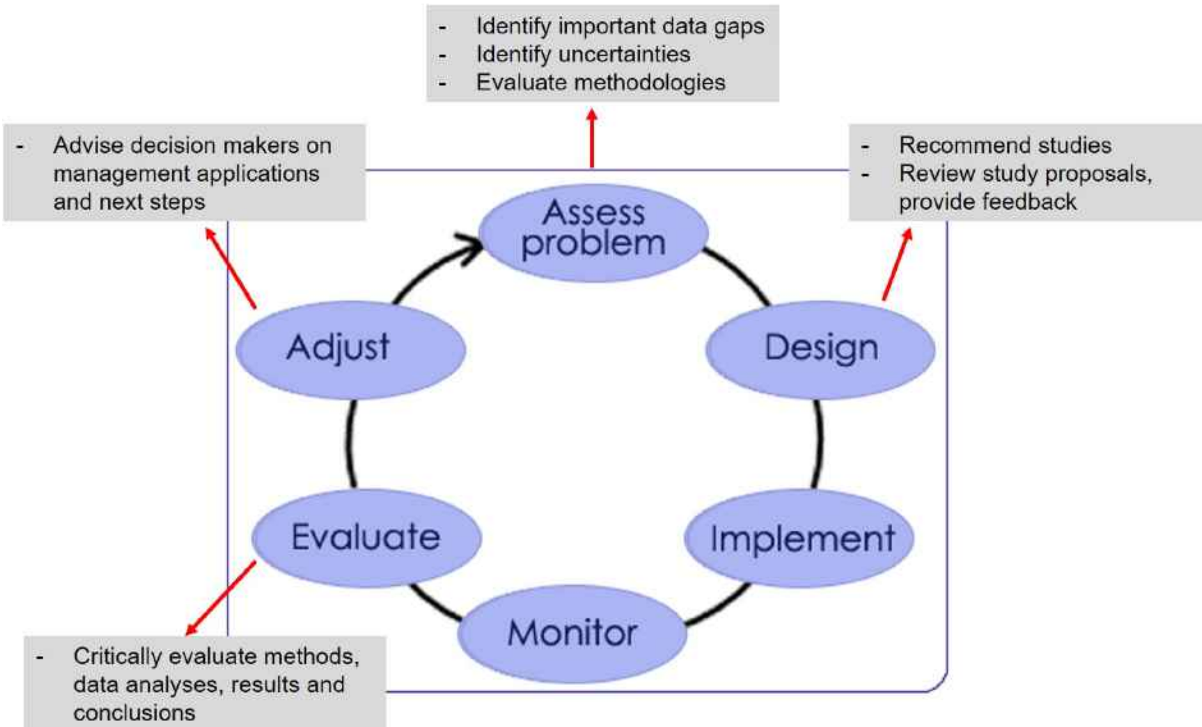

Figure 11. Potential roles for independent science advisors through various stages of the Adaptive Management cycle.

While this level of independent science engagement is recommended, we recognize that fiscal constraints ultimately dictate how often and what form independent science advisors can realistically be incorporated into a MRG AM program. Stand-alone ISPs can be expensive and depending upon the topics, level of complexity and panel charge can cost upwards of $50,000 to $100,000. The U.S. Office of Management and Budget (OMB) states that engaging ISPs is appropriate for highly complex and influential scientific issues and are especially valuable in establishing the bounds of the scientific debate when methods or interpretations are a source of controversy among stakeholders (OMB 2004). This description clearly applied to the scientific topics addressed by the recent ISPs convened by Collaborative Program partners.

However, for many of the beneficial roles for independent science advisors discussed above (Figure 11), a less intensive process may be more appropriate and fiscally attainable. For example, *Electronic Reviews* (E-Reviews) by one or more individual ISAC members of study plan proposals or study result reports may be the most cost-effective process for incorporating independent science review into the *Design* and *Evaluate* Stages of the AM cycle, respectively. Turner (2009) describes two different review approaches, depending upon the level of topic complexity, as follows:

- E-Reviews: Materials to be reviewed are distributed electronically to selected reviewers who typically are given a specific charge or set of review criteria, instructions, and up to several weeks to provide ratings and supporting review comments. A program manager or review board evaluates the results and makes decisions or recommendations to fund, publish, or otherwise proceed. E-Reviews are most appropriate for relatively simple proposals or products. This is the least expensive means of convening experts to review applications or proposals.

- Panel reviews: Selected reviewers evaluate materials on-line as in an E-Review, but then meet (face-to-face or virtually) to discuss their evaluations. This interaction allows the reviewers to adjust or calibrate their ratings or comments based on improved understandings and the relative ratings of others on the panel. This process usually produces more consistent and better supported ratings or conclusions, and is often necessary for more complex proposals, progress reports, or products. The program manager or board often gains a better understanding of the reviewers' evaluations if they hear the discussion at the panel meeting. A panel review is an intermediate-cost, higher-touch version of the E-Review, and usually clarifies communication among participants.

These are just two of many different approaches to addressing cost-efficiencies and effectiveness for integrating independent science advisors across the AM cycle. In the sections that follow, we provide examples of how three well-established AM programs in the United States are integrating independent scientists into critical stages of their management and decision-making process. These include broad overviews of how the Glen Canyon Dam Adaptive Management Program (GCDAMP), the Platte River Recovery Implementation Program (PRRIP), and the Missouri River Recovery Program (MRRP) are generally structured and how standing independent science advisory teams are utilized to support their program's evaluation and decision-making processes.

7.3.1 How Other Adaptive Management Programs Utilize Independent Scientists

Glen Canyon Dam Adaptive Management Program

The GCDAMP was established in 1996 by the Secretary of the Interior to implement the Grand Canyon Protection Act of 1992, the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS) and the 1996 Record of Decision (ROD; USGS 2007a). The GCDAMP addresses a wide-range of resource values associated with the effects of Glen Canyon Dam operations of the Colorado River through Glen Canyon National Recreation Area and Grand Canyon National Park. The focus is on optimizing flow management from Glen Canyon Dam to improve fluvial-geomorphic processes, recreational resources, cultural resources, water quality, riparian and aquatic habitat functions and conditions, and fish and wildlife resources, including, but not limited to federally threatened and endangered species (e.g., humpback chub [*Gila cypha*]; SWFL) while simultaneously meeting downstream hydropower demands (Gloss et al. 2005).

The organizational structure of the GCDAMP includes four entities with distinct roles and responsibilities described and summarized as follows (USGS 2007a):

- The **Adaptive Management Work Group (AMWG)** is a Federal Advisory Committee that facilitates the implementation of the GCDAMP. The AMWG is made up of 25 stakeholders and the Secretary of the Interior's Designee serves as the AMWG chair. The primary purpose of the AMWG is to address the impacts to the downstream ecosystem resulting from the operations of the dam and to make recommendations to the Secretary of the Interior on actions to improve resources in Glen and Grand canyons.

- A **Technical Work Group (TWG)** translates AMWG policies and goals into information needs, provides questions that serve as the basis for long-term monitoring and research activities, and conveys research results to AMWG members. The TWG is comprised of technical representatives from each of the stakeholder groups serving on the AMWG. TWG tasks include developing criteria and standards for monitoring and research programs, providing periodic reviews and updates, developing resource management questions for the design of monitoring and research by the Glen Canyon Monitoring and Research Center, and providing information for preparing annual resource reports and other reports for the AMWG.
- The **USGS Grand Canyon Monitoring and Research Center (GCMRC)** provides objective scientific information on the effects of Glen Canyon Dam and related factors on natural, cultural, and recreational resources along the Colorado River from Glen Canyon Dam to Lake Mead. The GCMRC is responsible for developing five-year SSPs that identify strategies, and for developing monitoring and research plans addressing core monitoring activities, research and development activities, and long-term experimental activities identified in the five-year SSPs. The GCMRC is also responsible for developing triennial work plans that outline works scopes, objectives and budgets for implementing the monitoring and research plans.
- A **Science Advisory Board (SAB)** is comprised of respected academic experts who are responsible for providing independent assessments of the GCMRC proposals, products and accomplishments to ensure scientific objectivity and GCDAMP credibility. The Science Advisors selected for the SAB provide independent scientific oversight and technical advice to ensure that GCMRC science programs are efficient, unbiased, objective, and scientifically sound.
- Science Advisors are managed by a **third-party Executive Coordinator** contracted by the USBR, Upper Colorado Division (S. VanderKooi, USGS GCMRC personal communication). The Executive Coordinator selects Science Advisors to serve on the SAB on the basis of their independence and technical expertise in scientific disciplines relevant to priorities addressed in triennial monitoring and research work plans.
- SAB members represent diverse fields of expertise such as AM, fisheries, ecosystem ecology, riparian ecology, geomorphology, aquatic ecology, cultural resources, etc.
- While actual requirements are defined in individual task orders, SAB members are typically responsible for reviewing, commenting and advising on (USBR 2015):
    - GCMRC's Triennial Work Plan and budget proposals, to ensure that the science program is efficiently and effectively responding to AMWG management objectives;

- The appropriateness of GCMRC's subcontracting Requests for Proposal, especially concerning their responsiveness to GCDAMP management objectives;
- The methodologies and protocols used in various GCMRC sponsored scientific activities;
- Results of ongoing and completed monitoring and research program activities, as well as any synthesis and assessment activities initiated by GCMRC;
- Leading specific scientific and technical review and evaluation tasks, and;
- Other program specific scientific and technical advice it is asked to address by the GCMRC or recommended by the AMWG and approved by the Secretary.

According to the SAB Executive Coordinator, GCDAMP leadership has been reviewing the SAB process and annual budget allocations and have found that demands on the program at full-operation will cost roughly $150,000/year (D. Braun, Executive Coordinator for Science Advisors, Sound Science, LLC, personal communication; Table 7). This is the level presently contemplated for the next triennial plan and budget, for FY2018-2020. The SAB Executive Coordinator states (D. Braun, personal communication) the program will involve the following:

1) A re-established standing panel of Science Advisors that will provide feedback to the larger GCDAMP community on annual reports and work plans, triennial work plans, and the planned triennial cycle of knowledge assessment that will support development of the triennial work plans. The standing SAB will also provide recommendations on the design and recruitment of members for stand-alone advisory panels (see below). This will take effect in Fiscal Year 2018, starting by recruiting a five-member panel and working out the details of panel structure, membership duration, and related topics over the next few months. The SAB will be budgeted to pay the panelists a stipend and cover their travel expenses to attend at least one meeting/per year. The one meeting/year specifically will be the "Annual Reporting Meeting" in January, at which the various investigative teams present summaries of their work and their progress toward addressing specific information needs for the GCDAMP.
2) Stand-alone, independent, neutral-party review panels, organized to provide feedback on specialized topics for which one or more components of the GCDAMP request an independent, external review. There might be 1-2 such special panels in any triennial work cycle. Each such panel effort will typically (but not necessarily) involve a workshop event, during which the panel hears presentations on the topic of concern and can query members of the GCDAMP on their views and concerns, to get a better picture of the issues of concern. The intention is to hold such workshops at a "free" venue (e.g., at a GCDAMP partner facility). Again, the SAB will be budgeted to pay the panelists a stipend and cover their travel expenses.
3) The Executive Coordinator runs the first two items and reports to USBR and the AMWG, and coordinates closely with the GCMRC and the TWG. The Executive Coordinator also may provide advice based on expertise, as/when appropriate.

As mentioned previously, the SAB evolved out of the original design for the GCDAMP, coming out of the Grand Canyon Protection Act of 1992 and the 1995 EIS and ROD arising out of that Act. The 1995 EIS and ROD established the GCDAMP and specified that the AMP would include something called "Independent Review Panels" (IRPs). However, there is no specific entity in the GCDAMP called the "Independent Review Panels" program (D. Braun, personal communication). This is because, over the many years of GCDAMP existence and evolution, the *functions* intended for the IRPs have come to be the shared responsibility of the GCMRC and the SAB together. The GCMRC handles (among other reviews) what are known as the "Protocol Evaluation Panels" (PEPs), which carry out periodic (originally intended to be five-year) reviews of individual components of the overall investigative programs that support the GCDAMP. Over time, the PEPs have evolved to address not just investigative methods and design, but the purposes and priorities of different investigative activities in relation to overall GCDAMP purposes and priorities (D. Braun, personal communication). Further, all reports prepared by GCMRC staff – whether for publication by the USGS itself or for publication in independent professional outlets – are now also subject to peer review. The GCRMC and the SAB Executive Coordinator see this peer review requirement as part of the "IRP" functions of the GCDAMP, in the sense that the requirement meets the needs of the Secretary of the Interior, USBR, the AMWG, and the TWG to know that the work carried out by the GCMRC and its investigative partners meet the highest standards for investigative integrity (D. Braun, personal communication). The SAB, in turn, has been responsible for "bigger-picture" concerns of the GCDAMP, including overall GCDAMP priorities and the effectiveness of the GCDAMP "AM" process. There is no sharp dividing line between which "IRP" functions the GCMRC and SAB address, and the GCMRC and the SAB Executive Coordinator collaborate to ensure that they coordinate the IRP functions to meet all the intended purposes of having an IRP program (D. Braun, personal communication).

Platte River Recovery Implementation Program

The PRRIP was initiated on January 1, 2007 and is the result of a Cooperative Agreement negotiating process that started in 1997 between the states of Colorado, Wyoming, and Nebraska; the Department of Interior; waters users; and conservation groups (PRRIP 2012). The PRRIP addresses issues related to the ESA and loss of habitat in the river in central Nebraska by managing certain land and water resources following the principles of AM to provide benefits for four "target species": the endangered whooping crane (*Grus americana*), interior least tern (*Sterna antillarum athaloassos*), and pallid sturgeon (*Scaphirhynchus albus*); and the threatened piping plover (*Charadrius melodus*) (PRRIP 2008). The PRRIP's long term goals include: 1) improving and maintaining migrational habitat for whooping cranes and reproductive habitat for least terns and piping plovers; 2) reducing the likelihood of future listings of other species found in this area; and 3) testing the assumption that managing flow in the central Platte River also improves the pallid sturgeon's lower Platte River habitat (PRRIP 2012).

The PRRIP developed an AM Plan (PRRIP 2006) that guides a systematic process to test priority hypotheses and apply the information learned to improve management. The PRRIP-AMP was developed collaboratively by PRRIP partners and cooperators under the guidance of independent experts from around the country. The PRRIP-AMP is centered on priority hypotheses developed jointly by PRRIP partners that reflect different interpretations of how river processes work and the best approach to meeting PRRIP goals (PRRIP 2008). The AMP's Integrated Monitoring and Research Plan guides implementation of monitoring and research protocols during the "First Increment", which spans 13-years from 2007-2019 (PRRIP 2006).

The principal organizational structure of the PRRIP (PRRIP 2005) is summarized as follows:

- An eleven-person **Governance Committee** is the decision-making body responsible for PRRIP implementation and all policy decisions. Membership includes one representative each from the states of Wyoming, Colorado and Nebraska; one representative each from the USFWS and USBR; three representatives from environmental groups, and; three representatives from different water user groups from different geographic segments (Upper, Middle, Lower) of the PRRIP decision making lies within the Governance Committee.
- A PRRIP **Oversight Committee** composed of the Secretary of the Interior and the Governors of the states of Colorado, Nebraska and Wyoming. The Oversight Committee is to be convened to address fundamental changes to the Program that would require a formal amendment to the Program Agreement, or to address potential Program dissolution issues.
- An **Executive Director**, selected by the Governance Committee, coordinates all PRRIP activities and is responsible for overseeing day-to-day PRRIP operations including, but not limited to, providing staff support, preparing budgets and overall financial management, providing recommendations and advice to the Governance Committee, etc. Headwaters Corporation, a private consulting company, provides the independent Executive Director and staff for the PRRIP.
- Four standing Advisory Committees that are overseen by the Governance Committee. These include a Land Advisory Committee, a Technical Advisory Committee, a Water Advisory Committee and an ISAC.
- **Ad Hoc Advisory Committees** are periodically established by the Governance Committee to address individual or time sensitive topics, as needed.

The function of the ISAC is to provide scientific advice and recommendations pertaining to implementation of the PRRIP-AMP. The ISAC is composed of six independent Science Advisors serving 3-year contract terms (Table 7). The ISAC's sole mission is to provide independent opinion on a scientific approach to AM, monitoring and research, including an assessment of ecological indicators and other measures of PRRIP progress (PRRIP 2012). While tasks for the ISAC are spelled out in 3-year work plans, the specific tasks identified in the 2012 work plan included:

- Providing independent opinion and recommendations on the design for implementation of the AMP's management strategies and testing of priority hypotheses. This includes the clarity of the hypotheses being tested, validity of the monitoring and research design, quality of data collection procedures, robustness of methods employed, and methods to analyze and synthesize data.
- Responding to specific scientific questions from the Governance Committee and the Executive Director's office.
- Participating in three meetings each year – an annual spring PRRIP-AMP Reporting Session to discuss, review, and critique AMP progress and direction and data analysis/synthesis from the prior year; a summer meeting focusing on agreed-upon topics and including time in the field; and a late fall/early winter meeting. Additional meetings each year are at the discretion of the Governance Committee.
- Preparing annual reports incorporating ISAC opinions on and a review of the scientific approach to AM, monitoring, and research related to AMP implementation.
- Advising the Governance Committee and the Executive Director's office on the need for additional outside peer review.

The PRRIP has allocated between $200,000 and $221,000 each year over the past five years towards funding ISAC activities (C. Smith, Director of Natural Resources Decision Support, Headwaters Corporation, personal communication). ISAC members are provided daily stipends to cover time and expenses associated with work plan tasks such as attending meetings and workshops, reviewing and commenting on PRRIP documents, study plans and reports, etc. The standing ISAC typically addresses "big-picture" science reviews of the PRRIP-AMP, progress on the Integrated Monitoring and Research Plan, priority hypotheses, study designs, and annual review of the "State of the Platte" report (C. Smith, personal communication).

Separate budgets are developed for implementing additional stand-alone ISP's assembled to address certain specialized topics. For example, a stand-alone ISP was implemented in 2016 to critically evaluate research results and conclusions associated with a multi-year study of whooping crane habitat selection and related topics (C. Smith, personal communication). Unlike the standing ISAC process, which is managed directly by the PRRIP Executive Director's Office, stand-alone ISPs are managed by an independent third-party contractor (similar to the Executive Science Coordinator from the GCDAMP described previously). The independent third-party manager is responsible for:

- Recommending candidates for each panel according to appropriate areas of expertise.
- Providing background information for all potential candidates.
- Recommending panelists and providing conflict of interest statements for all panelists.

- Communicating with panelists (PRRIP provides scope of work and handles contracting for payment).
- Summarizing comments from each panel.
- Delivering final report to the Executive Director's Office for each panel.

The PRRIP utilizes stand-alone ISP's on an as-needed basis, thus 1-3 years may go by without utilizing these services (C. Smith, personal communication). The PRRIP Fiscal Year 2017 budget allocated $72,000 to enable three peer review panels (with three panelists each), plus the independent third-party manager to review up to three PRRIP documents and provide written findings reports.

Missouri River Recovery Program

The MRRP was established by the USACE in 2005. The USACE operates six dams and reservoirs along the Upper Missouri River in Montana (Fort Peck), North Dakota (Garrison), and South Dakota (Big Bend, Fort Randall and Gavins Point), making this the largest reservoir system on any North American river (USACE 2016). The MRRP was initiated to replace lost habitat resulting from USACE reservoir operations and the Bank Stabilization and Navigation Project and to address requirements of the 2003 BiOp for three federally-listed threatened and endangered species (pallid sturgeon, interior least tern, and piping plover). Section 7 consultation was recently reinitiated and a new BiOp will be completed in 2018.

The MRRP has a stakeholder body that collaborates with the agencies - the **Missouri River Recovery Implementation Committee (MRRIC)**. Authorized in the Water Resources Development Act of 2007 and established in 2008, the MRRIC is composed of nearly 70 members from 15 federal agencies, 8 states, 21 American Indian Tribes and 29 stakeholder members within the Missouri River basin (MRRIC 2016). The MRRIC is responsible for developing recommendations to the USACE and USFWS on the implementation of MRRP actions. To this end, the agencies and MRRIC have established a governance process that guides interactions between the agencies and MRRIC including the development and implementation of an AM Plan (MRRIC Charter 2008).

The agencies and MRRIC receive independent scientific review and advice to support their decisions through two standing independent panels funded by the USACE -the **Independent Social Economic Technical Review Panel (ISETR)** and the **Independent Science Advisory Panel (ISAP)** (https://projects.ecr.gov/moriversciencepanel/). Both standing panels are managed by a "Third-Party Science Neutral", who is contracted by the U.S. Institute for Environmental Conflict Resolution. The **Third-Party Science Neutral** serves as the lead advisor and is responsible for ISAP and ISETR management including panel member selection, developing individual task orders and budgets, and review and delivery of panel products to the USACE and MRRIC. Development of charge questions for the panels is a joint effort of the USACE, USFWS, and MRRIC. The independent panels have played a key role in development of a comprehensive science and AM plan (Bonneau et al. 2011) and review of the foundational science underlying the recent Biological Assessment (BA) and draft BiOp.

The ISAP is a standing panel of up to six science advisors (Table 7). ISAP members commit to a three-year contract term, which may be extended. Standing panel members have expertise in diverse scientific disciplines including aquatic/riverine ecology, river hydrology/geomorphology, quantitative ecology/statistics, and conservation biology, plus two individuals with specialized expertise with the least tern/piping plover and the pallid sturgeon. Additional ad-hoc specialists can be added as needed for a particular topic if certain expertise not represented by the standing panel members is required. Needed expertise is expected to change as the program progresses. According to information obtained through the Missouri River ISAP website (see website link above), ISAP support tasks include:

- Synthesis of all available information on a specific topic that may include meetings with scientists, agency personnel and stakeholders and culminates in a written report providing independent advice and recommendations to the USACEs or MRRIC.
- Scientific or technical services to gather, evaluate, and synthesize the best available information/data on a scientific topic resulting in a report to the USACE.
- Providing independent opinion and recommendations on the topics presented.
- Evaluation of scientific proposals and making recommendations on how to proceed.
- A standing program of independent opinions and recommendations for the overall MRRP-ISP.
- Assessment of documents (models, data, monitoring plans, management plans, and recovery actions) for contextual clarity and their application to a specific project planning effort, resulting in a letter report to the USACE.
- Responding to scientific questions from the USACE, USFWS, or MRRIC.

The annual budget for the ISAP and Third-Party Neutral varies depending upon support needs, but recent MRRIC annual reports show the MRRP budgeted $503,931 and $658,870 in fiscal years 2014 and 2016, respectively.

Table 7. Attributes of standing science advisory panels from three U.S. Adaptive Management programs.

	Glen Canyon Dam AM Program	**Missouri River Recovery Program**	**Platte River Recovery Implementation Program**
Standing Independent Science Panel	Yes (Science Advisory Board)	Yes ISAP	Yes ISAC
Number of Members	5	6	6
Contract Length	3-year contract term, max. 2 consecutive terms	3-year contract term, no limit to number of terms	3-year contract term, no limit to number of terms
ISP Chair reports to…	Independent Executive Science Coordinator	Third-Party Science Neutral Manager	PRRIP Executive Director
Annual ISP Budget (most recent)	$150,000	$658,870	$203,000

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Appendix A: General Convening Assessment Summary Notes

PROGRAM GUIDANCE CONVENING ASSESSMENT (PGCA)

GSA carried out an assessment of the opinions of many Collaborative Program partners regarding the current state of knowledge and management of the Middle Rio Grande. A primary goal with this assessment is to identify, for the participants, those areas where there is certainty or uncertainty regarding the scientific issues. The PGCA identifies areas the partners either substantively agree or disagree on the available information.

A convening assessment is an impartial approach, which will help all partners to identify those monitoring and research issues that can be immediately addressed. For such issues, we may be able to move rapidly to the design and implementation of an AM program. The convening assessment identifies areas where there is not a current consensus. For such issues, the assessment lays out the nature of disagreements. It is particularly important that we understand the nature of uncertainties and disagreements: do they stem from differences in opinion on existing science, or from other sources (e.g., tolerance of risk, management needs)?

This information has been gathered in a value neutral way, and is not intended to be critical of any partner or of the program as a whole. It is simply a means of focusing attention on the important issues for the partnership to resolve. The results can be used in various ways. Importantly, they will form the basis of GSA's work-plan for the remainder of the AM design program, and for prioritizing issues.

Through the PGCA process, we have established that there are indeed areas of substantial agreement. There are also areas where the partners feel relatively certain on the science and other technical information. These two characteristics—***certainty*** and ***agreement***—are at the heart of AM. Where there is high certainty and confidence in the existing state of knowledge, there may be little need for linking new investigations (monitoring or research) to possible future changes in management. If the answer to the question "Do we know enough to manage this system with high confidence?" is "yes," then this issue may be a low priority for investigation.

There are also areas where the partners agree that the available information is insufficient. Such areas may be a high priority for AM.

Finally, there are areas where the partners do not agree on the current state of knowledge, the level of certainty associated with it, and on whether it is sufficient to make changes to management. These areas will be a high priority for a structured process that will allow the partners to make well-reasoned decisions on how to proceed.

This summary of the PGCA, for the most part, does not identify 'who said what.' We believe that (at this stage) the process is best served by simply identifying the issues and focusing on developing increased cooperation.

Convening Assessment Participants:

- Army Corps of Engineers (USACE)
  - John D'Antonio, Kris Schafer, Susan Bittick, Mickey Porter, Ondrea Hummel, Danielle Galloway, Ryan Groenwald
- Fish & Wildlife Service (USFWS)
  - Wally Murphy, Dave Campbell, Joel Lusk, Vicky Ryan
- Bureau of Reclamation (USBR)
  - Jennifer Faler, Jim Wilber, Leann Woodruff, Ann Demint, Jen Bachus
- Interstate Stream Commission (NMISC)
  - Rolf Schmidt-Petersen, Grace Haggerty, Rich Valdez, Deb Freeman, Alison Hutson.
- Game & Fish (NMGF)
  - Matthew Wunder
- Middle Rio Grande Conservancy District (MRGCD)
  - Mike Hamman, Yasmeen Najmi, Brooke Wyman, David Gensler
- Albuquerque-Bernalillo County Water Utility Association (ABCWUA)
  - John Stomp, Rick Billings
- University of New Mexico (UNM)
  - Tom Turner, Megan Osbourne, Evan Carson
- Sandia Pueblo
  - Frank Chavez, Michael Scialdone
- Isleta Pueblo
  - Cody Walker, Ruben Lucero
- Santa Ana Pueblo
  - Alan Hatch, Nathan Schroeder
- City of Albuquerque Open Space Division (COA OSD)
  - Matthew Schmader
- Bosque Ecosystem Monitoring Program (BEMP)
  - Kim Eichhorst
- Assessment Payers Association (APA) of the MRGCD.

- Janet Jarrett

The text of the assessment questions, with interpolated responses or overall summaries of the responses follows.

PROGRAM GUIDANCE CONVENING ASSESSMENT - RESULTS COMPILATION

Main Text of the Assessment with Summaries of Responses

GSA is working with the Collaborative Program partners engaged in management of the MRG. Our goal is to help all parties develop a working AM plan for the river. The USACE has provided the funding to support developing a cooperative, science-based approach that is 'owned' by all partners.

As part of this work, we are asking governments, agencies, stakeholders and others to provide us with their frank and honest opinions on endangered species recovery, bosque and river management, and how AM can be improved and implemented. This set of questions is being asked of all participants. There are 11 questions in all, and we expect to spend a total of an hour talking to you. The first set of question asks about general satisfaction with the existing Program and your agency's priorities with regard to endangered species recovery. The second set of questions (6 in all) asks about species and ecosystem issues. The last set of questions (3 in all) asks about management decisions and governance structures. Your responses will either be noted or recorded for later transcribing. These notes will become part of our record, although in our summary document we will not identify persons or organizations unless they wish us to.

1. **What are your agency's priorities with regard to endangered species recovery on the Middle Rio Grande? What types of recovery activities (e.g., physical restoration, water management, research/monitoring, policy, etc.) is your agency involved with? Have you identified specific tasks/actions that you intend to undertake over the next 3-5 years?**
   - MRGCD
     - Implementable BiOp that will move towards a viable recovery program.
     - Need ESA coverage to continue mission of water delivery, but also to contribute to overall sustainable service level to farmers and middle valley.
     - Focus on ecosystem restoration. See lots of opportunities to expand work in habitat restoration.
     - Upcoming projects maintaining wetted refugia at outfalls.
     - Monitoring at outfall locations. Trying to help keep river wet.
     - Definitely depend upon collaborative relationships with other agencies to achieve their restoration goals. Rely a lot on NMISC and USACE especially.

- MRGCD wants to take a close look at whether they are doing enough to offset their water diversions.

● ABCWUA

- Compliance with permit with USFWS re: how they operate drinking water diversion.
- On-going monitoring activities.
- As thriving municipality they have responsibility to obtain water resources in the future so helping recover species in cooperative manner is in everyone's best interest and it's the right thing to do.
- ABCWUA is involved in physical restoration, fund the City of Alb. rearing facility on the order of $165k/year, participate in Program committees using own funding.
- Specific tasks/plans:
  1. Continue with what they've been doing "and more."
  2. Setting up space in Abiquiu Reservoir for long-term environmental pool and trying to put water in that space. 10% of water rights purchases will be going into that pool.

● USBR

- Committed to supporting recovery of listed species within hydrologic realities.
- Continue to meet agency mission of water delivery.
- Involved in all the above (physical restoration, water management, research/monitoring, policy, river maintenance).
- Actions over next 3-5 years:
  1. Committed to spending $1-3m annually over next 3-5 years.
  2. Working on lots of habitat restoration projects with Pueblos, State, etc.
  3. River Integrated Operations (RIO):
     a. Following DOI's step-wise process for AM without prescribing specific actions, to allow annual flexibility in water management (parts 4 and 5 of BA describe).
     b. Framework for testing hypotheses about hydrologic flow objectives. Don't want to be locked in to rigid prescriptive approaches because the river system changes.

- NMISC
  - Biggest priority is to complete BA.
  - Would like to have AM Plan and Recovery Implementation Program (RIP) that works in concert with a BiOp. Rigid BiOp will not advance Program.
  - ISC has identified specific conservation measures. (e.g., conservation pool development in collaboration with other agencies).
  - Implement habitat restoration that addresses some of the geomorphology/sediment supply issues in the river.
  - Mechanical treatments to create connected floodplain habitat.

- USFWS
  - Primary mission/mandate is species recovery.

- USACE
  - Primary mission is flood control and to operate their dams per congressional authorization.
  - Priorities to advance endangered species recovery are to continue implementing large-scale ecosystem restoration, perform monitoring and research, and support water management within the confines of the legislating authorities.

- NMGF
  - Since recent NMGF reorganization, the agency is less involved in endangered species management and science on the MRG.
  - Participate on the EC and provide technical review on compliance plans at stakeholder request.

- Pueblo of Isleta (POI)
  - POI developed a riverine management plan that addresses how they will address endangered spp management.
  - POI has done nothing to contribute to demise of species and feel they should not be forced to implement recovery projects. Does not want their land included in Critical Habitat Designations.

- Projects have included:
  1. Fuels reduction, non-native spp treatments, native riparian revegetation.
  2. Mitigating SWFL habitat for island removal downstream of Isleta Diversion Dam.
  3. Have implemented some scour hole projects downstream of outfalls.
  4. Collaborates in studies with other agencies:
     a. WQ studies with MRGCD/USACE
     b. RGSM monthly population monitoring with USFWS
     c. SWFL monitoring/habitat characterization
     d. SWFL training and surveys
- Upcoming projects:
  1. Conservation/maintenance of quality of existing resources.

- Pueblo of Santa Ana
  - Priority is to improve overall ecosystem function and health for tribal members while maintaining sovereignty and self-governance.
  - Long history of implementing management to contribute to endangered species recovery.
    1. Developed a Safe Harbor Agreement.
    2. Implements large-scale habitat restoration.
    3. Actively participates on EC and CC.
    4. Is trained and permitted to monitor for RGSM, SWFL and YBCU on Santa Ana lands.

- Pueblo of Sandia
  - Management goals are for the health of the overall riparian/riverine ecosystem, all species, not solely for endangered species.
  - Some projects have focused on SWFL and RGSM habitat improvements.
  - Monitoring SWFL and YBCC via funding from Bureau of Indian Affairs (BIA).
  - Upcoming project goals include:
    1. Improving flow-through channel and other floodplain manipulations to improve off-channel habitat for riparian recruitment.

2. Manipulation of existing borrow pits to create wetland ponds improve habitat diversity in bosque.
3. Fuels reduction and revegetation.
4. Allows USFWS to monitor RGSM

- UNM
    - Science, research to understand role of water management and river system interactions on RGSM, and collect data and provide data interpretations that contribute to sustainable wild population.
    - Work closely with captive propagation facilities. Test propagation techniques, evaluate genetic diversity using different prop techniques, use results to advise how to propagate the fish.
    - Monitoring genetic diversity in river population.
    - Rely on all folks, not just FWS, to help them obtain fish that they can use for their study samples. They have permits, but also rely on other collections (clip fins and test genes).
    - Perform modeling to see how water management, fish passage structures, hatchery contributions, etc., could affect genetic diversity.

- APA
    - Constituents (farmers) interested in maintaining the agrarian culture and the economic viability of agricultural pursuits while maintaining endangered spp. None of the constituents wants to see the spp go away as they are indicators of a healthy river system.
    - Actively participates on EC. Goal is to ensure that voices of farmers are heard and not disproportionately affected by Collaborative Program decision.

- AOS
    - AOS is primarily focused on broad habitat improvements, but does occasionally participate in ES centric projects for both RGSM and SWFL.
    - Active participant on EC.
    - AOS plans into future is to continue with mosaic habitat restoration work.

- BEMP
  - BEMP doesn't focus on ES. They set up long-term ecological monitoring – evaluating general ecosystem response/resilience to environmental conditions.
  - Recently became a Program signatory and participates on the ES.
  - Recently awarded USACE contract to implement BEMP sites on 2-3 restoration projects.

2. Are you satisfied with current management on the river? What do you think is working well? How could things be improved?

- While there is overall enthusiasm for the joint effort on the Rio Grande, there is general consensus that water management and restoration could be improved.
  - Consensus on what has been/is working well:
    1. There is widespread recognition that the water management agencies have come a long way with how water management is performed in basin. Water managers work well to quickly coordinate decisions during crisis periods about how to modify water operations (to keep as much of the river wet as possible, and to adjust operations to accommodate species needs).
    2. The Minnow Action Team (MAT) was repeatedly mentioned as an effective forum for improving communication between water managers and species biologists. There was a general sense that the working relationships and actions had worked very well, but that the team was later unsuccessful in producing formal guidance and reports to Program.
    3. We also repeatedly heard a general consensus that middle managers can work well together. However, there was widespread opinion that attempts to formalize water management policies at higher levels were where things fall apart.
  - Consensus on where improvement is needed:
    1. General consensus that more operational (storage and release) flexibility is needed at Cochiti and Abiquiu Reservoirs.
    2. General consensus is that better management will require better monitoring procedures to enable evaluation of whether management actions (water management and habitat restoration) are achieving species recovery goals.

3-6. There are currently four federally endangered species in the Middle Rio Grande. Taking each of these in turn, do we know enough to manage the species for long-term survival? What new information is most needed to help ensure survival of the species? What new information would improve management capability?

a. Southwestern Willow Flycatcher

- There is consensus that we know more about the SWFL's life-history and habitat requirements than for any other MRG listed species. In large part that is due to the wide range of the species, and the many studies and programs that have been carried out within the MRG and elsewhere.
- In general, respondents were comfortable with extrapolating life-history results from other areas to the Middle Rio Grande.
- Many respondents noted the impacts of saltcedar leaf beetle (*Diorhabda spp*), and identified them as a potential issue of importance to SWFL populations, especially in the population centers at/near Elephant Butte delta.
- We received varying responses as to whether restoration science is advanced enough to construct suitable SWFL habitats. Some individuals thought that while we understand SWFL habitat choice and needs, we have limited knowledge on how to intentionally (through restoration) foster such habitat. There appeared to be consensus that SWFL restoration projects have not attracted nesting birds to date.
- From the responses we received, it appeared that many signatories or biologists did not feel that they fully understood the habitat restoration process/treatments that are being implemented to promote SWFL territorial expansion.

b. Yellow-Billed Cuckoo

- There was general consensus that we need to gain better understanding of territory size requirements for the YBCC. This appeared to be the main issue of concern for most participants.
- While most agencies are just getting up to speed on YBCC, the general perception was that 'habitat requirements for YBCC are fairly similar to SWWF.' While more effort may be needed towards performing YBCC surveys, and in understanding territory size (as noted), few participants identified uncertainties regarding YBCC as major concerns.
- A concern raised during several interviews is that large territory delineations (e.g., 2-mile buffer around nest sites) for the YBCC could severely limit where habitat restoration project for other species (RGSM, SWFL) could be implemented.

c. New Mexico Meadow Jumping Mouse

- Most agencies have little understanding of NMMJM, but most believe that we need more data to understand population distribution in the MRG.
- Many participants felt that conservation measures for this species would have little impact, since they would be largely restricted to USFWS reserves.
- USFWS feels that the population of NMMJM is potentially so small that any monitoring efforts (to better understand population numbers or distribution) must use non-destructive sampling methods.

d. Rio Grande Silvery Minnow

Principal Areas of Agreement

- There is general consensus that we know enough about the species' life-history requirements to form hypotheses, but we don't know enough about how to manage the system to bolster populations.
- There is also consensus that the existing population-monitoring program does not provide us with a good understanding of population size or spatial distribution.
- Participants agreed that we are not monitoring effectively to understand how fish populations respond to water management and habitat restoration.
- There was widespread discussion as to whether USFWS is 'too restrictive' in providing permits to monitor RGSM use of habitat restoration projects. Several participants voiced concern that the current permitting process constrains advancement of scientific understanding of critical aspects of the RGSM life-history and the complex interactions between the fish and environmental factors central to an effective AM Plan.
- There is consensus that both longitudinal and lateral connectivity is important to bolster RGSM populations.

Principal Areas of Disagreement/Disconnect

- Some believe that river drying is the primary obstacle to RGSM recovery. Others argue that long river segments have always experienced periodic/seasonal drying, and that the species adapted by moving to wetted areas upstream or in off-channel wetlands that were once common.
- There is disagreement among the signatories regarding principal water/restoration management drivers to bolster populations numbers, that is:
  i. Spring/Summer peak flow requirements:
     1. Do we need specific target "high flows" (5,000 – 7,000 cfs) or do we need whatever peak flows are necessary to achieve floodplain inundation for

durations long enough (8-10 days) to promote strong larval recruitment? Some suggested that we can compensate for reductions in peak snowmelt runoff by lowering floodplain habitats to promote floodplain inundation at lower flows (1,500 -2,500 cfs, depending upon the reach).

ii. River drying:

1. During times of severe water shortages, long river segments of Isleta and San Acacia reaches are dry, and diversion dams restrict ability of fish to move upstream to perennial river segments. There is no consensus as to whether fish passage at diversion structures would off-set mortality (e.g., do RGSM really swim long distances to find perennial river segments?), or are there other more cost-effective options that could effectively reduce mortality (e.g., more proximal areas of wetted refugia)?

- We noted a lack of understanding, and general caution by USFWS and some others of what water management agencies are doing/are willing/can do to prevent river drying and accommodate species life-cycle requirements.
- There also appears to be limited communication between restoration scientists and some Program signatories (managers and their species biologists) regarding restoration practices (and logic behind those practices) that are being implemented to bolster RGSM (and SWFL) populations.

7. **Regarding overall ecosystem dynamics, and water flow patterns, do we know enough to manage the system for ecosystem recovery and persistence? What new information would be most valuable?**

- Water management agencies believe that there is a reasonably good understanding of how infrastructure (dams, reservoir operations) can be used to improve ecosystem conditions.
- However, there is general consensus that we still have a lot to learn about how to manage the system to promote species recovery in the face of reduced snow-pack/runoff and extended drought.
- All participants stated that there is a clear need for well-designed monitoring programs to evaluate whether management actions are achieving desired species habitat/population benefits.

8. **Considering your answers to questions 3-7, how should available scientific resources be prioritized? Some issues that you might consider could be: near- and long-term return on science; relevance to management options; relevance to persistence of the species; possibility for agreement among parties; likelihood of unequivocal scientific results.**

   - A clear finding from the assessment was that an important priority for many was implementing an independent science review process. Many participants volunteered this issue as being critical, and of over-arching importance. They felt such a process was needed to break the gridlock resulting from distrust, and disagreement regarding science and critical uncertainties.
   - A second clear and widespread opinion was that resources should be focused on improving methods for how we measure/estimate RGSM population size. We need to improve the sampling precision and accuracy necessary to detect change, and understand how the RGSM population responds to water management and habitat restoration.
   - Opinion also clearly favored expanded monitoring to understand the role of inundated floodplain habitat in RGSM recruitment.
   - There was also consensus that we need to better understand "spatial occupancy" of RGSM populations during periods of low-flow/river drying.
   - In general, participants favored focusing resources on areas of disagreement, where there would be clear relevance to management, and to conservation of the species. There appeared to be recognition that some of these issues might take years to resolve.

9. **Turning now to issues of AM and governance: do you think there is a clear pathway for the integration of science into management? Do decision-makers, managers and scientists understand each other's roles, and communicate effectively? How are technical disagreements resolved? How are differences of opinion on management resolved? If log-jams happen, where and why do they occur?**

   - There is a clear consensus (in fact unanimity) on the following:
     - There is not a clear pathway for integration of science into management.
     - Scientific data are (at present) poorly/rarely used by decision makers to inform and adjust management decisions.
     - Communication between scientists/restoration practitioners and decision makers is uncommon/infrequent.
     - There is no structured process to enable science to guide decision-making or to resolve technical disagreements.
     - There is understanding by scientists and managers of each other's roles, but not necessarily in the context of the AM Cycle.

- EC members are more likely to listen to their own scientists and generally don't trust other agencies' scientists.
- Disagreement/gridlock has centered around monitoring methods and results associated with the RGSM and how the river should be managed to bolster populations.
- There is a widespread feeling that science is selectively used to bolster individual agency positions on management.
    - Gridlock occurs when one CP entity doesn't like or agree with monitoring results.
- Only rarely (if ever) do strong technical disagreements pertain to the SWFL.
- As stated above (8) many participants strongly advocated for an objective scientific review process to resolve disagreements and advance science. There was widespread hope that the upcoming CPUE workshop would be a step in this direction, but also some concern about how the workshop was being managed to resolve uncertainties.

10. How effectively are affected parties (Tribes, stake-holders, etc.) able to participate in scientific assessments and evaluations?

- Perspectives varied on this topic.
- There was a general perception that Tribes (with exceptions) and other stakeholders lack the technical resources and support required to participate in scientific assessments/evaluations in substantive manner.

11. Does the current Program and the proposed RIP decision making process operate effectively to guide management of the Rio Grande ecosystem and affected resources? What (if any) changes and improvements would you welcome?

- There appeared to be widespread agreement on the following:
    - The Collaborative Program has not yet been effective in advancing species recovery, or in generating agreed co-management (notably AM)
    - There is a clear need for consistent and effective Program Management – there is too much (near constant) turnover and prolonged vacancies.
    - The USACE's formal participation in any Program is critical to success, but their role/commitment is unclear.
    - Any future Program re-structuring should incorporate an independent scientific review process to advance science-based decisions.
    - There should be 'co-ownership' and a feeling of shared/proportional risk in order to break the status-quo.

- EC meetings are rarely an effective forum for important debate or substantive discussion.
- Future management options must be structured to enable AM to work (e.g., no rigid or static water management prescriptions).
- Lack of funding and authorization limits the group's ability to establish the level of organizational structure and monitoring required to enable a functional Program.
- Many participants noted that there is a BiOp in progress, which will be developed at the same time as the AM activities under GSA's work-plan. Similarly, there is on-going discussion about the future structure and operation of the RIP, which may be resolved under the BiOp. Given these uncertainties over governance and structure, it will be important that AM design is compatible with whatever arises through the BiOp and other ongoing discussions among the parties.
- Other important areas that were raised (but without consensus):
  - There are too many representatives on the EC.
  - Impartial third party management may be important to program success.
  - There need to be some improvements to process and structure so that the EC or a subcommittee/parallel process can efficiently identify and recommend management actions.

Appendix B-1: New Mexico Meadow Jumping Mouse Workshop Summary Notes

MIDDLE RIO GRANDE ENDANGERED SPECIES COLLABORATIVE PROGRAM
ADAPTIVE MANAGEMENT FRAMEWORK

New Mexico Meadow Jumping Mouse Technical Workshop
Sevilleta National Wildlife Refuge Visitor Center
September 7, 2016

WORKSHOP SUMMARY

Goals and Objectives:

- Learn about the state of the science for the NMMJM;
- Discuss key management-relevant uncertainties related to NMMJM life history, habitat, and distribution;
- Discuss survey methodologies for the NMMJM; and
- Prioritize key uncertainties for further monitoring and research so results can be used to inform conservation management decisions.

Key Take-Aways:

The SMEs came up with the following priority research areas for the NMMJM in the MRG:

- Improving understanding of the MRG population distribution;
- Improving understanding of dynamics of the MRG populations;
- Improving understanding of habitat associations in the MRG;
- Improving understanding of genetic variability of the MRG population compared to other New Mexico populations;
- Improving understanding of the impacts of physical human disturbance (e.g., restoration activities) on the MRG population;
- Improving understanding of hibernation triggers and consequences in the MRG; and
- There is a need for valid non-invasive methods to survey, monitor, and study the species:
    - The only known population in the MRG is at the BdANWR, but this population is likely so small that invasive study protocols on this population may not be prudent (there is a critical need to identify any other populations in the MRG or other possible surrogate populations).

Based on those priority research areas, the SMEs then identified research questions in each area, and then prioritized their top five research questions. These priority questions were:

- How do non-invasive methods compare to trapping for survey and monitoring?
- Do other NMMJM populations occur within the MRG outside of the BdANWR?
    - Answering this question would involve:
        - Performing surveys at historically occupied sites to determine if there are still NMMJM populations;
        - Developing expert-informed screening criteria (e.g., GIS species distribution models and HSI models) to map potential habitat areas within the MRG;
        - Prioritizing the identified potential habitat;
        - Field-verifying areas identified as suitable habitat to determine need and precise locations for implementing population surveys; and
        - Conducting field surveys at priority areas of suitable habitat.
- What are the population dynamics for the NMMJM?
    - Answering this question would involve long-term monitoring (e.g., for mortality rates, reproductive rates, overwinter survivorship).
    - Rearchers/Managers must realize that the key aspect of population dynamics for the MRG population are likely different in comparison with montane populations.
- What are the attributes for NMMJM foraging, day nesting, maternal nesting, and hibernation habitats?
- What is the genetic variation within the former and current MRG populations and how does that variation relate to other populations? This information is critical to inform potential genetic causes of population decline in the MRG (e.g., inbreeding) and to inform potential translocations or captive management.

WORKSHOP NOTES

I. Introduction

On September 7, 2016, the GSA team convened the designated SMEs for NMMJM at Sevilleta National Wildlife Refuge in Socorro, New Mexico, to discuss the state of the science for NMMJM and help with prioritizing monitoring and research questions that could advance conservation management of NMMJM populations in the Middle Rio Grande. The information obtained from this workshop will be used to prioritize monitoring and research to inform decision-makers from the Collaborative Program.

Kathy Granillo, the Refuge Manager, welcomed the workshop participants to Sevilleta. Debbie Lee, the facilitator from the GSA team, reviewed the meeting agenda and invited workshop participants to introduce themselves. Ten participants from the following organizations were present:

- Bosque del Apache National Wildlife Refuge (BdANWR)
- New Mexico Department of Game and Fish (NMGF)
- New Mexico State University (NMSU)
- U.S. Army Corps of Engineers (USACE)
- U.S. Bureau of Reclamation (USBR)
- U.S. Fish and Wildlife Service (USFWS)
- U.S. Forest Service (USFS)

In addition to Ms. Lee, the GSA team members included Todd Caplan, Project Manager, who for the purposes of this workshop was serving as a riparian ecology expert; Steven Courtney (via conference phone), process expert; and Monika Hobbs, note-taker.

Mr. Caplan provided a brief overview of the Collaborative Program and the larger AM process. The GSA team has been working with SMEs for each of four endangered species, of which the NMMJM is one, to identify the top monitoring and research priorities that would guide management actions. The GSA team will also solicit decision-makers for their priorities. Priorities from both the SMEs and the decision-makers will be used to inform the development of study plan frameworks. The scope of the GSA contract ends with those frameworks, but the plan is that those frameworks will be further developed into detailed study plans and implemented by the MRGESCP in the future. The goal is that over time, the list of uncertainties will shrink as monitoring and research are carried out.

Ms. Lee explained the format for the day. She introduced Dr. Jennifer Frey, MNSU, who had prepared presentations on the evolution, life history, distribution, habitat, and survey methods for the NMMJM. Ms. Lee emphasized the discussion for the day will focus on *management-relevant* science.

All documents related to the NMMJM technical workshop, including Dr. Frey's presentation slides were archived online at: https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/NMMJM%20Background%20 Literature.html.

Citations from Dr. Frey's presentation were also archived online at: https://webapps.usgs.gov/ MRGESCP/Wiki/mainSpace/NMMJM%20Technical%20Workshop.html.

II. Evolutionary Perspective and Life History

Dr. Frey presented on the evolutionary history of the NMMJM and compared it to closely related taxa, including *Z. h. preblei* and *Z. h. pallidus*. She noted that while there were similarities, she cautioned against extrapolating from one taxon to the next due to differing behaviors. Dr. Frey's presentation slides for NMMJM Evolutionary Perspective and Life History are located online at: https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/files/NMMJM%20Workshop%20Presentation%20 1.pdf.

Dr. Frey then presented on the life history of the NMMJM. She listed some thoughts of key uncertainties related to NMMJM life history, including: 1) hibernation triggers and survivorship; 2) summer torpor; 3) factors influencing reproduction timing and survival; 4) population viability; 5) diet and its relationship to habitat; and (6) how interspecies interactions influence NMMJM distribution, population numbers, and survival.

During and after Dr. Frey's presentation, participants asked clarifying questions. In response to those questions, Dr. Frey and Gregory Wright (USFS) made the following points:

- **Hibernation**
  - Soil temperature determines timing of emergence from hibernation.
  - Cues that determine immergence of NMMJM into hibernation are poorly understood.
  - It is possible that NMMJM may go into summer torpor in response to drought or other unfavorable conditions. Summer torpor might be a normal aspect of the life history of the BdANWR population
  - Photoperiod does not play a role in determining when NMMJM emerge from hibernation.
  - Surveys during warm spells in the non-active season (late fall-early spring) did not detect NMMJM at the BdANWR (but that does not mean above-ground activity did not occur).
- **Diet**
  - NMMJM at the BdANWR foraged in the canopy of the herbaceous vegetation. The herbaceous structure allows NMMJM access to seed heads and likely provides other benefits, including concealment cover from predators and avoidance of other species.

There was almost no evidence of NMMJM climbing trees or shrubs (NMMJM was observed once in a Russian olive shrub [*Elaeagnus angustifolia*] about a meter [m] high).

- There are observations of a NMMJM avoiding foraging on plant species it had been eating a few weeks earlier. Mr. Wright suggested that the species preferreds some seeds over others, noting that he observed NMMJM feeding on only ten species out of dozens available. He noted he had field observations of active feeding. There were very few species NMMJM were observed to feed on, and that pictures were taken to document the observations. Based on observations, he is confidentof some of the plant species NMMJM is feeding upon.

- **Reproduction**
  - There is a longer period of maternal care for NMMJM in comparison with other rodents.
- **Locomotion**
  - NMMJM are highly philopatric, with activity mostly confined to the day nest and a specific patch of foraging habitat. Individuals move quickly in a linear fashion between day nest and foraging site. To increase detection rates, surveys must target the foraging habitat.
  - An exception to this would be narrow (one to two m wide) linear riparian habitats, such as the Riverside Canal, which is used both as foraging habitat and as a movement corridor. Such sites could be good places to target survey efforts.
- **Interspecies Dynamics**
  - Historically, beavers (*Castor canadensis*) may have played a large part in NMMJM life history as they created more habitat via building dams, changing stream planform, and converting riparian habitat to earlier seral stage. Management actions remove beavers and their dams resulted in diminished ecological services provided by beavers in the MRG and BdANWR.
  - There are likely a number of possible parasites and diseases that may affect the NMMJM, but it is not known how these may affect the species.
- **Distribution**
  - Dr. Frey presented on what is known about the distribution of NMMJM, the basis for that known distribution, and potential NMMJM distribution.
  - Dr. Frey's presentation slides for NMMJM Distribution are located online at: https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/files/NMMJM%20Workshop%20Presentation%202.pdf
  - Dr. Frey then focused on distribution in the Rio Grande and status at the BdANWR, which is the only known population in the MRG. She stated there were uncertainties

related to: 1) the current NMMJM distribution in the MRG, 2) its potential distribution, and 3) the factors which have contributed to the species' decline in distribution.

During and after Dr. Frey's presentation, participants asked clarifying questions. In response to those questions, Dr. Frey made the following points about the historic distribution of NMMJM:

- At Isleta, NMMJM were historically found in wet meadow systems. They were not found in the areas of deep water dominated by cattails (*Typha* spp.), but rather occurred around the edges in willow (*Salix* spp.)-grass associations.
- At the BdANWR, NMMJM were historically relatively well distributed. Currently, the population is very small, and could be less than 25 individuals.
- Dr. Frey emphasized that knowing the habitat in which NMMJM occurs is critical for species recovery. The group discussed current modeling capabilities, which are limited by scale and inputs specific to NMMJM. Mr. Caplan noted that the scale of the current vegetation mapping along the MRG is very coarse and would not be very useful for identifying suitable habitat. He suggested that there are other available tools which could help identify potential suitable habitat, such as LIDAR, high-resolution aerial imagery, and riparian groundwater maps, that can be used to identify areas with shallow groundwater, vegetation community structure, and other suitable habitat attributes.
- Dr. Frey stated that there are currently no good distribution models because resolution is not fine enough, or they lack information about NMMJM biology. Dr. Sarah Lehnen (USFWS) had developed preliminary models for the BdANWR based on LIDAR and fine-resolution vegetation layers. Those models appeared to offer advances over other model products. Dr. Frey stated that she had an ongoing study to develop a spatially explicit ecological niche model for the NMMJM based on hydrological, climatological, and vegetation variables. Jeff Sanchez (BdANWR) stated that the main limiting factor for NMMJM is water availability and soil saturation. Therefore, depending on the size of the area, including hydrology in models could help identify and hone in on potential habitat.

III. Habitat

Dr. Frey presented on known NMMJM habitat associations, and what is still uncertain. She noted that the NMMJM requires different habitats for foraging, day nests, maternal nests, and hibernation, and that the species appears to require very specific habitat attributes. She explained the different habitat surveys done at the BdANWR and in montane habitats.

Dr. Frey's presentation slides for NMMJM Habitat are located online at: https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/files/NMMJM%20Workshop%20Presentation%203.pdf

During and after Dr. Frey's presentation, participants asked clarifying questions. In response to those questions, Dr. Frey and Mr. Wright made the following points:

- Habitat Associations: Water
  - The stated relationship between NMMJM and "flowing water" is a scale issue. All known populations are in riparian areas that have flowing water. However, at the finer spatial scale, some occupied sites may not have flowing water.
  - The studies cited in the presentation recorded the distance of the NMMJM observation to water, not just flowing water.
  - The presence of flowing water (as opposed to stagnant, standing water) may be important for mitigating soil salinity, as flowing water would flush salt from the soil.
  - Soil moisture may provide a cooling effect, which may be a requirement for the NMMJM when they are on the ground and exposed to the sun during the day at the day nest.
- Foraging Sites
  - At the BdANWR, sacaton grass appeared to be a dominant vegetative species for the transitional habitat between foraging and nesting sites.
  - Plants included in microhabitat selection at the BdANWR were both foraging and cover plants. For example, dogbane (*Apocynum* spp.) was not part of NMMJM diet, but provided structure and cover for the NMMJM to forage safely.
  - Carex is an important indicator of NMMJM habitat in montane locations. Carex seeds do not appear to be an important food source, but the plants probably contribute to herbaceous cover and habitat structure.
  - The vegetation is usually diverse and determining which areas to study based on a select plant species will likely not be productive. However, at the BdANWR, researchers have had success locating NMMJM by searching for a particular suite of several species of plants.
  - NMMJM can use willow habitat if the willow (*Salix* spp.) is young and found with understory herbaceous plant species. Beavers help with maintaining willows at an early seral stage (thereby allowing herbaceous plants to grow in the understory).
  - Foraging sites are the limiting habitat for NMMJM.
  - There has to be suitable nesting habitat in close proximity to foraging sites.
- Day-Nest Sites
  - Adequate ground cover is a critical component of day-nest habitat (for NMMJM habitat monitoring, "ground cover" refers to aerial cover provided by herbaceous plants). Many resources describe the nest as a "ball", but the grasses used to create the nest are often still attached to the ground so the ball can be subtle.

- At the BdANWR, day-nest sites were in grassy areas on moist soil with a mean vertical cover of 41 centimeters (16 inches) based on Robel pole measurements. The Robel pole is a visual obstruction measurement that provides a measure of vegetation height and density.

- Maternal Nest Sites
  - Only four maternal nests sites are known for the NMMJM.
    - If the maternal nest is in a floodplain, it could flood in the summer, drowning the nest.
    - The mother stays in the maternal nest once established; however, there is no transmitter data available past 21 days (when the signal died), so the full nesting period has not yet been monitored.
- Hibernation Nest Sites
  - Only a single hibernation nest site is known for the NMMJM.
  - Constant cold temperatures are beneficial for hibernation. Local features can influence local temperatures (e.g., a hibernation site on a north-facing slope would be relatively cooler than one on a south-facing slope).
  - It is assumed that hibernation sites are not limiting.
- Habitat Data for Montane versus BdANWR sites
  - Most data on habitat associations are from montane sites, which may not be relevant to the BdANWR population.
  - BdANWR data is better for lowland sites; while the data from montane sites is fragmented and more descriptive.

The group specifically discussed the NMMJM habitat at the BdANWR. Dr. Frey noted that the abundance of habitat deemed suitable for the NMMJM has declined on the refuge due to canal dredging, the loss of beaver dams, laser-leveling managed wetlands, and other causes. BdANWR representatives Megan Goyette and Mr. J. Sanchez informed the group that the Refuge no longer employs laser leveling. Instead, the refuge is trying to create undulating topography to promote microhabitat variability. According to the BdANWR representatives, managing for waterfowl in the winter results in good NMMJM habitat, whereas managing for NMMJM does not necessarily result in good habitat for waterfowl. The BdANWR staff scientists discussed that flexible water management is key for developing and maintaining good habitat for wildlife (including NMMJM), but BdANWR is limited in their ability to deliver and manage water during summer months on the refuge.

In response to a question from Mr. Caplan about the efficacy of creating a HSI for NMMJM to evaluate and score site-specific habitat suitability, Dr. Frey stated that HSIs for mammals have had limited value, and suggested that remote sensing data would likely be more suitable. She added that different methods would likely be better suited for different scales, and that tools such as GIS models currently being developed for NMMJM would be applicable for a broader scale, but a much finer tool would be required for BdANWR.

The group developed a list of habitat attributes for NMMJM. These included:

- Areas of saturated soil within the historical river floodplain;
- Transitional habitat with sufficient cover between foraging, day-nest, and maternal-nest sites; and
- Foraging habitat in close proximity to day-nest and maternal-nest sites.
- Foraging Sites:
    - Diversity of plant species;
    - Vegetation structure, including herbaceous canopy cover and plant height; and
    - Availability of forage plants.
- Day-Nest Sites:
    - Large grass component, and
    - Soil moisture (humidity).
- Maternal Nest Sites:
    - Pre-existing burrow,
    - Above the water table,
    - Often a more woody habitat with tree cover,
    - Within about 100 m from foraging sites, and
    - Low summer flood potential.
- Hibernation Nest Sites:
    - Cooler temperatures result in longer hibernation (north-facing slopes, shade, snow);
    - Above the water table; and
    - Low spring flood potential.

The group listed the following scientific uncertainties for which more information is needed in order to inform management actions:

- Understanding how the NMMJM responded to historical and current disturbance regimes (e.g., flooding, wildfire, beaver activity). Because the current river does not provide natural disturbance regimes, it is necessary to determine how to use management to provide necessary habitat elements that would have historically been created by natural disturbances;

- Interspecies relationships (e.g., bullfrogs [*Lithobates catesbeianus*], house mice [*Mus musculus*], beavers, predators, competing small mammals);
- Changes in foraging behavior, and thus foraging sites, before hibernation (drier, grassier habitat may be critical for pre-hibernation foraging);
- Effects of soil salinity on suitable vegetation and NMMJM physiology (influence of hydrology); and
- Population density;
- Day-Nest Sites:
  - The needed temperature and humidity level.
- Maternal-Nest Sites:
  - Burrow attributes (i.e., narrowness, length, depth);
  - Species that initially made the burrow;
  - Potential burrow alternatives; and
  - Distribution of individual maternal nests from one another.
- Hibernation-Nest Sites:
  - Habitat characteristics,
  - Soil depth and depth to water table,
  - Soil moisture (does it cause stable temperature and humidity in the winter?), and
  - Impacts to survivorship.

IV. Priority Questions

Ms. Lee asked workshop participants to list their top three questions related to NMMJM in the MRG region (montane and BdANWR). Several people asked the same or similar questions. The questions generally fell into the six umbrella categories, which are listed below.

- **Distribution**
  - Where does the NMMJM currently occur in MRG? *[eight participants listed this as a priority question]*
  - Where is potentially suitable habitat for NMMJM in the MRG?
  - What is the connectivity of potential habitat in the Middle Rio Grande (and on BdANWR)? *[three participants listed this as a priority question]*

  - How should we best prioritize surveys for foraging habitat?
  - How can we accurately assess NMMJM population at the landscape level? At the site level? (Is there a tool that can be consistently used by different observers to reduce observer bias?)
  - What are the dispersal capabilities of NMMJM?
- **Population Viability and Dynamics**
  - What are the survival and reproductive rates for NMMJM?
  - Is the population growing or shrinking?
  - Do we know enough for a captive-breeding program?
    - What would the impact on the wild population be?
    - What husbandry is required to build a captive-breeding population?
    - At what population level should a captive-breeding program be implemented?
- **Habitat Requirements**
  - What is the relationship between habitat area and population size of NMMJM?
  - What are habitat sources and sinks? What habitats foster increased NMMJM populations?
  - What habitats cause increased mortality/decreased reproductive success?
  - What do NMMJM eat (fecal study)? [*Three participants listed this a priority question]*
  - What are local habitat requirements? *Three participants listed this as a priority question]*
    - For the day nest?
    - For the maternal nest?
    - For the hibernation site? *[Four participants listed this as a priority question]*
  - What is the role of flowing water in NMMJM habitat?
- **Physical Disturbance Impacts**
  - How do water management actions and other physical disturbances impact NMMJM habitat? *[Two participants listed this a priority question]*
- **Hibernation Triggers**
  - What are the triggers for hibernation immergence and emergence?
  - What are the differences in hibernation in different populations?
  - What is the relationship between hibernation and reproduction, and hence the impact to survival and population demography?

- **Bosque del Apache National Wildlife Refuge Population**
  - What is the current state of the BdANWR NMMJM population? *[Two participants listed this a priority question]*
    - What is the population size?
    - What is the population density?
    - What is the population growth or decline?
  - What is the population viability of the BdANWR NMMJM population?
  - What is the reason for the BdANWR NMMJM population decline (e.g., habitat, climate, invasive species)?
  - Is suitable habitat a limiting factor for the BdANWR population? If so, how can habitat connectivity be increased?
  - What is the genetic diversity of the BdANWR NMMJM population, and if it is low, how can it be managed?

V. Survey Methods

Dr. Frey then presented on survey methodology for NMMJM, which is a very difficult species to detect and capture.

Dr. Frey's presentation slides for NMMJM Survey Methods are located online at: https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/files/NMMJM%20Workshop%20Presentation%204.pdf

She developed a survey protocol for NMMJM that: 1) increased detection rates, 2) prevented false positive/false negative results, 3) prevented harm to the animal and its habitat, 4) prevented harm to the researchers, and 5) incorporated quality control/quality assurance of data. The USFWS has adopted this protocol in its Survey Guidelines for NMMJM, finalized in 2015, and Dr. Frey has developed a training workshop for this protocol. Dr. Frey also provided an overview of non-invasive survey methods, such as track plates and remote cameras, which are currently being tested in the field.

Dr. Frey noted that the USFWS permit requirements are extremely strict for NMMJM, and that taking the training is a prerequisite for being issued a permit. However, the training course has not yet been offered due to funding issues. The group discussed the optimal timing for researchers to take the training. Jodie Smithem, USFWS, suggested the training should be offered during the winter to allow researchers adequate time to secure permits before the active season.

VI. Priority Monitoring and Research Areas

Based on the presentations and conversations throughout the day, Ms. Lee asked meeting participants to list top monitoring and research questions that would inform management decisions for the NMMJM.

She asked them to keep in mind what is possible with current survey methodology, as well as what can realistically be funded and carried out.

In addition to the six categories already developed above, Dr. Frey suggested the inclusion of a seventh category for survey methodology. Participants came up with the following long list of management-relevant monitoring and research questions/studies:

- **Survey Methodology**
  - How do non-invasive survey methods compare to trapping?
- **Distribution**
  - Is the NMMJM still occupying portions of its historical range?
  - What are the screening criteria for the landscape scale to identify potential habitat?
  - Do NMMJM exist in new habitat sites?
- **Population Dynamics**
  - What are survival, reproduction, and mortality rates?
  - Implement a long-term population monitoring study.
  - Implement a long-term capture/recapture study.
  - What are the demographic traits linked to habitat?
  - In a small population, how is population density estimated?
  - Can a Population Viability Analysis be implemented?
- **Habitat Requirements**
  - Perform a fecal analysis to determine diet.
  - Better characterization of habitat requirements for foraging, nesting, and hibernation:
    - Information for hibernation sites is especially needed for management.
  - What spatial configuration of habitat (area, proximity) is necessary to maintain a population?
  - What is the importance of the relationship among temperature, salinity, humidity requirements, and hydrology?
  - What habitat attributes are limiting factors?
  - Is there variation in habitat requirements in different portions of the Rio Grande watershed?
  - How do invasive species (e.g., bullfrogs, house mice) impact NMMJM?

- What causes transitions of habitat (including disturbance regimes and vegetation shifts)?
  - Physical transitions, and
  - Temporal transitions.

- **Physical Disturbance Impacts**
  - How does management affect natural processes?
- **Hibernation**
  - What are the triggers for hibernation immergence and emergence?
    - What is the soil temperature needed?
  - What cues immergence into hibernation?
  - Multiple questions regarding attributes and drivers of summer torpor in MRG populations.
- **Genetics**
  - Need to determine if the BdANWR population is inbred, and if so, how to manage;
  - Genetics study within a population, and between populations; and
  - More information needed to inform captive breeding and translocation.
- **Bosque del Apache National Wildlife Refuge Population**
  - What are the BdANWR population characteristics? Study would evaluate:
    - Population density,
    - Population size,
    - Population distribution throughout the refuge, and
    - Population trends.
  - What are specific life history patterns?
    - What are females doing at the end of the summer?
    - When do juveniles go into hibernation?
  - Is the BdANWR population genetically different than other NMMJM populations?
  - How to best monitor the population (need for non-invasive study methods)?
  - How does winter flooding affect hibernation sites?
  - What is the historic population distribution?

The group acknowledged that several of the research questions would be difficult to tackle with only the BdANWR population in the MRG region. Several participants expressed concern about carrying out studies on that population given its small size. This led participants to move a number of the monitoring and research topics down in priority until either additional populations of NMMJM are discovered or the BdANWR population has recovered to a sufficient population size. These specific monitoring and research topics were identified:

- A fecal study to determine NMMJM diet;
- Studies to understand to hibernation triggers;
- Studies to determine what causes summer torpor; and

The group then further reduced the list down to five priority research questions. Several of the above questions were able to be combined together.

The SMEs agreed to the following top five priority questions:

1.) What is the genetic variation within NMMJM populations, and between NMMJM populations?
2.) How do non-invasive survey methods compare to trapping?
3.) Where are NMMJM populations located?
    - Answering this question would involve:
        - Looking at historical sites and determining if there are still NMMJM populations,
        - Developing screening criteria to map potential habitat area at different scales,
        - Prioritizing the identified potential habitat for surveys, and
        - On-the-ground surveys of priority potential habitats.
4.) What are the attributes for foraging, day-nesting, maternal-nesting, and hibernation habitats in the MRG?
5.) What are the population dynamics for NMMJM?
    - Answering this question would involve long-term monitoring (e.g., for mortality rates, reproductive rates, overwinter survivorship) of the BdANWR population.

VII. Wrap Up

Mr. Caplan thanked the workshop participants for their participation and contributions. He stated that the workshop was extremely productive and that the priorities developed would be used to inform the study plans developed under the AM framework. He informed participants that the presentation and all materials related to the workshop, including scientific reference papers and reports, would be posted online at: https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/NMMJM%20Technical%20Workshop.html.

MIDDLE RIO GRANDE ENDANGERED SPECIES COLLABORATIVE PROGRAM
ADAPTIVE MANAGEMENT FRAMEWORK

New Mexico Meadow Jumping Mouse Technical Workshop
Sevilleta National Wildlife Refuge
September 7, 2016

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Appendix B-2: Detailed Technical Discussion – Critical Scientific Uncertainties for the New Mexico Meadow Jumping Mouse

CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE NEW MEXICO MEADOW JUMPING MOUSE

Listing History, Recovery, and Population Status

The NMMJM is a well-differentiated taxon that is endemic to the American Southwest. It has a confusing taxonomic history, previously recognized as a distinct species (*Zapus luteus*), and subsequently as a subspecies of the western jumping mouse (*Z. princeps*) and the meadow jumping mouse (*Z. hudsonius*; Miller 1911, Krutzsch 1954, Hafner et al. 1981). Recent molecular data have verified its status as a monophyletic group within a separate species, the yellow jumping mouse (*Z. luteus*; Malaney et al. 2017); however, as of this report the new status has not been formally adopted by the USFWS.

The geographic range of this taxon, a riparian obligate, includes perennial streams in portions of southern Colorado, New Mexico, and central Arizona (Frey 2008, USFWS 2014a). The distribution and abundance of the NMMJM has declined significantly across its range, with 70 formerly occupied locations considered extirpated. The Species Status Assessment (SSA) Report (USFWS 2014a) concluded that 29 populations were extant (two in Colorado, 15 in New Mexico, and 12 in Arizona) spread across eight conservation areas (two in Colorado, five in New Mexico, and one in Arizona). However, almost all the populations are isolated and widely separated, and all occur in habitat patches that are considered too small to support a resilient population (USFWS 2014a). Further, since 2005, 62% of those remaining populations have been seriously compromised, and some are believed to have been extirpated, further eroding viability of this taxon (USFWS 2014a; unpublished data). The main threat to the NMMJM is habitat loss (USFWS 2014a, 2014b, 2014c). The primary cause of this habitat loss is lack of water and livestock grazing, while other sources of habitat loss include severe wildfire, flooding that causes scouring, highway reconstruction, unregulated recreation, loss of beaver ponds, and mowing of riparian vegetation (USFWS 2014a, 2014b, 2014c).

In the MRG, the NMMJM is thought to have been widespread throughout the Rio Grande floodplain prior to radical alteration of the river's hydrology, but it is currently only known to exist at the BdANWR, Socorro County. However, there have been no recent comprehensive surveys for the species in the MRG and no surveys have occurred in the active floodplain (Frey 2006). Consequently, the NMMJM could occur in other areas, especially in places such as near Isleta and Espanola where the taxon was known to occur in 1987 (Morrison 1988; see critical uncertainty #1 for additional information).

The NMMJM was listed as endangered throughout its range in July 2014 (USFWS 2014b), although it was first made a candidate for listing in 1985 (USFWS 1985) and its listing was deemed warranted in 2007 (USFWS 2007). It was listed as threatened by New Mexico in 1983 and up-listed to endangered in 2007 (NMDGF 2016). In March 2016, Critical Habitat was designed for the NMMJM (USFWS 2016a), which included 272.5 km of perennial streams, irrigation ditches, and canals in eight conservation units. The Critical Habitat area designation focused primarily on the current (since 2005) known distribution of the

NMMJM. Consequently, only one Critical Habitat conservation unit was designated in the MRG: Unit 6 BdANWR. However, it is important to understand that this designation in no way discounts the possibility that other populations of NMMJM might occur in the MRG but have not been detected due to a lack of comprehensive recent survey work. Unit 6 consists of 403 ha along 21.1 km of irrigation ditches and canals and their associated management units located on the BdANWR. The features considered essential to the conservation of the NMMJM in this unit that may require special management include: water use and management; severe wildfires; and thinning, mowing, or removing saltcedar (*Tamarix* spp.) and decadent stands of willow (USFWS 2016a).

No recovery plan has been approved for the NMMJM. However, the SSA (USFWS 2014a) and a recovery outline (USFWS 2014c) for the NMMJM considered concepts of *resiliency, redundancy*, and *representation*: known as the "3Rs" (Figure 12). The 3Rs describe viability of a taxon, which is the ability of a taxon to sustain populations in the wild beyond a defined period. A taxon can only be considered viable if it meets all three Rs:

- *Resiliency* is the ability to withstand annual environmental variation and stochastic events, such as extreme weather events.
    - The SSA considered resiliency to be best measured by habitat size (critical uncertainty #4), which is a proxy for the size and growth rate of a population (critical uncertainty #5) and is influenced by its genetic makeup (critical uncertainty #2).
- *Redundancy* is the ability to withstand catastrophic events, such as long-term droughts or large-scale high-intensity wildfires.
    - The SSA considered redundancy to be provided by the duplication and distribution of resilient populations across the taxon's range. This requires information on the taxon's distribution, genetics, and habitat (critical uncertainties, #1, #2, and #4).
- *Representation* is the ability to adapt to changing environmental conditions, such as via occurrence in different environments or possession of genetic variation.
    - The SSA considered representation to be measured by genetic diversity within and among populations and the ecological diversity of populations and that these are indicated by the extent of the geographic range (critical uncertainties #1, #2, and #4).

Addressing these scientific uncertainties will require field studies that would be facilitated by the development of non-invasive survey methods (critical uncertainty #3). The main area of uncertainty identified in the SSA was the minimum amount of suitable habitat needed to support resilient populations and the number of redundant populations needed to provide for adequate redundancy and representation. The SSA concluded that the NMMJM currently lacks resiliency and redundancy, and has low representation.

In 2008, NMDGF developed a recovery plan for the NMMJM, but the plan was not approved by the State Game Commission (NMDGF 2016). In addition, in a recent review of threatened and endangered species, the NMDGF made specific recommendations for the conservation of montane populations, but did not make recommendation for populations in the Rio Grande, except for the need to survey and monitor (NMDGF 2016).

Because of the recency of the federal listing actions for the NMMJM, the species has not been included within the MRGESCP. However, the 2015 Joint Biological Assessment (2015 Joint BA) for the MRG included information and an assessment of impacts to the NMMJM (USBR 2015). Some important information presented in the 2015 Joint BA about the NMMJM was incorrect, such as the BdANWR having the largest population of NMMJM in New Mexico (it is one of the smallest populations). Regardless, the 2016 BiOp concluded that the proposed actions may affect, but is not likely to adversely affect, the NMMJM or its designated critical habitat, largely because known populations of the NMMJM occur along irrigation systems and, hence, are more buffered against water shortages. However, it is important to recognize that no surveys for the NMMJM have been conducted in the active floodplain of the Rio Grande and there exists potential for NMMJM to occur in these areas; this was not recognized in the 2015 Joint BA, 2016 BiOp, or USFWS listing documents. The USFWS concurred with this determination based on the following proposed actions: "*USBR and the BA Partners will provide a minimum of 25 cubic feet per second (cfs) to the north boundary of [BdANWR] through the Socorro Riverside Drain and Low Flow Conveyance Channel (LFCC) from April 15 through September 30. Combined flows will not fall below 25 cfs for more than a total of 5 days annually, when water is available*." (USFWS 2016b: 2).

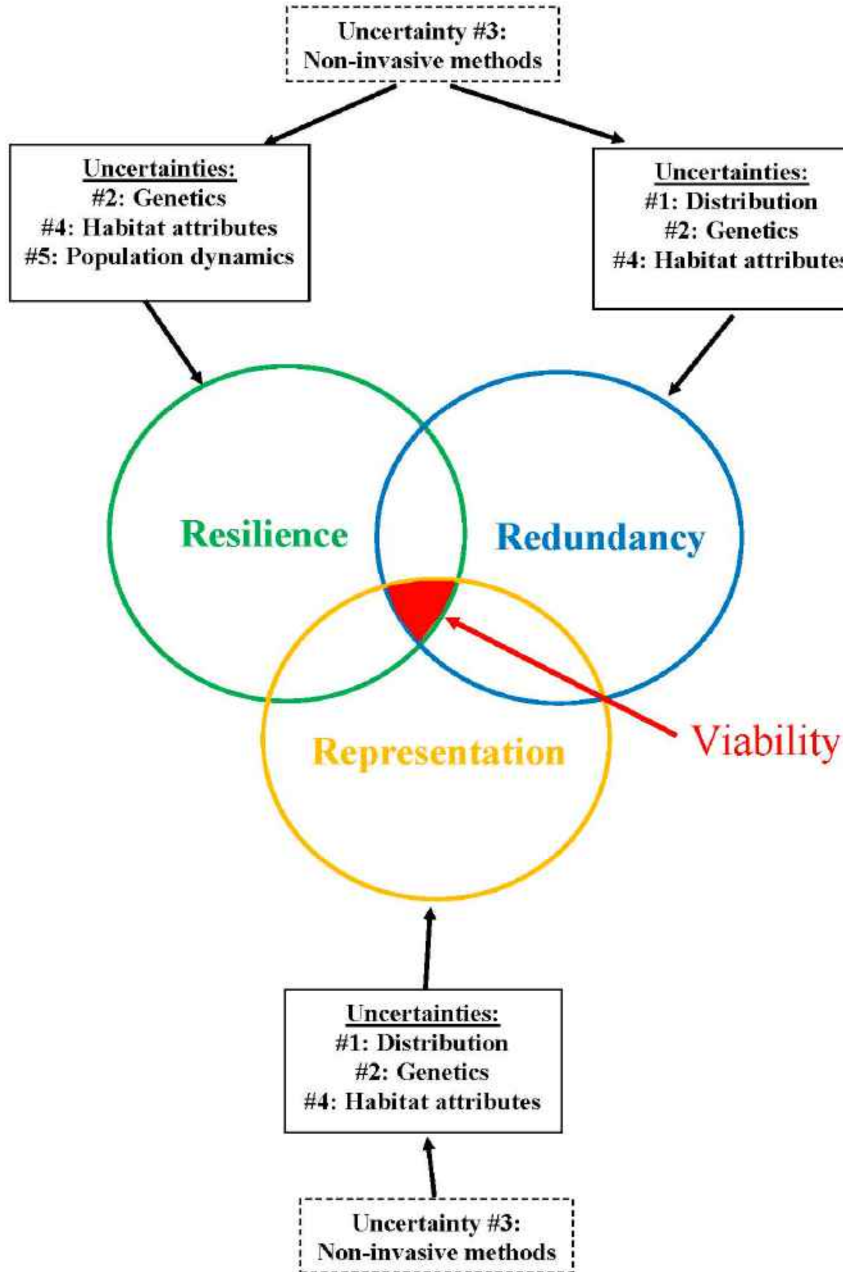

Figure 12. Relationship between the "3 Rs" of viability (resilience, redundancy, and representation) and the critical uncertainties for managing and recovering the New Mexico meadow jumping mouse in the Middle Rio Grande, New Mexico.

Middle Rio Grande Past and Current Management Activities

Very few recovery actions have been implemented for NMMJM in the MRG since 2005 (USFWS 2014c). With exception of management actions at the BdANWR, most efforts in the MRG have consisted of surveys and research. The USBR supported a study that developed a GIS map of potential habitat for the NMMJM in the active flood plain from Isleta to Elephant Butte and field surveys for potential habitat along certain irrigation drains and the LFCC in Socorro County (Frey and Kopp 2014). NMDGF supported a survey at Casa Colorada SWA (Frey 2012) and USFWS supported a survey at the BdANWR (Frey 2013a). At the BdANWR, the USFWS supported research on habitat selection (Frey and Wright 2012) and NMDGF supported research on cool season activity (Wright and Frey 2010).

The BdANWR has supported monitoring (BdANWR 2013, 2014, 2015, 2016) and field studies to develop a non-invasive method for detecting NMMJM using remote cameras (Lehnen et al. 2017). The BdANWR has also undertaken proactive management actions to increase habitat availability and reduce threats, including mowing and clearing areas of decadent willows in an attempt to restore and expand habitat along the Riverside Canal (USFWS 2014c). The Refuge purchased and replaced water control structures with Langemann gates, which are capable of finely managing water levels in canals (USFWS 2014c). Beginning in fall 2015, artificial intermittent streams were constructed to create new habitat areas. The refuge also conducts continual removal of bullfrogs, which are a potential non-native predator of the NMMJM (BdANWR 2016).

At the BdANWR, the NMMJM uses riparian habitat along the Riverside Canal and adjacent moist soil management units (Wright and Frey 2015). The timing and spatial extent of management activities in each of these areas are managed with respect to needs of NMMJM. Traditional moist soil management consists of annual flooding, annual dewatering, and periodic disturbance (e.g., drought, tillage, discing, fire) to inhibit NMMJM, but also are necessary to generate the early seral habitat required by the species. Beginning in mid-April, water levels are raised in the Riverside Canal to overtop ditch banks to saturate adjacent soils. In moist soil units, water is managed to periodically flood the area. After water has been drawn down, a small stream of water is allowed to flow into the unit to provide flowing water and support saturated soil during the active season of the NMMJM (late May-late October; BdANWR 2016). The refuge has developed a system of ranking moist soil units for management actions based on management priorities, climatic variables, and regulatory compliance requirements, using a 1- to 4-tier scale (BdANWR 2016). Tier 1 wetlands have been recently disturbed and have the highest plant productivity. Any managed wetland with ESA requirements is tier 1. Tier 4 wetlands are characterized by poor plant production.

Critical Scientific Uncertainties

A workshop was held on September 7, 2016, at the Sevilleta National Wildlife Refuge, New Mexico, that included a team of taxon experts and agency representatives to evaluate the state of the science for the NMMJM and to identify critical scientific uncertainties regarding NMMJM natural history, threats, and responses to management actions (see Section 2.2.1), with the following primary objectives: 1) contribute to scientific knowledge, 2) ensure that monitoring, research, and experiments funded by the MRGESCP reduce management uncertainties, and 3) improve the rigor of the science informing resource management decisions and actions directed at avoiding jeopardy to the continued existence of the NMMJM while still providing for current and future water users.

Identified Critical Scientific Uncertainties

Workshop participants prioritized the following five critical scientific uncertainties for the NMMJM:

6) Where are NMMJM populations located? Answering this question requires:
    a. Conducting field surveys of historical sites to determine if NMMJM persist
    b. Developing screening criteria to map potential habitat at different scales
    c. Prioritizing the identified potential habitat for surveys
    d. Conducting field surveys of priority potential habitats
7) What is the genetic variation within NMMJM populations, and between NMMJM populations?
8) How do non-invasive survey methods compare to trapping?
9) What are the attributes for foraging, day nesting, maternal nesting, and hibernation habitats in the MRG?
10) What are the population dynamics for NMMJM?
    a. Answering this question would involve long-term monitoring for mortality rates, reproductive rates, overwinter survivorship, and other metrics.
    b. Addressing this scientific uncertainty may not be feasible at this time because the only known population of NMMJM in the MRG is at the BdANWR, which may be too small to support this type of research.

Connectivity among Critical Scientific Uncertainties

The five critical scientific uncertainties identified for the NMMJM are connected: information pertaining to one uncertainty may be necessary to inform research on another uncertainty. In this context, information regarding Critical Uncertainty #1 (distribution) is central to studying the other four critical uncertainties (Figure 13). Specifically, information about distribution is necessary to inform understanding of genetic status and relationships among populations. Samples for genetic analyses also may be obtained during field studies of distribution. Second, information about distribution is necessary to identify populations of NMMJM suitable for study. Currently, the only population of NMMJM known to exist in the MRG is that occurring at the BdANWR (USFWS 2014a). The population of NMMJM at the BdANWR is thought to be very small (ca 25 individuals) and it occupies only a small area of suitable habitat (Wright and Frey 2015; unpublished data). Hence, risk of extinction of the BdANWR population is high. Thus, studies on this population using invasive methods such as trapping (e.g., to test non-invasive survey methods), or that require larger sample sizes (e.g., studies of habitat or population dynamics) are likely not appropriate. Further, there are critical differences in habitat use and population demography between low elevations sites (e.g., the MRG) and montane sites (Frey 2015a). Consequently, comprehensive surveys are necessary to identify any additional populations of NMMJM that may be suitable for study to inform management in the MRG. Because of the central role of critical uncertainty #1 (distribution), it was assigned priority *Level 1* (highest). Critical Uncertainty #2 (Genetics) was also assigned priority *Level 1* because of the urgent need for information on the genetic health of the BdANWR population. Although more thorough distribution data would improve insight gained from a genetic study, the need for genetic information on the BdANWR population is considered so critical that it should not wait for completion of distribution studies.

Given the generally small and isolated populations and that the USFWS survey guidelines are based on invasive trapping methods which can pose substantial risk to populations (USFWS 2015, Frey 2013b), critical uncertainty #3 (investigating non-invasive survey methods) has a priority *Level 2* (important, but of less immediate concern). Development of non-invasive survey methods would reduce risk to populations and may allow addition types of studies to occur (e.g., habitat attributes and population dynamics), particularly on more vulnerable populations. Lastly, habitat studies are necessary to inform studies of population dynamics as many demographic attributes, such as survival, may be linked to habitat quality.

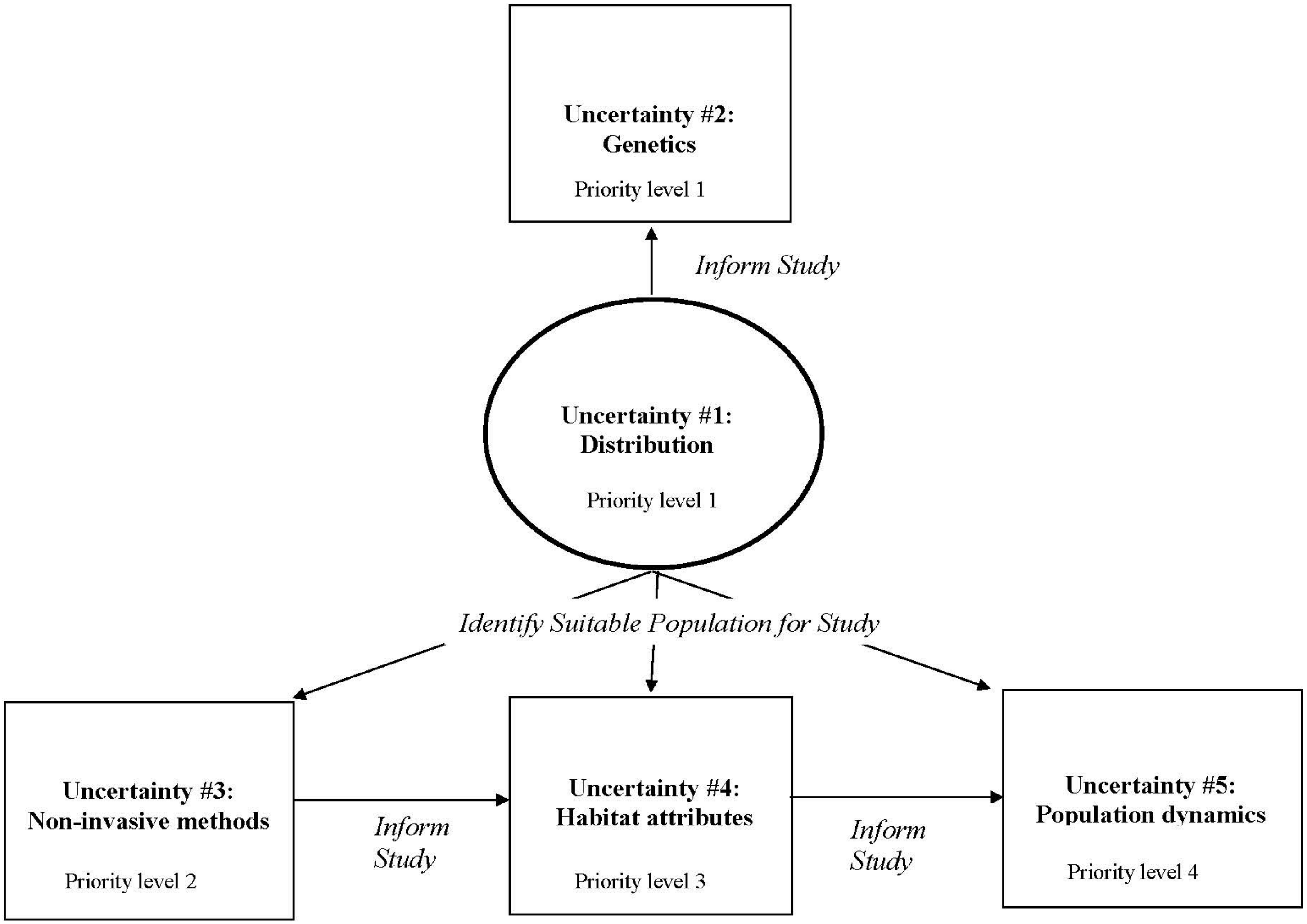

Figure 13. Relationships among critical scientific uncertainties influencing management and recovery of the New Mexico meadow jumping mouse in the Middle Rio Grande, New Mexico.

CRITICAL SCIENTIFIC UNCERTAINTY #1: MIDDLE RIO GRANDE POPULATIONS DISTRIBUTION

Study Question: Where are NMMJM populations located?

Scientific Relevance

NEW MEXICO MEADOW JUMPING MOUSE POPULATION LOCATIONS

SCIENTIFIC RELEVANCE

Evidence suggests the NMMJM had a broad historical distribution in the MRG. However, information on current distribution of NMMJM in the MRG is limited. Since 1987, reliable surveys have only occurred at two locations in the MRG (BdANWR and Casa Colorada SWA).

The NMMJM is considered difficult to survey (Frey 2013b). Unlike most other small mammals, general small mammal surveys have rarely resulted in captures of NMMJM; most records have been obtained by taxon experts during field work designed to specifically target the species. Therefore, there are relatively few historical locations where the species has been documented, despite a likely broad historical distribution (Hink and Ohmart 1984). Current permitting criteria and survey guidelines require specific prior experience working with NMMJM and specialized methods that target the NMMJM and prevent harm to captured animals or their habitat (Frey 2013b, USFWS 2015). Because few people have this specific experience, many regions have been poorly sampled for presence of NMMJM.

Frey (2006) reviewed historical records of the NMMJM in the Rio Grande Valley. The historical distribution in the Rio Grande Valley extends from Canon Del Rio Grande (i.e., 21 km above mouth Chama River) in the north and southward at least through BdANWR. However, the NMMJM has also been documented on most of the major tributaries to the Rio Grande in New Mexico, including Rio Hondo, Rio Pueblo de Taos (Rio Grande del Rancho), Embudo Creek (Rito la Presa), Rio Chama (including El Rito Creek), Santa Fe River, and Jemez River (Frey 2008). Thus, its distribution may have extended above the Canon Del Rio on the Rio Grande based on occurrence in most of the major tributaries above this point in New Mexico.

Historical records of occurrence for the NMMJM from the MRG (Cochiti Dam to Elephant Butte Dam) include five general locations: Albuquerque (1917), Isleta (1981-1982, 1987), Casa Colorada SWA (1987), Socorro (1909), and BdANWR (1976-1979, 1987, 1991-1992, 2009-2011, 2014-2016) (Frey 2006; BdANWR 2014, 2015, 2016; Wright and Frey 2015). Records from Albuquerque and Socorro were of single specimens collected in the first decades of the 20th century. Initial captures at several locations near Isleta occurred during a 1981-1983 biological inventory of riparian habitats and associated vertebrate animals in the MRG (Hink and Ohmart 1984). The survey area included 262 km from Española to the San Acacia Constriction. During 21 months of survey effort involving 71,820 trap-nights, only six NMMJM were captured (capture rate = 0.008%)—all from the vicinity of Isleta. Morrison (1988, 1992) conducted the first surveys specifically targeting NMMJM in the MRG and elsewhere in the Rio Grande watershed in 1987. She surveyed four general areas which included: 1) seven sites in the vicinity of Espanola (including three on San Juan Pueblo, two in the lower Rio Chama Valley, and one in Española); 2) five sites near Isleta (including the two areas where NMMJM had been captured by Hink and Ohmart [1984]); 3) 10 sites between Belen and Bernardo, including one site in Belen, one site adjacent to Casa Colorada SWA near Turn, three sites in vicinity of Bernardo Wildlife Management Area, and five sites at La Joya Wildlife Management Area; and 4) 18 sites at the BdANWR. NMMJM were captured in each of the four general areas, but not at most sites. In vicinity of Española, the species was not captured at four of seven sites, including a historical locality in Española. At Isleta, NMMJM were not captured at two of five sites, but it was captured at two areas where Hink and Ohmart (1984) had captured the species five years earlier. In the Belen-Bernardo area, it was not captured at nine of 10 sites (90%); it was only documented at Casa Colorada. Finally, at the BdANWR, it was not captured at 13 of 18 sites. Overall, the species was rare (capture rate = 0.29%) and populations were considered highly isolated.

The only recent surveys in the MRG were at the BdANWR and Casa Colorada SWA. No NMMJM were detected at the Casa Colorada SWA (Frey 2012). NMMJM have been documented fairly consistently at the BdANWR (but see Frey 2013a). However, distribution and abundance of NMMJM at BdANWR has precipitously declined since Morrison's survey in 1987 (Frey and Wright 2012, Wright and Frey 2015). The current area occupied by NMMJM at the BdANWR is about 25 ha and may consist of about 25 individuals (USFWS unpublished data).

Three studies have attempted to model distribution of the NMMJM using GIS-based spatial analyses. However, none of these have produced useful results for understanding current distribution of the NMMJM in the MRG. Malaney et al. (2012) developed a species distribution model based on a set of historical and recent occurrence records across the range of the NMMJM and climate variables at a 1-km scale, which they used to portray both current and Pleistocene distribution. However, the Malaney model was aimed at understanding geographic range of the species and is too coarse for predicting current distribution in the MRG. Friggens et al. (2014) developed a species distribution model for NMMJM in the Rio Grande watershed of New Mexico with aim of forecasting future impacts of fire, hydrological change, and climate change on the NMMJM's distribution. The Friggens model was based on a set of historical and recent occurrence records of NMMJM within the Rio Grande watershed, and developed using seven variables at a 1-km scale that represent climate (precipitation, evaporation), biophysical environment (elevation and distance to water), and biome type. However, based on recent advances in species distribution modeling, their methods are considered inadequate and prone to bias (e.g., no tuning of beta parameters and feature classes). Consequently, the Friggens model overpredicted current distribution of the NMMJM, showing nearly continuous distribution along all perennial waterways in the watershed, and hence is not useful for predicting current distribution. Lastly, Frey and Kopp (2014) developed a GIS model to predict areas of potential habitat for the NMMJM within the active floodplain of the Rio Grande from the Isleta to Elephant Butte Dam reach of the MRG. They did this by adapting the fine-scale vegetation classification and map developed for the SWFL in the MRG based on recent aerial photography. However, the SWFL vegetation classification and map emphasized components of the woody vegetation, which is not particularly useful for understanding NMMJM distribution, which is tied to the herbaceous vegetation layer. The resulting model predicted potential habitat for NMMJM in 17.6% of polygons within the active floodplain of the Rio Grande in the study area. In addition, Frey and Kopp (2014) conducted field surveys of NMMJM habitat along selected state drains and the LFCC. The field surveys found potential habitat at 7% of survey points (all on state drains). However, no follow-up trapping surveys were completed to determine if NMMJM occur within potential or predicted habitat.

To summarize, the current state of knowledge regarding distribution of the NMMJM in the MRG can be summarized as follows: 1) the NMMJM is thought to have been widespread in the MRG based on historical habitat availability, 2) there are few historical records of NMMJM in the MRG because it is difficult to survey (absence of a record does not imply species did or does not occur), 3) the only recent surveys for the NMMJM in the MRG have occurred at the BdANWR (present) and Casa Colorada SWA (not found), 4) GIS models constructed thus far have been largely inadequate in predicting current distribution of NMMJM in the MRG, and 5) the only location where NMMJM are known to persist in the MRG is the BdANWR.

Management Application

NEW MEXICO MEADOW JUMPING MOUSE POPULATION LOCATIONS MANAGEMENT APPLICATION

Knowledge about where the NMMJM occurs is necessary to focus population safeguards on occupied areas. Conversely, knowledge about where the NMMJM does not occur can prevent needless expenditure of resources.

Currently, the only known population of NMMJM in the MRG is located at BdANWR. However, the NMMJM is thought to have had a wide historical distribution in the MRG prior to widespread modification of the river's hydrology (Hink and Ohmart 1984). Further, based on studies in other regions, it is known that populations of NMMJM have persisted in often small, isolated areas that have been more or less protected from threats (e.g., Frey and Malaney 2009, Frey 2017, USFWS 2014b). There have been no apparent major alterations in habitat at some historical locations in the MRG (e.g., Isleta). Reliable surveys (using specialized methods) have only occurred at two locations in the MRG since 1987. In addition, at no time have surveys been conducted in the active floodplain of the Rio Grande. Thus, it seems likely that additional populations of NMMJM exist in the MRG, but have not been detected. Knowledge about where the NMMJM occurs is necessary to focus population safeguards on occupied areas. Conversely, knowledge about where the NMMJM does not occur can prevent needless expenditure of resources.

Recovery Application

NEW MEXICO MEADOW JUMPING MOUSE POPULATION LOCATIONS RECOVERY APPLICATION

The recovery outline considers the NMMJM to currently lack resiliency and redundancy, and to have low representation. The only population of NMMJM currently known in the MRG is at the BdANWR. Thus, discovery of other populations in the MRG would increase redundancy and may contribute to enhanced resiliency and representation.

No recovery plan has been approved for the NMMJM. However, a recovery outline (USFWS 2014c) concluded that the NMMJM currently lacks resiliency and redundancy and has low representation. The only population of NMMJM currently known in the MRG is at the BdANWR. Thus, discovery of other populations in the MRG would increase redundancy and may contribute to enhanced resiliency and representation. Discovery of other populations of NMMJM in the MRG, or elsewhere in the watershed (e.g., Espanola, Chama River), may allow some research to occur if the population was deemed large enough (the current population at the BdANWR is considered too small to support research using invasive methods).

Study Plan Considerations

The distribution of NMMJM in the MRG is best evaluated using several approaches, which would likely form separate, but interrelated, studies. The most basic way to begin to understand current distribution is to conduct field surveys at sites where the NMMJM was historically documented. Although this step is warranted, one difficulty is that locations for some historical records are not precisely known. Thus, additional research may be necessary to determine where specimens were collected and professional judgment will be necessary to determine appropriate habitat to sample at sites. NMMJM are associated with early successional herbaceous wetland communities that undergo natural spatio-temporal shifts. Thus, loss of habitat at a specific point through time does not necessarily equate with loss of a population. Further, there are relatively few historical locations for the NMMJM in the MRG, and so resampling these sites provides only limited information about distribution of the species.

The second necessary approach is to develop GIS models that can be used as screening criteria to identify areas of potential habitat and prioritize areas for field surveys. To be most useful, models should be developed that focus on different scales, in a nested hierarchy (likely as separate, but interrelated, studies). The NMMJM is an extreme habitat specialist at multiple scales and can only occur where all habitat features are met (Wright and Frey 2015). For instance, its geographic range is associated with perennial streams and rivers, while at the landscape scale, the species selects certain early successional riparian vegetation communities, and at the microhabitat scale, it requires tall, dense herbaceous communities on moist soil (Wright and Frey 2015, Frey 2017). Consequently, a spatial model developed based on 1-km pixel can only predict geographic range and would be incapable of predicting specific locations where the species currently occurs (since 1-km pixel cannot provide information on microhabitat). Conversely, a fine-scale spatial model developed based on 5-m pixel data (e.g., LIDAR, National Agricultural Imagery Program), which can predict suitable microhabitat, could not be developed for the entire MRG due to data and computational limitations. Thus, coarser scale models based on current hydrology or vegetation condition are necessary to identify areas of potential habitat, while finer scale models that can predict microhabitat are necessary to predict local areas of occurrence. Models should be developed by a team that includes a taxon expert who can ensure that appropriate variables and design are considered, and a modeling expert who can insure adherence to currently accepted methodologies, given that the field is rapidly changing.

The third necessary approach is to conduct field surveys at priority areas identified by the screening criteria. Surveys require land access permission and must be conducted following USFWS-permitting requirements and survey guidelines (USFWS 2015, 2017). Surveys and field research studies on NMMJM can impose a risk to the species and to the specialized habitat upon which populations depend. The NMMJM is restricted to a small number of isolated populations that may consist of a relatively small number of individuals. Non-invasive detection methods for this species are being developed, but they have not been fully tested and vetted for survey purposes (see Section 3.5 and Appendix B-2). Consequently, surveys depend on investigators capturing and handling animals. Surveys conducted by investigators with a high level of training and experience will likely have reduced risk of injury or death to animals, reduced damage to habitat, and higher detection rates (Frey 2013b, Perkins-Taylor and Frey 2016). Consequently, a NMMJM survey training class was developed in partnership between the USFWS and NMDGF (Frey 2015b) to provide permittees with specific knowledge necessary to increase capture rates, prevent injury to NMMJM and their habitat, and to prevent false negative or false positive results while following the Service's survey guidelines.

Priority Ranking

This study is considered a *Level 1* priority (Table 8) because accurate information about distribution is essential for management and recovery, and because this information is necessary to inform studies on the other critical uncertainties.

CRITICAL SCIENTIFIC UNCERTAINTY #2: GENETICS

Study Question: What is the genetic variation within NMMJM populations, and between NMMJM populations?

Scientific Relevance

NEW MEXICO MEADOW JUMPING MOUSE GENETIC VARIATION

SCIENTIFIC RELEVANCE

The only known population of NMMJM in the MRG occurs at the BdANWR. This population is thought to be highly isolated and to consist of only a few individuals. Consequently, inbreeding could cause genetic abnormalities that reduce population fitness and contribute to population declines. In addition, preliminary morphological and genetic information suggest that NMMJM in the MRG may be different compared to other populations in New Mexico.

Genetic studies have primarily focused on the relationship of the endemic southwestern form, *Z. luteus*, to other forms of jumping mice (*Zapus* spp.). The taxon has a confusing taxonomic history, first described as a distinct species (*Z. luteus*; Miller 1911), then allocated as a subspecies of the western jumping mouse (*Z. princeps*; Krutzsch 1954), and then allocated as a subspecies of the meadow jumping mouse (*Zapus hudsonius*; Hafner et al. 1981). However, more recent molecular data have reaffirmed that *Z. luteus* is a distinct species, which also includes the Great Plains form, *Z. l. pallidus* (King et al. 2006; Malaney et al. 2012, 2017; Malaney and Cook 2013). However, because these studies were focused on evolutionary relationships at higher levels, they do not provide much information about genetic composition of populations within the southwestern form, *Z. l. luteus*, which occurs in the MRG.

Thus far, Malaney et al. (2012) is the only study to evaluate genetic relatedness among populations of NMMJM. They evaluated two mtDNA genes (maternally inherited) of 96 NMMJM (historical and recent specimens) representing six geographic regions. There were 16 historical specimens from the MRG: Isleta (n=2), Casa Colorada (n=1), and BdANWR (n=13). All specimens from the MRG shared the same haplotype, which was not documented in other populations of NMMJM. In contrast, two specimens from the upper Rio Grande (Ohkay Owingeh Pueblo, lower Rio Chama near La Chuachia) had a haplotype that was found in all specimens from the Jemez Mountains and was also found in some specimens from the Sacramento Mountains. Overall, there was little deviation in genetic structure, with mice from the White Mountains, Arizona, exhibiting the greatest divergence from other populations. However, NMMJM from the MRG formed a cluster that was separate from other specimens in Colorado and New Mexico. Results also demonstrated a lack of gene flow among populations, indicating isolation. Thus, results suggest at least some level of genetic uniqueness of the MRG population. This is supported by the fact that specimens from the MRG have been described as a distinct subspecies, *Z. l. australis*, although this name usually has been synonymized into *Z. l. luteus* (Bailey 1913).

To summarize, the current state of knowledge about genetics of the NMMJM is limited, but can be summarized as follows: 1) the taxon "*luteus*", which was formerly regarded as a subspecies of *Zapus hudsonius* (meadow jumping mouse), is a distinct species *Zapus luteus* (yellow jumping mouse), which includes the central Great Plains form "*pallidus*"; 2) the form of jumping mouse found in the MRG is *Zapus luteus luteus* (New Mexico yellow jumping mouse); 3) there is little genetic structure within *Zapus l. luteus*, 4) specimens from the MRG share unique genetic characteristics not found in other populations of *Z. l. luteus*. Currently, there is little population genetic information for the jumping mouse, such as estimates of inbreeding and gene flow. In addition, the methods that have been applied thus far (single locus mtDNA) lack refinement that may better elucidate important genetic characteristics of populations.

Management Application

NEW MEXICO MEADOW JUMPING MOUSE GENETIC VARIATION MANAGEMENT APPLICATION

Information on the genetic health of the population of NMMJM at the BdANWR is necessary to inform need for active management to reduce any inbreeding that might be contributing to decline of this population. Such management would require genetic knowledge of appropriate source populations for infusing new genetic variation into the BdANWR population.

Malaney et al. (2012) concluded that although there was minimal divergence among contemporary populations of the NMMJM, isolated populations possessed unique genetic signatures that warrant preservation. Malaney et al. (2012) recommended that NMMJM management should seek to bolster populations to prevent loss of existing genetic variation. Further, they cautioned that any repatriation effort would need better genetic information to ensure the genetic integrity of populations. They warned that attempts to infuse genetic variation into inbred populations might result in an artificial admixture of genes that could erase or alter unique evolutionary trajectories. Consequently, they recommended that additional studies be conducted using independent markers of the nuclear genome to better resolve genetic relatedness among populations. They also stressed that conservation should preferentially focus on expanding remnant populations via restoration of habitats, with repatriation considered as a secondary measure.

Recovery Application

NEW MEXICO MEADOW JUMPING MOUSE GENETIC VARIATION RECOVERY APPLICATION

The only population of NMMJM currently known in the MRG is at the BdANWR and this population is considered small and declining. Genetic inbreeding due to the relatively small, isolated nature of this population could be contributing to this decline, but genetic status of the population is poorly understood. Genetic data are needed to understand the degree to which inbreeding might be compromising the population and to inform management actions that could increase resiliency of this population. Increased resiliency would improve representation.

The only population of NMMJM known to currently exist in the MRG is at the BdANWR, and this population has declined since the 1980s and is currently very small (ca 25 individuals; Wright and Frey 2015; unpublished data) and consequently at high risk of extinction. This is particularly concerning given that populations in the MRG have unique genetic signatures not found in other regions. A major reason for this decline has been loss of the specialized habitat required by the species (Wright and Frey 2015). However, it is possible that other unrecognized factors have contributed to this decline as the current population does not seem to occupy all available habitat at the BdANWR (Wright and Frey 2015). One potential cause of population decline is genetic inbreeding depression, which can occur when populations are relatively small and isolated. Genetic inbreeding can cause a spectrum of deleterious problems to individuals (and hence populations), including reduced fecundity and death. Consequently, there is an urgent need to evaluate the genetic make-up of the BdANWR population to evaluate potential influence of inbreeding on population declines.

The recovery outline (USFWS 2014c) concludes that the NMMJM currently lacks resiliency and redundancy and has relatively low representation. Extinction of the last known population of the NMMJM in the MRG (BdANWR) would be a serious event, especially given that it contains a unique genetic signature. Clearly, this would further reduce resiliency, redundancy, and representation further imperiling the taxon. Consequently, if studies demonstrate that the BdANWR population exhibits genetic inbreeding that may be contributing to the population's decline, then it will become an urgent necessity to "rescue" the population via infusion of new genetic material (Frankham 2015). Such efforts would be management intensive and could pose further risk to populations if not done appropriately. Decisions about source populations must be based on high-quality, fine-resolution data about genetic relatedness among populations. In addition, given that the sole population in the MRG is precariously small, it could be determined that recovery will require captive breeding and repatriation. Genetic studies would be necessary to identify potential source populations for possible future translocations or captive-breeding programs. Such efforts would also require information on patterns of genetic variation within and among populations.

Study Plan Considerations

Although the goal of this study is to understand the extent of inbreeding depression in the BdANWR population (or any other populations of NMMJM that might be discovered in the MRG in the future) and to evaluate relationship of the MRG populations with others, this question should ideally be addressed within the context of all populations of the jumping mouse to understand range-wide patterns of variation. Study methods should focus on multiple loci, particularly within the nuclear genome (e.g., single nucleotide polymorphisms; whole genome sequencing), to provide fine-grained information, including: bottlenecking and loss of diversity (such as through inbreeding), gene flow, signals of selection, changes in allele frequencies through time and space (landscape genomics), relative divergence, and relatedness with other populations. One difficulty with implementing this study may be obtaining adequate samples for analysis, both in terms of populations and numbers of individuals per population. Whole genome sequencing methods provide more information from smaller numbers of samples per population. For many populations, the only samples are historical museum specimens. Further, surveys have not been conducted to identify all current NMMJM populations. Since the only population of NMMJM currently known to occur in the MRG (BdANWR) is considered very small, it might not be prudent to trap individuals to obtain tissue samples; benefits should be weighed against the risk of injury or death of individuals because of trapping. Any such trapping should be conducted with care in accordance with USFWS permitting requirements and survey guidelines, to help prevent any trapping injuries or deaths.

Priority Ranking

Addressing this critical uncertainty is considered a *Level 1* priority (Table 8) as the sole known population of the NMMJM in the MRG continues to decline and is at high risk of extinction due to relatively small size and isolation (Wright and Frey 2015). The technical workshop participants considered this study to have the highest urgency as results could be instrumental in preventing extinction of the BdANWR population. Although additional samples gained from distribution surveys would benefit a genetic study, the panel determined that a genetic study focused on the health of the BdANWR population was so important that it was determined that a genetic survey should not be delayed while surveys occur.

CRITICAL SCIENTIFIC UNCERTAINTY #3: NON-INVASIVE SURVEY METHODS

Study Question: How do non-invasive survey methods compare to trapping?

Scientific Relevance

> **NON-INVASIVE SURVEY METHODS**
>
> **SCIENTIFIC RELEVANCE**
>
> Current USFWS survey guidelines are based on invasive trapping methods that can pose risk to populations and their habitat (USFWS 2015; Frey 2013b). Other commonly employed field methods to study small mammals (e.g., radio-telemetry) are also considered highly invasive. Many populations of NMMJM, including the only currently known population in the MRG, are likely currently too small to warrant use of invasive methods. Thus, there is an urgent need for effective non-invasive methods that can be used to survey for NMMJM and address other research on the critical uncertainties. Two non-invasive detection methods are currently being developed in research contexts, including track plates (Chambers 2017) and remote cameras (Lehnen et al. 2017), while other methods are also possible (e.g., eDNA).

Surveys and many other types of research require that the target species be detected at a specific location. Numerous methods have been used to detect species of jumping mice (Zapus spp.), including several types of spring-operated kill traps (e.g., Morrison 1990), several types of box live traps (e.g., Anthony et al. 2005), several types of pitfalls (e.g., Handley and Kalko 1993), several types of funnel traps (e.g., Kaufman and Kaufman 2010), track plates (e.g., Wiewel et al. 2007), remote cameras (e.g., Buckner 1964), and far-infrared thermal imaging (Boonstra et al. 1994). However, a distinction must be made between detection methods and survey methods. Ability to detect the target species is not the only component of a valid survey. Survey methods also must consider detection rates, detection biases (e.g., age, sex, species, time of year), trap malfunction rates, potential harm to animals or their habitat, efficiency, and expense. In addition, valid survey methods must reduce errors when interpreting results. There are two possible sources of error. A false positive result (type I error) occurs when an animal is misidentified as the target species, which is more likely to occur when using non-invasive methods and in areas with morphologically similar species (Frey 2017). A false negative result (type II error) is a potentially more serious outcome (and a potentially more common outcome) and occurs when a survey fails to detect the target species when it is present (Frey 2013b, 2015, 2017). Both situations can lead to inappropriate management actions that can result in risk to populations.

The current USFWS survey guidelines for the NMMJM (Frey 2013b, 2015; USFWS 2015) provide specific information, requirements, and steps that should be taken during surveys to increase detection rates, prevent harm to animals or their habitat, and minimize error. However, these survey guidelines are based on capturing animals alive in Sherman live traps. Sherman live traps revolutionized the field of mammalogy as they provide an efficient and effective means of sampling small mammals alive. Sherman live traps are the most common method of live capturing small mammals, and their use in research and for surveys has been widely tested and compared with other methods. When deployed correctly, Sherman live traps are a reliable means of surveying for the NMMJM (e.g., Frey 2013b, 2015, 2017; USFWS 2015). However, use of Sherman live traps is not without risk to populations of NMMJM. Surveys require setting large numbers of traps over multiple nights and handling animals. These invasive survey activities can pose a direct threat to populations: animals can be stressed, injured, or killed because of trapping or handling; and small patches of microhabitat that serve as critical resources to a population can be trampled and temporarily eliminated by the activities of the researchers. Although the protocols for conducting surveys provide methods for reducing these threats, live trapping still presents a threat to the NMMJM populations. Where populations are very small and isolated, such as in the BdANWR (where the sole remaining population of the NMMJM in the MRG is known to exist), trapping may be deemed inappropriate as the risk of death or injury of even one animal may be considered too great. Consequently, there is need to develop valid survey methods using alternative non-invasive detection methods.

Currently, two methods for non-invasively detecting the NMMJM are being developed in research contexts: remote cameras (Lehnen et al. 2017) and track plates (Chambers 2017, Harrow et al. 2016). The remote camera method is being developed at the BdANWR and involves placement of motion-activated cameras mounted on specially designed frames without bait (Lehnen et al. 2017). The track plate method is being developed in montane areas and involves placement of track plates (self-adhesive paper with associated ink-saturated pad) in a shelter (plastic shoe box) with bait (Harrow et al. 2016). Pros and cons of these detection methods were reviewed by Mills et al. (2016). Advantages of remote cameras include long deployment periods (e.g., 20 nights or more), readily interpretable physical evidence (photographs of animals), data on age and reproductive status, potential for use with marked animals, and collection of data on other species; disadvantages include cost of equipment and labor required for reviewing and archiving photographs. Advantages of track plates include relatively low cost, ease of deployment, and rapid preliminary results; disadvantages include need to check track plates frequently (which can damage habitat via trampling), inability to distinguish tracks from other species of jumping mice, and less interpretable physical evidence (need comparative data on other species and statistical algorithms to verify track identity). A study comparing cameras and track plates for detecting other species of small mammals have produced similar results (Mills et al. 2016). Thus, both detection methods show promise for use in research and development as valid non-invasive survey methods for NMMJM.

The track-plate detection method is being used in an occupancy model research framework alongside conventional Sherman traps (Chambers 2016), which will allow for some direct comparisons of detection methods. Preliminary results indicate the methods have similar ability to detect the NMMJM under the controlled research study design (Chambers 2016). However, due to the research objectives, the manner of trap placement in the controlled research study design differs from manner of deployment of traps in the USFWS survey guidelines for the NMMJM (Frey 2013b, USFWS 2015). It is unknown how well track plates will be adaptable for use by other researchers in non-research settings for presence/absence surveys. Track plates potentially offer a basis for developing non-invasive survey methods for NMMJM, except in the zone of sympatry between the NMMJM and the western jumping mouse (i.e., northern New Mexico and southern Colorado). Research using remote cameras has been hampered by the relatively small size of the population of NMMJM found at the BdANWR, which limits statistical strength. Testing the method in other areas in needed with higher densities of NMMJM. However, preliminary results indicate relatively good detection rates and higher efficiency of detecting NMMJM in comparison with conventional Sherman trapping. The ability to monitor sites for presence of low density population of NMMJM in small patches of habitat over an extended time period using camera traps is a clear advantage. In addition, photographs can provide unambiguous physical evidence of the species' presence. Although both track plates and remote cameras have proven to be effective non-invasive methods for detecting NMMJM, additional research is necessary to evaluate use of these detection methods for conducting valid surveys, including detection rates, detection biases (e.g., age, sex, species, time of year), trap malfunction, potential harm to animals or their habitat, efficiency, expense, and the potential for false-positive or false-negative results. Further, remote cameras and track plates are not the only potential non-invasive detection methods that could be used for surveys. Other possibilities include eDNA and DNA collected from hair snares or fecal pellets.

Management Application

NON-INVASIVE SURVEY METHODS

MANAGEMENT APPLICATION

Development of effective non-invasive methods would allow for surveys and research studies on NMMJM that could potentially eliminate many of the risks posed by traditional invasive *survey* methods.

Many populations of the NMMJM, including the sole currently known population in the MRG (BdANWR), may be too small and isolated to warrant use of invasive methods to study the populations due to the serious risk imposed by live-trapping methods. However, because there have been so few surveys for the NMMJM in the MRG and relatively little research on the natural history of the NMMJM, there is a need to study the taxon to inform management. Consequently, development of an array of different non-invasive methods could allow for surveys and research, while minimizing risk to NMMJM populations.

Recovery Application

NON-INVASIVE SURVEY METHODS RECOVERY APPLICATION
Development of recovery plans requires research to address critical scientific uncertainties. However, conducting this research may not be prudent on many populations, including the sole known population in the MRG (BdANWR), because available methods are invasive and can pose a threat to population persistence. Development of non-invasive methods would allow for surveys and research to be conducted with reduced risk to existing populations.

Given the recency of the listing for the NMMJM, no recovery plan has been developed. Development of a scientifically defensible recovery plan will require research that addresses critical scientific uncertainties. For instance, the recovery outline (USFWS 2014c) concluded that conservation management will require research on critical aspects of NMMJM life history (e.g., reproduction, abundance, survival, and movement behavior), and to determine the ideal spatial configuration of restored suitable habitat along linear waterways, such as canals or streams. However, conducting this research may not be prudent on many populations, including the sole currently known population in the MRG (BdANWR), as available methods are invasive and likely pose a significant threat to population persistence. Consequently, development of non-invasive methods may provide the only avenue to obtain needed information to address the critical uncertainties necessary to manage and recover the species (Figure 12).

Study Plan Considerations

Because the current survey guidelines are based on live-trapping, a study to develop survey methods based on non-invasive detection methods should ideally directly compare the non-invasive method with accepted live-trapping methods. Such comparisons should include detection rate, effort required to document NMMJM at a site if present; biological (e.g., non-target species, competitors, predators), environmental (e.g., habitat quality), and surveyor factors (e.g., expertise) that influence detection; and flexibility and efficacy of the methodology for different situations. A distinction should be made between non-invasive detection methods (i.e., methods that detect the target species) and valid non-invasive survey methods (i.e., a complete program for documenting presence/absence of the target species at survey sites). Survey methods should evaluate sources of bias as well as false-positive and false-negative errors. Ideally, non-invasive methods should be developed and tested in multiple populations representing an array of situations. Thus, most studies will require multiple years of surveys. The only population of NMMJM currently known to occur in the MRG (BdANWR) is considered very small. It is likely not prudent to use invasive methods (trapping) to study this population given its relatively small size and elevated risk of extinction. Therefore, in most instances, non-invasive methods should be compared with conventional trapping methods in other populations that are comparatively large and have relatively lower threats.

Priority Ranking

Addressing this critical uncertainty is considered a *Level 2* priority (Table 8) as the sole known population of NMMJM in the MRG is realtively small and use of invasive methods to survey and study this population is likely inappropriate in most instances due to the risk these methods pose to NMMJM and their habitat. However, additional studies are needed to inform management and recovery actions.

CRITICAL SCIENTIFIC UNCERTAINTY #4: MIDDLE RIO GRANDE POPULATION HABITAT ATTRIBUTES

Study Question: What are the attributes for foraging, day nesting, maternal nesting, and hibernation habitats in the MRG?

Scientific Relevance

MIDDLE RIO GRANDE HABITAT ATTRIBUTES

SCIENTIFIC RELEVANCE

Information on habitat selection by the NMMJM in the MRG is limited to a single study based on a small number of individuals at the BdANWR, and which focused on foraging habitat. Information on habitat associations from other areas of the MRG or similar low elevation sites on managed high order rivers, are non-existent or anecdotal.

Most information about habitat use and selection (i.e., habitat selection is use versus availability, which is considered a more robust metric than simple use) for the NMMJM is derived from montane populations that occur on smaller headwater streams (e.g., Morrison 1992, Frey and Malaney 2009, Frey 2017). In contrast, populations that occur in the MRG are associated with the floodplain of a highly managed large order river at low elevation that has different vegetation types. Therefore, some information about habitat learned from research at high elevation montane sites may not be directly applicable to the MRG. Yet, detailed information about habitat use is vital to informing management and recovery efforts.

The NMMJM uses different habitats for different aspects of its life history (summarized in Frey 2017). The NMMJM hibernates during about nine months of the year, during which time it uses underground burrows in drier areas with more woody cover (Wright and Frey 2010, 2015; Frey 2015a). During its brief summer active season, it uses herbaceous riparian wetland vegetation for its nightly activity, which primarily consists of foraging (but may also include other activities, such as breeding and exploration; hereafter, termed ‘‘foraging habitat’’). Availability of foraging habitat is considered the primary limiting factor that determines occurrence of the NMMJM (Frey and Malaney 2009; Wright and Frey 2015, Frey 2017). During the day, the NMMJM uses open grassy areas where it constructs aboveground nests where it sleeps. Finally, females rearing young use underground burrows in drier areas with more woody cover, similar to locations used for hibernation (Wright and Frey 2015).

Few published papers have evaluated habitat use or selection by the NMMJM (reviewed in Frey 2017). All but one focused on montane populations. Morrison (1990) described habitat at sites where she caught the NMMJM in New Mexico (data were combined from montane and low elevation sites). Her results described the general conditions of survey sites, but not specific habitats selected by NMMJM at those sites. Further, her study was descriptive in that most variables were qualitative and there was no comparison of used versus unused sites. Occupied sites were in riparian zones (including irrigation canals) or wet meadows and were composed of diverse plant communities dominated by grasses and forbs. Based on qualitative observations, occupied sites had moist soil and ground covered by dense (0.5-m high) vegetation. Traps that captured NMMJM were located near water. Although Morrison (1990) captured NMMJM at sites where livestock grazing was occurring, she concluded that livestock grazing was the greatest threat to the species habitat.

Frey and Malaney (2009) surveyed for the NMMJM at historical locations and new sites with potentially suitable habitat in the Jemez Mountains and Sacramento Mountains, New Mexico. They compared quantitative microhabitat features at sites where NMMJM were captured versus sites where they were not captured. They found that capture locations were typified by saturated soil dominated by sedges and forbs with significantly higher vertical cover and stubble height in comparison with non-capture locations. Frey and Malaney (2009) concluded that livestock grazing was the primary cause of habitat and population loss.

Frey (2017) surveyed for the NMMJM at historical locations and new sites with potentially suitable habitat in the White Mountains, Arizona. She compared quantitative habitat features, at both a landscape and microhabitat scale, by comparing capture versus non-capture sites. She found that habitat use in the White Mountains was similar to that reported for other montane populations by Frey and Malaney (2009), characterized by tall, dense herbaceous vegetation composed primarily of forbs and sedges on saturated soil in close proximity to flowing water. However, there was significantly more cover provided by alders (*Alnus* spp.) at capture sites at both the stream reach and microhabitat scales. NMMJM were more likely to occur at sites where there were no signs of unauthorized livestock grazing. Further, there was a significant positive relationship between alder cover and time since an area was excluded from livestock grazing.

In the MRG, three studies have reported habitat associations of the NMMJM. In an unpublished report, Morrison (1988) reported habitat characteristics at capture locations during surveys in four regions in the Rio Grande watershed. Results from this report were also summarized in Morrison (1992). Her report described habitat conditions and provided lists of plant species observed at capture sites. She concluded that NMMJM require a specific combination of conditions, including: close to perennial flowing water; diverse plant composition consisting primarily of grasses, forbs, and willow; tall, dense cover; and close proximity to higher dry ground (i.e., for use in nesting and hibernation). She found these conditions along irrigation channels and in wet meadows that also contained ponds or cattail marshes (although ponds and cattail marshes are not themselves considered habitat). In the southern part of the MRG (Belen and BdANWR), all captures were associated with irrigation channels that occasionally overbanked, providing moist soil and lush vegetation. NMMJM were not found in areas with standing, stagnant water and soggy soils. NMMJM also were not found along irrigation channels that had been recently dredged or cleaned. In the northern part of the MRG, captures were associated with large, wet meadow complexes that were occasionally flooded and which often contained ponds and marshes (NMMJM were not captured in the marshes with standing water). Plant species common to all sites where NMMJM were captured included willow, Baltic rush (*Juncus balticus*), bulrush, spikerush (*Eleocharis* spp.), bluegrass (*Poa* spp.), saltgrass (*Distichlis spicata*), foxtail barley (*Hordeum jubatum*), and wild licorice (*Glycyrrhiza lepidota*).

Zwank et al. (1997; also reported in Najera 1994 and Najera et al. 1994) surveyed for NMMJM at the BdANWR and reported general habitat types at capture locations. They caught NMMJM in all habitat types sampled: irrigation channels (51%), wetland impoundments (37%), a woodland (i.e., a "wooded slough"; 11%), and cropland (i.e., a "clover field"; 1%). The capture location in the clover field was near (less than 30 m) a canal that provided typical habitat and was occupied by NMMJM. There was seasonal variation in frequency of habitat use. The highest capture rates occurred in wetland impoundments in spring, along irrigation channels in summer, and in a woodland in fall. Capture locations had relatively high soil moisture and understory and mid-story vegetation.

To date, the most comprehensive study of habitat relations of the NMMJM occurred at the BdANWR (Wright and Frey 2015; also reported in Wright 2012 and Frey and Wright 2012). Wright and Frey (2015) analyzed habitat selection (i.e., use versus availability) at three spatial scales by radio-collared NMMJM at BdANWR. NMMJM used different habitats for different aspects of their life history. At the landscape scale, NMMJM selected canals, water, Foxtail Barley Herbaceous Temporarily Flooded association, and Narrowleaf Willow Mesic Graminoids Shrubland association. At the macrohabitat scale, NMMJM selected canals and Foxtail Barley Herbaceous Temporarily Flooded association. At the microhabitat scale, active NMMJM selected areas that were near water and contained moist soil, dense herbaceous canopy cover, dogbane (*Apocynum cannabinum*), foxtail barley, and common threesquare (*Schoenoplectus pungens*); active NMMJM avoided habitats represented by eight plant species, including Rio Grande cottonwood (*Populus deltoides wislizeni*), plains bristlegrass (*Setaria vulpiseta*), alkali sacaton (*Sporobolus airoides*), saltgrass, mule-fat (*Baccharis salicifolia*), spikerush, kochia (*Bassia scoparia*), saltcedar (*Tamarix ramosissima*). They concluded that NMMJM can only occur where there is an overlap of the required habitats at all three scales and that this is a key limiting factor for the NMMJM. Following emergence from hibernation, NMMJM used both managed wetlands and canal banks, but during the summer NMMJM almost exclusively used canal banks and other habitats associated with flowing water or temporarily flooded habitats. Day nests were usually in open saltgrass meadows on moist soil, near water, and in tall herbaceous vegetation with little woody canopy cover. Maternity nests and a hibernation nest were in burrows under shade provided by the canopies of trees and shrubs and usually were located in areas devoid of dense green vegetation, and under fallen sticks and limbs of willow, cottonwood, and screwbean mesquite (*Prosopis glandulosa*).

To summarize, the current state of knowledge about habitat associations of the NMMJM in the MRG is limited. Most studies have been conducted on montane populations. Only one study (Wright and Frey 2015) rigorously analyzed habitat selection on basis of quantitative data collected at three spatial scales. However, that study was conducted on one population (BdANWR) composed of few individuals. Consequently, sample sizes were small and the range of variation in available habitats was limited. Very little information is available about habitats associated with maternal nests and hibernation sites.

Management actions by agencies to improve habitat for NMMJM have been conducted based on best available information (see Appendix B-2 *MRG Past and Current Management Activities*), but no research has been conducted to determine the efficacy of habitat restoration strategies for increasing occupied habitat.

Management Application

MIDDLE RIO GRANDE HABITAT ATTRIBUTES

MANAGEMENT APPLICATION

Knowledge about habitats used by the NMMJM is necessary to identify and safeguard potentially occupied sites. Conversely, knowledge about habitats that are not used by the NMMJMcan prevent needless expenditure of resources.

Knowledge about habitat associations is essential for informing management activities, particularly any activities that occur on the ground. Knowledge about habitats associated with the NMMJM is necessary to identify and safeguard habitats of potentially occupied sites or dispersal corridors. For instance, water manipulation and canal maintenance can either enhance or degrade microhabitat, depending on timing and location. Further, because the NMMJM requires early seral vegetation, some disturbance might be necessary to develop or maintain suitable habitat. Yet, degradation of habitat might occur in the short-term due to this disturbance or due to long-term suppression of appropriate disturbance. Riparian restoration treatments, whether specifically to aid the NMMJM or for other purposes, should be developed based on accurate habitat information. This is especially important because the NMMJM uses different habitat types for different aspects of its life history. Conversely, knowledge about habitats that are not used by the NMMJM can prevent needless expenditure of resources that might otherwise be required to conduct surveys or develop mitigation measures.

The 2015 Joint BA stated that USBR will use the Frey and Kopp (2014) report as a guide for areas to investigate for suitable NMMJM habitat through field checks. USBR recognized that due to imprecision of the Frey and Kopp (2014) model, suitable habitat may exist in other areas within the MRG. However, USBR (USBR 2015: II-53) cited USFWS 2014c (USFWS 2014b in this report) in concluding that "these areas often lack sufficient patch size and habitat connectivity needed to allow for dispersal of individual mice to new areas [and consequently these] locations would likely be unoccupied." However, this conclusion misconstrues information and is questionable given that some populations of NMMJM have persisted in extremely small and highly isolated habitat patches as small as 0.3 ha (Cox Canyon; USFWS 2016a). USBR stated that areas would be evaluated for NMMJM habitat on a project and location specific basis. Given that all information about habitat selection in the MRG was collected based on a small number of individuals in a small study area with a limited range of habitats, it is essential that additional habitat studies are conducted so that potentially occupied habitat patches can be correctly identified in order to prevent harm to undocumented populations. Small habitat patches should not be dismissed as potentially occupied by NMMJM.

Recovery Application

MIDDLE RIO GRANDE HABITAT ATTRIBUTES

RECOVERY APPLICATION

The recovery outline considers the NMMJM to currently lack resiliency and redundancy and to have low representation. Availability of suitable habitat is a requirement for existence of a population. Information on habitat associations will help prevent curtailment of habitat and will allow for protection and restoration of suitable habitat to increase resiliency, redundancy, and representation.

No recovery plan has been approved for the NMMJM. However, a recovery outline (USFWS 2014c) concludes that the NMMJM currently lacks resiliency and redundancy and has comparatively low representation. It attributed the loss of populations across the range of the taxon to cumulative habitat loss and fragmentation. According to the recovery outline, "recovery efforts should preferentially focus on restoring habitats and increasing the connectivity among suitable areas. The expansion of all remaining populations is an immediate and long-term need for the NMMJM" (USFWS 2014c:8).

The recovery outlined considered that a resilient population (i.e., those of adequate size and ability to endure adverse events) would require at least about 27.5 - 73.2 ha of suitable habitat along 9.0 - 24 km of flowing streams, ditches, or canals. However, given the limited amount of information about habitat use by the NMMJM in the MRG or similar ecological setting, it is difficult to identify such areas or to inform restoration of requisite habitat. The recovery outline determined that there must be at least two resilient populations within each of eight identified geographic conservation areas. For comparison, the current habitat occupied by the NMMJM at BdANWR is less than 2.7 km (Wright and Frey 2015). Thus, additional habitat would need to be restored, but this must be informed by information regarding the species' relationship with a range of conditions. The recovery outline stated that research is specifically needed to determine the appropriate spatial arrangement of habitat, and what size (if any) of gaps in habitat can still foster population persistence and connectivity. Research is needed to understand core habitats that support source populations and whether other habitats can serve as corridors without become sinks of ecological traps.

Study Plan Considerations

Studies designed to better understand the habitat relations of the NMMJM should be field based and should be conducted on populations within the MRG. Such field studies would likely need to occur over multiple years and include several MRG reaches to better understand the range of variation in use of habitat attributes. Habitat selection studies are usually done using telemetry to obtain fine-scale information on habitats selected by animals for different aspects of their life history. However, the only currently known population of NMMJM in the MRG (BdANWR) is considered very small. It is questionable that adequate sample sizes could be obtained by studying this population at this time. In addition, it is likely not prudent to use invasive methods (trapping; telemetry) to study this population given its small size and high risk of extinction. Telemetry studies are considered particularly hazardous to small populations of NMMJM due to the relatively high potential that animals fitted with a radio collar will have reduced survival as a result. If the BdANWR population remains considered too small to safely conduct a telemetry study, or if no other populations of NMMJM are found within the MRG, then information gained from other select populations outside the MRG might provide some relevant information that can be applied to the MRG. However, such populations should be selected with care and should be located on a floodplain of a large-order river in a non-montane, low elevation location, especially where the hydrology of the valley floor has been altered by irrigation works. However, studies conducted in other non-montane, low elevation locations that are not irrigated may also provide useful information about habitat use. Further, methods based on non-invasive detection methods should be explored as a means for studying habitat use at BdANWR.

Several study designs are available to evaluate habitat requirements. The simplest approach is description of habitat features at locations where the species is detected. However, a superior method is evaluation of used sites versus available sites as a resources selection function (Manly et al. 2002). Resource selection studies are recommended because they can determine the relative importance of habitat features (either selected or avoided by the species) and habitat selection can be evaluated at different scales (e.g., within geographic range, within home range). Habitat is usually investigated on basis of animal occurrences. Ideally, these occurrences should be corrected for detection probability to reduce sample bias. Critical independent variables should include those that have been found to be important for NMMJM in prior studies, including soil moisture; herbaceous layer composition, density and height; shrub layer composition, density and height; tree canopy cover, woody debris, soil type, hydrology, and vegetation type. However, other variables also might be appropriate.

Priority Ranking

Addressing this critical uncertainty is considered a *Level 3* priority (Table 8). Information on habitat associations is vital for managing and recovering species. However, the main reason this critical uncertainty ranks as a lower priority is because some information on selection of foraging habitat already exists for the MRG (BdANWR), as well as for montane populations. However, the existing data for the MRG represents a single study site of a small population and hence may not represent the range of variation that the species may occupy. In addition, there is relatively little information, range-wide, about selection for other habitat components, including day nests, maternal nests, hibernation burrows, and travel corridors.

CRITICAL SCIENTIFIC UNCERTAINTY #5: POPULATION DYNAMICS

Study Question: What are the population dynamics for NMMJM?

Scientific Relevance

NEW MEXICO MEADOW JUMPING MOUSE POPULATION DYNAMICS SCIENTIFIC RELEVANCE

There is very little information on population dynamics of the NMMJM. Existing data are limited to basic information about timing of emergence/immergence from hibernation by sex and basic information about timing of reproduction and litter size. No data exist on key population vital rates, such as survival, fecundity, and immigration/emigration.

Very little is known about population-level characteristics of the NMMJM. Thus far, research has only addressed timing of seasonal life history activities, home range and movements, and limited information on reproduction. However, those data are based on relatively small sample sizes. No data exist on important population vital rates (survival, fecundity, immigration, emigration), population structure (sex and age), densities, population viability, source-sink metapopulation dynamics, and others.

Frey (2015a) reviewed the annual seasonal population cycle of the NMMJM across its range. The NMMJM is a cold-adapted animal that hibernates during the winter (Wright and Frey 2010, 2015; Frey 2015a). Hibernation is considered a key life history feature that impacts many other crucial aspects of its biology, such as its survival and reproduction. Emergence from hibernation in the spring is thought to be cued by soil temperature, with males emerging prior to females (i.e., males emerge at a lower temperature than females). Consequently, timing of emergence varies depending on the geographic location of a population. Populations of NMMJM in the MRG, which are at the lowest elevation and consequently have the warmest temperatures, emerge from hibernation first, typically in mid-May, while high elevation montane populations may not begin to emerge until late June. Timing of emergence is also thought to vary by local habitat conditions and weather (e.g., late cold spells can cause populations to emerge later). Based on studies on other species of NMMJM, immergence into hibernation is thought to be cued by photoperiod and survival rates are generally higher during hibernation. Consequently, immergence occurs as soon as individuals are capable of it. In the NMMJM, there is no evidence of differences in timing of immergence between valley and montane populations, but older adults enter hibernation during early September, while young of the year do not enter hibernation until late October (hibernation in older males may start as early as August). Thus, taken together, NMMJM in the MRG have an active interval (earliest emergence to last immergence) of 162 days (Frey 2015a).

Based on studies on other species of NMMJM, they are thought to begin reproducing shortly after females emerge from hibernation, although only older females with higher mass might breed. In montane populations of NMMJM, where most data are available, pregnant females are known from July to late August and evidence suggests that they have a single litter per year (Frey 2015a). At BdANWR, two peaks in reproduction were expected based on similarity of active season compared to *Z. h.preblei*. However, only one peak was clearly evident, possibly due to later first reproduction and possible torpor during late summer. At BdANWR, pregnant females are known from June and July (Frey 2015a). Litter size averages 6.7 (range three to seven; J. Frey unpublished data).

The mean home range size of NMMJM at BdANWR, based on 20 radio collared individuals, was 1.37 ha (range = 0.02–4.15 ha) and there was a trend toward males having larger home ranges than females (Wright and Frey 2015).

Management Application

NEW MEXICO MEADOWN JUMPING MOUSE POPULATION DYNAMICS

MANAGEMENT APPLICATION

Lack of information about population dynamics increases uncertainty in predicting population viability and impacts of management or other actions on populations.

The management of wildlife populations is fundamentally based on knowledge of population attributes. For instance, survival rates that can maintain and increase populations may be linked to certain environmental conditions. Conversely, some environmental conditions could increase mortality rates, ultimately causing a population to decline. It is essential to be able to tie population attributes to habitats. For instance, it is conceivable that some restored and artificially created habitats could cause higher mortality rates, and hence a population decline, if these habitats lure animals into relatively risky environments.

Recovery Application

NEW MEXICO MEADOW JUMPING MOUSE POPULATION DYNAMICS

RECOVERY APPLICATION

Lack of information about population dynamics precludes ability to understand causes of population decline, which limits ability to devise recovery plans that can be assured of addressing factors that will result in resiliency.

No recovery plan has been approved for the NMMJM. However, the recovery outline (USFWS 2014c) concluded that the NMMJM currently lacks resiliency and redundancy and has low representation. Resilient populations are the cornerstone of recovery as redundancy and representation are based on resilient populations. Resilience is a population-level attributed that describes the ability to withstand annual environmental variation and stochastic events (Figure 12). At its most basic, an understanding of resiliency is based on population demographic attributes, especially when these are then tied to particular aspects of habitat such as size, configuration, and quality. Currently, a paucity of information about key demographic traits prevents ability to understand which populations are resilient and what management actions must be taken to increase resiliency for those populations that are not resilient.

Study Plan Considerations

Evidence suggests that there is considerable variation in key population attributes (e.g., emergence dates, number of possible litters) between populations of NMMJM in montane locations and the MRG (Frey 2015a). Thus, information about population demographics drawn from other species or montane populations of the NMMJM, may not apply to populations of the NMMJM in the MRG. Consequently, population demographic studies should be conducted on a population in the MRG. However, the only currently known population of NMMJM in the MRG (BdANWR) is very small and it is unlikely that adequate sample sizes could be obtained by studying this population. In addition, it is likely not prudent to use invasive methods (trapping) to study this population given its small size and high risk of extinction. Population demography studies must be long-term (multi-year) to understand the range of variation in environmental factors and how NMMJM respond to them. Estimating key vital rates, including natality, mortality, immigration, and emigration, likely requires regular capturing and marking of individuals although there have been recent advances in models based on unmarked animals which should be considered. Survival rates should be evaluated relative to season, sex, age, body condition, habitat composition, and other environmental factors. Of particular interest is the number and timing of litters based on age, body condition, emergence date, and environmental factors and overwinter survival as function of sex, age, body condition, emergence/immergence dates, and environmental factors.

Priority Ranking

Addressing critical uncertainty #5 population dynamics, is considered a *Level 4* priority (Table 8). Information on population dynamics is vital for managing and recovering species. However, the main reason this critical uncertainty ranks as a relatively low priority is because there exists very little basic information on the NMMJM and the only currently known population of NMMJM in the MRG (BdANWR) is likely too small to be the focus of a study on population dynamics, which must occur on large numbers of animals over many years. Therefore, currently, the other critical uncertainties rank higher in importance simply because they are more feasible to implement.

Table 8 summarizes the critical scientific uncertainties and recommended studies discussed in this report section.

Table 8. Summary of New Mexico meadow jumping mouse critical scientific uncertainties and recommended studies.

Uncertainty Statement /Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Priority
Where are MRG populations located?	• Few reliable surveys done • Essential for population identification and protection • Opportunity to research habitat selection and population dynamics, if a large, sustainable population is discovered	Field surveys: • Historical sites (where there is potential habitat) • Priority potential habitat Model development: • Inform screening criteria to map potential habitat at different scales • Prioritize field survey areas	Field studies: • Detection/non-detection with habitat data (soil moisture; herbaceous/shrub layer composition, density, height; tree canopy cover) Modeling: • Probability of occurrence • Relative occurrence rate • HSI	• Multi-year • All MRG reaches	• Access/landowner ship issues • Permitting requirements • Distribution and habitat difficult to model • Vegetation type and microhabitat dependent • Need information on spatial habitat requirements for modeling	Level 1
What is the genetic variation within and between populations?	Level of inbreeding due to: • Isolation • Small population size Relationships among persisting populations Necessary for reversal: • Inbreeding depression • Translocations • Captive-breeding program • Habitat restoration for population connectivity and gene flow	Genetic analysis: • Fine-grained evaluation of genetic health (inbreeding) • Estimate contemporary gene flow among populations • Estimate evolutionary divergence of populations	• Inbreeding • Gene flow • Divergence • Relatedness	Range-wide: • Population comparisons • Identify potential source populations for translocation/captive-breeding programs	• Difficult to obtain adequate sample sizes • Need surveys to identify all current populations • Invasive methods discouraged given small population size • Weigh risks/benefits of invasive methods	Level 1
How do *invasive survey methods* (trapping, telemetry) compare to *non-invasive methods* (e.g., models, remote cameras, track plates)?	Invasive: • Serious risk to the health of captured animals • Damage to sampled habitats • Some populations too small Non-invasive: • Develop reliable detection methods • Other uses (population trend monitoring and size estimation, habitat selection)	• Field surveys	• Detection rate • Effort required to document at a site if present • Biological (non-target species, competitors, predators), Environmental (habitat quality), and surveyor (expertise) factors that may influence detection • Sources of bias and error rages • Flexibility and efficacy of method	• Multi-year Non-invasive: • Develop different techniques • Different studies for each technique • Test in multiple populations • Represent array of situations	• The only currently known population in the MRG (BdANWR) is very small • Difficult to obtain adequate sample sizes • Invasive methods discouraged per small size and relatively high risk of extinction • Conduct in other, larger populations with lower threats	Level 2

Table 8. Summary of New Mexico meadow jumping mouse critical scientific uncertainties and recommended studies.

Uncertainty Statement /Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Priority
What are the attributes for foraging, day nesting, maternal nesting, and hibernation habitats in the MRG?	• Little studied • Current habitat selection info (use vs availability) based on a single study of radio-collared individuals at the BdANWR • Specific habitat uses and relations vary within and across ecotypes • Must fully understand habitat relations to understand threats, or develop conservation/mitigation measures	• Resource selection study design • Field study using telemetry • Explore non-invasive detection methods (e.g., combo of fine scale spatial models and using detections from remote cameras)	Dependent variable: • Occurrence: preferably as corrected by detection probability Independent variables: • Soil moisture, type • Herbaceous/shrub layer composition, density, height • Tree canopy cover, woody debris, hydrology, vegetation community	• Multi-year • Include several reaches • Different, discrete studies in each area to better understand the range of variation in habitat attributes	• Only currently known population in the MRG (BdANWR) is very small • Difficult to obtain adequate sample sizes • Invasive methods discouraged given small population, higher risk of extinction	Level 3
What are the population dynamics?	• No population dynamics studies done • Essential for determining population decline causal factors • Information from other species may not apply	• Long-term field monitoring of vital rates such as natality and mortality rates, im-/emigration • Regular capturing, individual marking; consider models based on unmarked animals	Survival rates based on: • Season, sex, age, body condition, habitat composition, environ factors Number/timing of litters based on: • Age, body condition, emergence date, environmental factors • Overwinter survival as function of sex, age, body condition, im-/emergence dates, environmental factors	• Long-term • Multi-year • MRG-focused • Large variation in key attributes (emergence dates, litter number) across ecotypes	• The only currently known population in the MRG (BdANWR) is very small • Difficult to obtain adequate sample sizes • Invasive methods discouraged given small population, higher risk of extinction	Level 4

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Appendix C-1: Southwestern Willow Flycatcher Workshop Summary Notes

MIDDLE RIO GRANDE ADAPTIVE MANAGEMENT FRAMEWORK
SOUTHWESTERN WILLOW FLYCATCHER
Technical Workshop

October 25, 2016
The Artichoke Café, Albuquerque, NM MEETING SUMMARY

Goals and Objectives *(from the agenda)*:

- Learn and discuss the state of the science for the SWFL.
- Develop a list of key *management-relevant* scientific uncertainties for each species in the MRG, and prioritize the group's top five.

1. Action Items and Next Steps

- ALL – Submit relevant SWFL and YBCU journal articles, agency reports and other relevant information to Debbie Lee at dlee@west-inc.com for inclusion in the project website: (https://webapps.usgs.gov/MRGESCP/Wiki/).
- GSA TEAM – Define and re-submit top five uncertainties to workshop attendees for additional review.
- GSA TEAM – Develop study plan frameworks to address top five uncertainties. Circulate draft study plan frameworks to workshop participants for review and comment prior to presenting to the Program AMT and EC.

2. Meeting Notes

Welcome and Introductions

Debbie Lee, WEST, opened the meeting by welcoming participants and inviting them to introduce themselves. Representatives from the following organizations were in attendance (a full attendee list is located at the end of this summary):

- Albuquerque-Bernalillo County Water Utility Authority (ABCWUA)
- Assessment Payers Association (APA)
- Bureau of Indian Affairs – Southwest Regional Office (BIA SWRO)
- City of Albuquerque Open Space Division (COA OSD)
- Middle Rio Grande Conservancy District (MRGCD)
- New Mexico Interstate Stream Commission (NMISC)
- Pueblo of Sandia
- Pueblo of Santa Ana
- US Army Corps of Engineers (USACE)
- US Bureau of Reclamation (USBR)
- US Fish and Wildlife Service (USFWS)
- US Forest Service – Rocky Mountain Research Station (USFS-RMRS)

Additionally, individuals from the GSA team (comprised of GSA, WEST, and Kearns & West) participated in the meeting.

Todd Caplan, the project manager from GSA, reviewed meeting goals and emphasized, by the end of each day of the workshop, the primary goal is to develop a list of five key *management-relevant* scientific uncertainties that will be used to craft study plan frameworks. GSA and the consultant team will work to refine these five uncertainties, vet them with workshop participants, and use them to develop study plan frameworks that will be reviewed by both workshop participants and the AMT before being submitted to the EC. These study plan frameworks will address key elements of a study plan needed to address monitoring and research questions for each species. The intent is that the Collaborative Program will utilize the study plan frameworks to solicit proposals and detailed study plans from the scientific community.

Ms. Lee reviewed the agenda and approach to the 2-day workshop noting that each day would begin with USBR SMEs presenting the current state of the science on the SWFL (Day #1) and the YBCU (Day #2), followed by discussion among workshop participants of key *management-relevant* scientific uncertainties.

Key Scientific Uncertainties

The following five key *management-relevant* scientific uncertainties for SWFL were identified by workshop participants as being of highest priority for future monitoring and research efforts along the MRG. Note that each key *management-relevant* scientific uncertainty is flushed out in more detail under Priority Scientific Uncertainties Discussion below. Additional uncertainties that were defined during the workshop are also captured below under Additional Scientific Uncertainties, Questions, and Suggestions for Further Study.

1. SWFL meta-population dynamics;
2. The impact of the saltcedar leaf beetle (*Diorhabda*) on SWFL habitat;
3. How best to identify and predict suitable SWFL habitat;
4. The criteria for prioritizing sites for habitat restoration; and
5. SWFL presence, population size, and population status along the Angostura Reach, particularly in Corrales and downstream of the Rio Bravo bridge.

3. *PRESENTATION*: Darrel Ahlers – Southwestern Willow Flycatcher

Darrell Ahlers, USBR, presented on the state of the science for the SWFL, focusing on the following six topics: 1) taxonomy and ESA listing; 2) description and identification; 3) survey methods; 4) breeding biology and life history; 5) habitat requirements; and 6) status, trends, and threats. The presentation is available online at https://webapps.usgs.gov/MRGESCP/Wiki/.

4. Southwestern Willow Flycatcher Discussion

Throughout Mr. Ahlers's presentation, workshop participants discussed the state of the science for SWFL in the MRG. This section summarizes the discussion by presentation topic.

<u>Taxonomy and ESA Listing</u>

Michael Scialdone, Pueblo of Sandia, asked if there is interbreeding between the *E. t. brewsteri* and *E. t. extimus* subspecies of willow flycatchers. Mr. Ahlers responded that there is interbreeding and, when interbreeding occurs, hybrids generally show more *E. t. brewsteri* characteristics.

Vicky Ryan, USFWS, reported that the USFWS is currently revisiting the validity of the subspecies classification with the SWFL by reanalyzing existing genetic samples (which were originally analyzed in 1995) and, perhaps, more recently collected samples. However, as verified by Greg Beatty, USFWS, via email correspondence during the workshop, the planned study was not funded, but might be conducted by a colleague at University of California, Los Angeles. Jean-Luc Cartron, Daniel B. Stevens & Associates (representing NMISC and ABCWUA as their SME), noted that historical genetics studies have yielded different genetics conclusions. Cathy Nishida, Pueblo of Santa Ana, agreed but noted that most studies showed willow flycatchers in the Southwest are genetically distinct and could be identified as a distinct population segment. A number of participants noted that several willow flycatcher subspecies are present along the MRG during migration and, thus, it is critical that samples for SWFL only be collected during the SWFL breeding season (it was suggested no earlier than June 10).

Yasmeen Najmi, MRGCD, asked if there are notable changes in SWFL migration patterns due to warmer spring weather, and Mr. Ahlers responded that variation in migration of a few weeks is normal, but not necessarily attributable to warming.

<u>Survey Methods</u>

In response to a question from Ms. Najmi about the extent previous years' siting data can be used to inform the current season, Mr. Ahlers noted that while site fidelity is considered high for SWFLs, they can and do move to new areas. Therefore, surveying previously-surveyed habitat for SWFLs is important, even if those areas had previously showed no evidence of breeding SWFL pairs. Ms. Ryan informed the group of USFWS weekly or bi-weekly survey updates released throughout the summer which can help inform project siting, and Hira Walker, GSA, added that development projects should consult with USFWS before breaking ground.

Mr. Ahlers noted that, for most survey areas, five surveys are performed. Ms. Ryan commented that survey protocol has been interpreted differently and that there is uncertainty as to whether all five surveys are needed if SWFLs are found during the first three surveys. Dr. Walker understood that to minimize harassment of birds, the protocol only required three surveys if SWFLs and breeding pairs were identified, but that five surveys were required to increase certainty in the absence of SWFLs if the first three did not document any SWFL presence. Mr. Ahlers stated that conducting the fourth and fifth surveys produced more accurate data on population numbers and breeding status. Mr. Ahlers also mentioned that a study on marginal survey value informed the survey protocol shift in 2012 from three to five surveys.

In response to a question from Dr. Cartron, Mr. Ahlers affirmed that SWFL are found throughout the MRG bosque during migration and that migrants and local breeders are distinguished from one another based on when they are present: individuals present in late June and July are considered breeding SWFLs. Mr. Ahlers also noted that no SWFL banding studies have been conducted along the MRG and that data on SWFLs within the MRG are primarily from detection surveys.

Mike Marcus, APA, asked if changes to survey protocol over time have introduced bias in SWFL data. Dr. Walker responded that changes in survey method are noted to qualify any SWFL trends over time, and survey data collected in 1995 are not directly comparable to survey data to data collected under the current standard survey protocol.

<u>Breeding Biology and Life History</u>
Mr. Ahlers noted that the earlier SWFLs fledge from the nest, the higher their likelihood of surviving.

When asked by Mr. Caplan about the degree to which observed site fidelity from banding studies from outside the MRG could be applied to within the region, Mr. Ahlers affirmed that he saw comparatively high site fidelity within the MRG as well, and can identify with 95% accuracy where the SWFLs will be in the MRG each breeding season. Dr. Walker observed that there are no banding data for the MRG and that data provided by banding studies would be valuable. Ms. Nishida indicated that SWFLs are not long-lived and are quick to occupy other SWFL's old habitat, increasing the cost of banding studies due to re-sightings. She noted the need to balance the cost of such studies with the results, adding that if funds are limited, studies focusing on site re-occupation and the characteristics that make those sites particularly attractive to SWFL breeding pairs may be more valuable. Ms. Ryan commented that, even without band data, the USFWS has information on SWFL breeding locations, and she posed the question: *Could information be gleaned from studying the Isleta population and nearby populations instead of banding?* Mr. Ahlers suggested that there are trade-offs when handling birds for banding studies, particularly stress to birds. He also stated that the USBR has amassed significant datasets on SWFLs, which could inform restoration siting. Dr. Walker reemphasized that banding data from the MRG would be valuable, providing such information as metapopulation dynamics individual movements, which is necessary to effectively site restoration efforts.

Ms. Najmi asked if the invasion of *Diorhabda*, the saltcedar beetle, imports value on the increased SWFL sightings in the northern MRG. Mr. Ahlers responded that it does, noting that extensive and contiguous surveys are important for the purpose of documenting new populations when previously occupied habitat has changed dramatically. Ms. Ryan commented that this movement in SWFL populations to more northerly habitats also corresponded with other actions within the BdANWR.

Dr. Walker brought up the topic of prey availability and the habitat conditions that support SWFL prey.

Some participants suggested that results of prey studies conducted outside of the MRG could be extrapolated to the MRG, while others question whether this was true. Dr. Marcus emphasized the need for food studies on restoration sites, and Dr. Cartron indicated that understanding prey dynamics is important and linked closely with hydrology. Dr. Walker expressed concern that managing for general habitat attributes is sufficient to guarantee a healthy prey base would not necessarily lead to increased SWFL population. Mr. Ahlers disagreed, stating the opinion that creating habitat for SWFL prey would lead to more breeding pairs establishing in the MRG.

Ms. Najmi commented that if SFWL breeding phenology is trending earlier, this trend will impact the timing of restoration and other projects in the MRG. Ms. Ryan noted that the current SWFL breeding time period includes a conservative buffer. Dr. Walker suggested that there is not sufficient information on SWFL arrival and departure dates in the MRG and on how they could be changing due to climate change. Mr. Caplan noted that, if moisture and hydrology are important factors of nest sites, earlier snowmelt predicted by climate change models might impact management actions, and that understanding the "error bar" of SWFL breeding phenology could potentially inform hydrological management actions. Dr. Cartron added that it is important to determine to what degree information uncertainty is acceptable on account of data extrapolation, and to what extent should local MRG studies be implemented to minimize uncertainty due to extrapolation: When does that margin of error become too great for making sound strategic decisions regarding conservation priorities along the MRG?

<u>Habitat Requirements</u>
Dr. Marcus questioned if distance to water and distance to river channel were of equal value in defining nest sites. Mr. Ahlers responded that they are not because surface water exists outside of the active river channel, such as backwater channels and wetlands.

Dr. Cartron asked how the abundance of insects would be characterized at a dry nest site. Mr. Ahlers responded that it would be difficult to quantify this abundance or differentiate between prey abundance at dry and wet nest sites because SWFLs travel outside of nest site habitats toforage.

Upon reviewing the USBR nest site suitability index model, Mr. Ahlers noted that bird distribution surveys were used as overlays to identify good habitat, and that moderate habitat identification required additional judgement calls. Mr. Caplan emphasized the importance of understanding the impact of hydrology on potential habitat and suggested building on USBR's suitability model by integrating surface water hydrology models and identifying decision criteria based on hydrologic cues. Ms. Najmi asked if USBR has analyzed the marginal difference between moderately suitable and suitable habitat. Mr. Ahlers responded that there has not been a clear delineation between suitable and moderately suitable habitat, but rather there is a spectrum, and to inform restoration, there needs to be a determination of where to set the bar for habitat acceptability.

Dr. Marcus summarized a publication in which he and his colleagues mapped SWFL site locations based on historical and recent data and proximate vegetation, including saltcedar, to inform restoration priorities. Dr. Marcus recommended that this study be updated every three years to ground-truth and update the study's findings.

In response to a question from Dr. Cartron, Dr. Marcus noted that restoration feasibility was taken into account when restoration priorities were developed, and Dr. Marcus expressed concern for SWFL presence in saltcedar patches that are vulnerable to the saltcedar beetle. Ms. Nishida asked if Dr. Marcus has management insights to inform on-the-ground restoration, such as how long it takes to grow usable habitat. Mr. Caplan responded that plant growth depends on, and can vary greatly by, the hydrology of a site. Mr. Ahlers echoed Mr. Caplan's assertion and noted that he has seen sites occupied from three years to 30 years after restoration planting. Dr. Walker identified site vegetation maturity based on hydrology as a research question – at what point does a site become mature or over-mature for a SWFL?

Ms. Nishida asked what other action can be taken at active restoration sites to best create habitat if there is no option to alter the hydrology? Mr. Caplan responded that there is a 2006 vegetation report by USBR (Moore 2007) that offers useful metrics on plant structure type and species composition. Mr. Caplan also mentioned a habitat characterization model (EcoMetrix) developed for the USACE that "scores" SWFL nesting habitat attributes that could be made available to assess SWFL habitat value/condition. The USACE tool is similar to HSI models developed by USFWS.

Dr. Marcus asked what habitat criteria and characteristics should be used to define restoration priorities. Participants commented that a standard protocol is needed to uniformly characterize SWFL sites within the MRG and to help determine what factors promote breeding (e.g., microclimates). Mr. Caplan cautioned that rigorous field methods, such as those developed by the Breeding Biology Research and Monitoring Database (BBIRD), that capture micro-climate data are labor intensive and expensive to implement and asked if there are tools that will accurately and expeditiously score habitat. Ms. Ryan identified the USFWS habitat suitability assessment tool for SWFL. Dr. Marcus suggested a need for a centralized resource repository. There was some concern for sharing SWFL locations via an open-access information repository, but participants identified methods for avoiding sharing precise locations with the public.

<u>Status, Trends, and Threats</u>

Ms. Najmi asked if SWFL territories have been recorded north of Albuquerque. Mr. Ryan responded that USBR had identified a few sites north of Alameda Bridge in Corrales where SWFLs were present during migration, but that no territories were found. Mr. Ahlers commented that a comprehensive survey of northern reaches of the MRG is needed, particularly because populations are shifting locations as habitat quality decreases. Mr. Caplan asked which reaches were a priority for survey efforts. Responses included north of the Pueblo of Isleta, south of the Rio Bravo Bridge, and areas around Corrales. There was general participant agreement that a thorough survey should be conducted in the Angustora Reach of the MRG.

Dr. Cartron asked what the following observations could indicate given historical nesting data and more recent vegetation data: 1) declining nest success; 2) increased mixed exotic-native vegetation; and 3) comparable exotic and native nesting successes. Dr. Cartron also suggested using a logistic regression model to tease out relationships as they relate to year. Mr. Ahlers noted that more could be done to analyze this data.

In response to a question from Dr. Walker about threats from contaminants and disease, Mr. Ahlers responded that there have been instances where deformities were observed and heavy metals were suspected as the cause.

5. Priority Scientific Uncertainties Discussion

Through thoughtful discussion and voting, workshop participants identified the top five key scientific uncertainties detailed in the section *Key Scientific Uncertainties* above. Participants discussed and flushed out the components of each key scientific uncertainty in detail, noting the following sub-questions and sub-topics:

1. *SWFL meta-population dynamics.*
    a. At what minimum and maximum distance are populations connected by meta-population dynamics?
    b. How far do individuals move from source populations?
2. *The impact of the saltcedar leaf beetle (Diorhabda) on SWFL habitat*
    a. What are the implications of potential saltcedar leaf beetle management actions (e.g., removal of saltcedar) on SWFL habitats and populations?
    b. Will the saltcedar leaf beetle significantly reduce habitat availability to the SWFL along the MRG?
3. *How best to identify and predict suitable SWFL habitat*
    a. How can we use habitat suitability modeling to better predict suitable habitat sites?
        i. Evaluate existing tools on their ability to score SWFL habitat quality at specific sites.
        ii. How could model predictability be improved by incorporating hydrologic modeling and other attributes (including climate change predictions) over a range of scales, both geographic and temporal?
    b. What are key habitat criteria/characteristics to input in a habitat suitability model? How do we deal with succession and maturation?

4. *The criteria for prioritizing sites for habitat restoration*
    a. Abiotic and biotic characteristics of restoration sites
    b. Proximity to existing breeding territories
5. *SWFL presence, population size, and population status along the Angostura Reach, particularly in Corrales and downstream of the Rio Bravo bridge.*

6. Additional Scientific Uncertainties, Questions, and Suggestions for Further Study

In addition to the top five key scientific uncertainties detailed above, the following uncertainties were identified during the workshop:

- SWFL literature, data, and pertinent species and habitat information should be consolidated and warehoused in an easy-to-access, central repository.
- Genetic samples should be collected from MRG SWFLs during the June-July time period to reduce the potential for other willow flycatcher subspecies to be confused with *E.t. extimus*.
- Does adding additional SWFL surveys have a negative impact on breeding pairs at a given nest site? (e.g., what is the marginal disturbance of five surveys versus three surveys?
- Is the SWFL food base/abundance a limiting factor in attracting SWFL breeding pairs to "SWFL-centric" habitat restoration sites and their reproductive success?
- What is the specific phenology of the SWFL along the MRG (MRG Habitat Restoration report conceptual model)?
    - Is there a phenology shift over time in response to climate change?
    - What are climate change predictions for SWFL population and suitable habitat distributions?
- To what degree can we extrapolate existing SWFL data from other river basins to SWFLs in the MRG?
- What are the best tools available to evaluate/score SWFL habitat quality at specific sites? (e.g., USFWS habitat suitability model for SWFL, USACE EcoMetrix Model)
- What habitats do SWFL's use during stopover and where are they located?
- To what extent is stopover habitat in the MRG limiting to population status?
- What tools could be developed to monitor trends in stopover habitat use?
- To what extent are contaminants and disease threats to SWFL populations along the MRG?

Appendix C-2: Detailed Technical Discussion - Critical Scientific Uncertainties for the Southwestern Willow Flycatcher

CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE SOUTHWESTERN WILLOW FLYCATCHER

Listing History, Recovery, and Population Status

The SWFL is one of four recognized subspecies of the willow flycatcher (*Empidonax traillii*; Unitt 1987, Paxton 2000). The SWFL historically bred in dense riparian vegetation almost always in the vicinity of surface water or saturated soils from southern California and extreme northwestern Mexico eastward through southern Nevada, Arizona, southern Utah, southwestern Colorado, New Mexico, and, possibly, Trans-Pecos Texas (Sedgwick 2000, USFWS 2002). Over the last century, SWFL breeding populations have become locally extirpated primarily due to degradation and loss of riparian breeding habitats resulting from anthropogenic alterations to the functioning of native riparian ecosystems through dam construction and operation, groundwater pumping, water diversions, and flood control (Hubbard 1987; Marshall and Stoleson 2000; Phillips et al. 1964; Rosenberg et al. 1991; Unitt 1987; USFWS 1995, 2002). The SWFL also is directly threatened by nest parasitism by brown-headed cowbirds (*Molothrus ater*), predation, disease, and environmental toxins (USFWS 1995, 2002).

In response to documented declines in SWFL breeding populations, the SWFL was listed by New Mexico as threatened in 1988 and then reclassified as endangered in 1996 (NMDGF 2016). The SWFL was federally listed as endangered in 1995 in response to range-wide population declines (USFWS 1995). Associated with federal listing, publication of a recovery plan (USFWS 2002; hereafter, "Recovery Plan"), designation of critical habitat (USFWS 1997, 2005, 2013), and development of standardized survey protocol (Tibbitts et al. 1994; Sogge et al. 1997, 2010; USFWS 2000) served to synthesize current knowledge on the SWFL, promote management and conservation of the SWFL and its habitats, and facilitate collection of SWFL population data.

To recover the SWFL, the Recovery Plan (USFWS 2002) recommends that efforts focus on increasing total SWFL population numbers, establishing functioning SWFL metapopulations, providing protection from threats, and creating and securing sufficient SWFL habitats. Specifically, the Recovery Plan (USFWS 2002) identifies nine necessary recovery actions:

1) Increase and improve occupied, suitable, and potential breeding habitat;
2) Increase metapopulation stability;
3) Improve demographic parameters;
4) Minimize threats to wintering and migration habitat;

5) Survey and monitor;
6) Conduct research;
7) Provide public education and outreach;
8) Assure implementation of laws, policies, and agreements that benefit the SWFL; and
9) Track recovery progress.

Because the SWFL's breeding range is large in geographic extent, the Recovery Plan uses a watershed approach to organize recovery, dividing the SWFL's range into six recovery units, which are each further subdivided into management units (USFWS 2002). Recovery units are defined based on large watershed and hydrologic units, while management units are based on watershed or major drainage boundaries at the Hydrologic Unit Code Cataloging Unit level.

The MRG (the approximately 273-km- [170-mile-] stretch of the Rio Grande from Cochiti Dam, Sandoval County, to Elephant Butte Dam, Sierra County) is encompassed in the Middle Grande Management Unit (MRGU), within the larger Rio Grande Recovery Unit (RGRU) (Figure 14; USFWS 2002). Currently, the numerical recovery criteria for both the MRGU (100 territories) and the RGRU (250 territories) are surpassed due to recent high SWFL territory numbers in the MRGU (344 territories in 2015), primarily within the lower San Marcial Reach near Elephant Butte Reservoir (Moore and Ahlers 2016). Thus, the current status of the SWFL within the MRG is considered stable (Moore and Ahlers 2016, USFWS 2016). However, nest success in the MRG might be trending downward partly due to high depredation rates (Moore and Ahlers 2016). Furthermore, SWFL populations within the MRG could experience future declines due to threats such as water management (particularly in the Elephant Butte Reservoir), habitat loss due to the tamarisk beetle (*Diorhabda*), vegetation succession, and climate change (USFWS 2016).

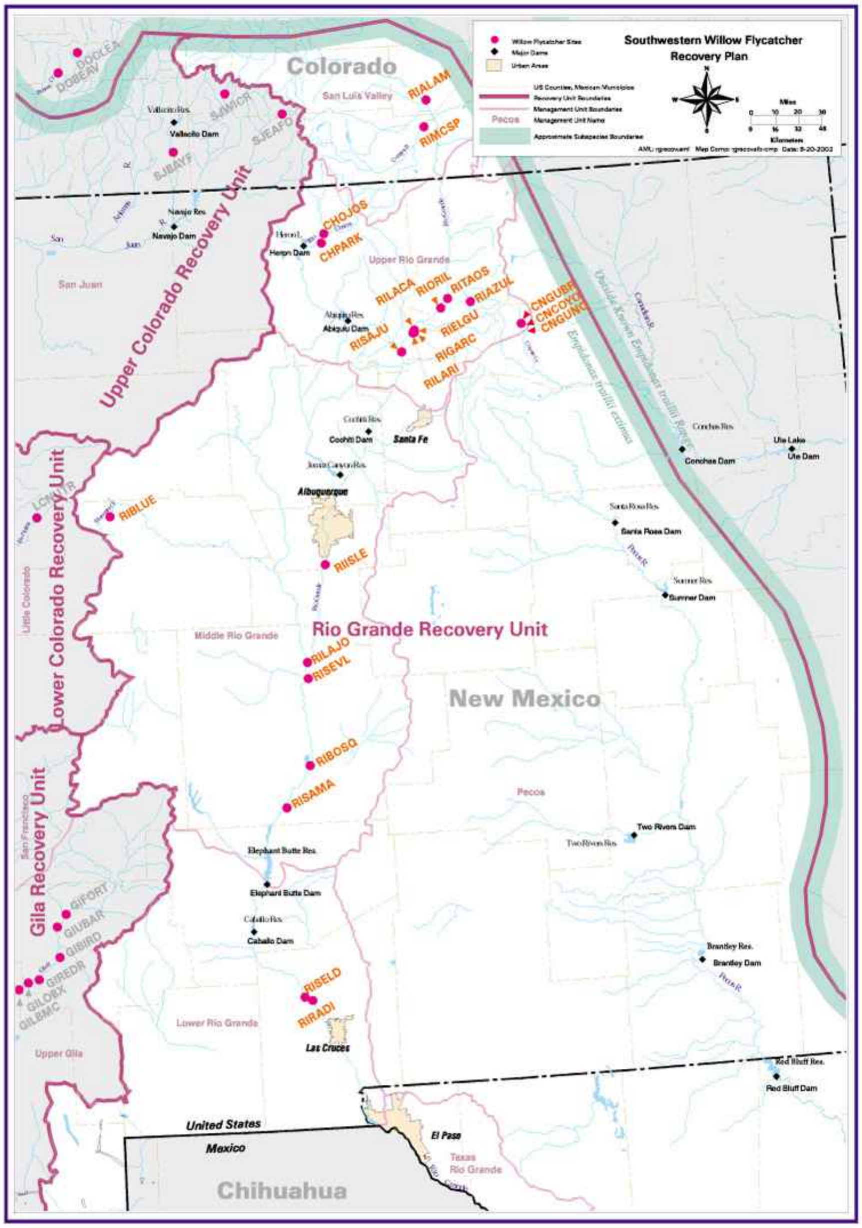

Figure 14. The Middle Rio Grande is encompassed in the Southwestern Willow Flycatcher Middle Grande Management Unit, within the larger Rio Grande Recovery Unit (Figure 11 in USFWS 2002).

MRG Management Actions

Owing to the SWFL's dependence on the resources provided by riparian and aquatic habitats, water management in the MRG can have profound impacts on the future of SWFL populations. SWFLs would disappear from the MRG and could experience statewide and rangewide declines should the flow regime of the Rio Grande be altered to the extent that it no longer sustains required habitats. In fact, without significant habitat improvements and other offsetting measures, the USFWS (2016) determined that current water management actions will continue and expand SWFL habitat degradation and destruction, and, thus, would threaten SWFL survival and recovery within the MRG.

To ensure that water demands in the MRG are adequately addressed while preserving, protecting, and improving the status of the SWFL, water operations managers began consultation with the USFWS under Section 7 of the ESA beginning in 1998. Then, in 2000, Federal and non-Federal partners with water interests in the MRG established the Collaborative Program to ensure compliance with all applicable laws (Murray et al. 2011, USFWS 2016). The Collaborative Program is involved in the following five activities:

1) Water acquisition and management;
2) Coordination and consultation with the USFWS, the NMDGF, and other stakeholders to obtain environmental clearances for proposed projects;
3) Protection and restoration of the aquatic and riparian environments required by SWFLs and impacted by water operations;
4) SWFL surveys, monitoring, and research; and
5) Implementation of AM.

Over the past decade and a half, ESA consultation documents such as BiOps have played an important role in guiding Collaborative Program activities. Prior to the most recent BiOp, various agencies and organizations contributed under the Collaborative Program to water management, habitat restoration, research, and monitoring activities prescribed in a 2003 BiOp (USFWS 2016). Currently, a number of Collaborative Program-signatories, including USBR, BIA, MRGCD, and NMISC, are involved in completing three tasks required in the current BiOp (USFWS 2016) to offset the potentially negative effects of proposed and on-going water management and river maintenance activities on the SWFL and designated SWFL critical habitat (USFWS 2016):

1. Implementing best management practices (BMPs) to minimize take of the SWFL as well as minimize the effects of water management actions and habitat restoration activities on the SWFL (Conservation Measures 51, 54-55, 58-59, 61, 64, and 80; USFWS 2016:162-169);
2. Conducting surveys, monitoring, and research of SWFL populations and habitats (see Sogge et al. 2010); and

3. Protecting, creating, and restoring SWFL habitats (Conservation Measures 29, 51-52, 55, 58-61, 70, 73, 78, 80-82).

In addition to BiOps, other guidance documents useful to the Collaborative Program include BAs (e.g., the 2015 Joint BA [USBR 2015]), the Recovery Plan (USFWS 2002), federal designations of critical habitat, AM plans (e.g., Murray et al. 2011), the New Mexico Wildlife Conservation Act (1978) and associated biennial reviews, the State Wildlife Action Plan for New Mexico (NMDGF 2016), and restoration prioritization strategies (e.g., Caplan et al. 2014, 2015; Tetra Tech 2004, 2015; USBR 2012). The Recovery Plan (USFWS 2002) and the federal designation of critical habitat (USFWS 2013), in particular, provide valuable guidance on habitat protection, creation, and restoration implementation. The Recovery Plan presents a detailed approach to habitat restoration (Appendix K in USFWS 2002), while the USFWS (2013) details which physical or biological elements provide for SWFL life-history processes (primary constituent elements [PCEs]) and are essential to SWFL conservation.

Critical Scientific Uncertainties

Federal, state, tribal, and private land and water managers require practical scientific information necessary for making well-informed management decisions – including developing alternative actions and evaluating effects of actions – for the SWFL within the MRG while implementing management actions. When identifying and selecting the best management strategy, managers are required to use the best scientific information available; however, in many cases, there is a lack of appropriate scientific data and information that cover all management objectives, are relevant to the specific location in question, and are peer-reviewed. Thus, to facilitate boots-on-the-ground management, there must be a cross-linkage between work completed by the scientific community on the SWFL and the information needs of the management community. Specifically, scientific experts should facilitate the AM process by helping to develop and describe the details of the design, implementation, and evaluation process for SWFL studies that meet management uncertainties.

On 25 October 2016, a team of SMEs met in Albuquerque, New Mexico, to learn and discuss the state of the science for the SWFL and to identify where there are critical uncertainties in the scientific knowledge for the SWFL (see Section 2.2.2). There was general consensus among the agency SMEs that extensive survey and substantive research efforts over the past few decades along the MRG and across the SWFL's range have elucidated the SWFL's natural history requirements, population status, threats, and response to recovery efforts. Nonetheless, the SMEs delineated approximately 15 (later combined into 11) scientific topics that were less studied and less understood, and they identified the top five scientific uncertainties that affect management decisions for the SWFL and, thus, should be the focus of future scientific efforts (Appendix C-1). After the conclusion of the meeting, via email correspondence, the SMEs ranked the top five critical scientific uncertainties to determine which should be given the highest priority for scientific inquiry, management action, and funding. During the meeting and subsequent review of the literature, questions were identified as a priority for study to address each critical scientific uncertainty. The primary objectives of identifying these critical scientific uncertainties and questions are to: 1) contribute to scientific knowledge; 2) ensure that Collaborative Program-funded monitoring, research, and experiments reduce management uncertainties; and 3) improve the rigor of the science informing resource management decisions and actions directed at protecting the SWFL while still providing for current and future water users.

This appendix provides in-depth reviews of the scientific relevance, management application, and recovery application for each critical scientific uncertainty; brief overviews of these topics are provided in Section 4. Study plan considerations for each critical scientific uncertainty also are offered both in this appendix and in Section 4 to guide Collaborative Program signatories with soliciting detailed *Requests for Proposals* from the scientific community.

Identified Critical Scientific Uncertainties

The agency SMEs prioritized the following four critical scientific uncertainties for scientific study (ranked 1 = Highest to 4 = Lowest):

5) The strategy for prioritizing sites for SWFL breeding habitat restoration in the MRG.
6) The impact of the tamarisk beetle (*Diorhabda*) on SWFL breeding habitats in the MRG.
7) SWFL breeding population sizes, distributions, and trends along the Angostura Reach.
8) SWFL metapopulation structure and dynamics in the MRG.

Ranked fifth was "The abiotic and biotic variables that predict suitable and unsuitable SWFL habitats across multiple spatial and temporal scales in the MRG;" however, this topic does not receive expanded review and consideration in this appendix because it was ranked as a significantly lower priority than the four critical scientific uncertainties listed above. The SMEs also identified six additional scientific uncertainties that were considered lower priority at this time (see Other Critical Scientific Uncertainties below).

Connectivity Among Critical Scientific Uncertainties

The top four critical scientific uncertainties for the SWFL are interconnected; research on one informs research (e.g., provides similar or baseline data) on the other (Figure 15). More specifically, all four critical scientific uncertainties relate, in some degree, to identifying the following:

- Where SWFLs and/or their habitats are on the landscape (critical scientific uncertainties #1-4);
- Threats to SWFL populations (critical scientific uncertainties #2-4);

- Which and where management and recovery actions, particularly SWFL habitat restoration, should be implemented to benefit or avoid jeopardy to the SWFL (critical scientific uncertainties #1-4); and
- The effects of management and recovery actions on SWFL populations (critical scientific uncertainties #1-4).

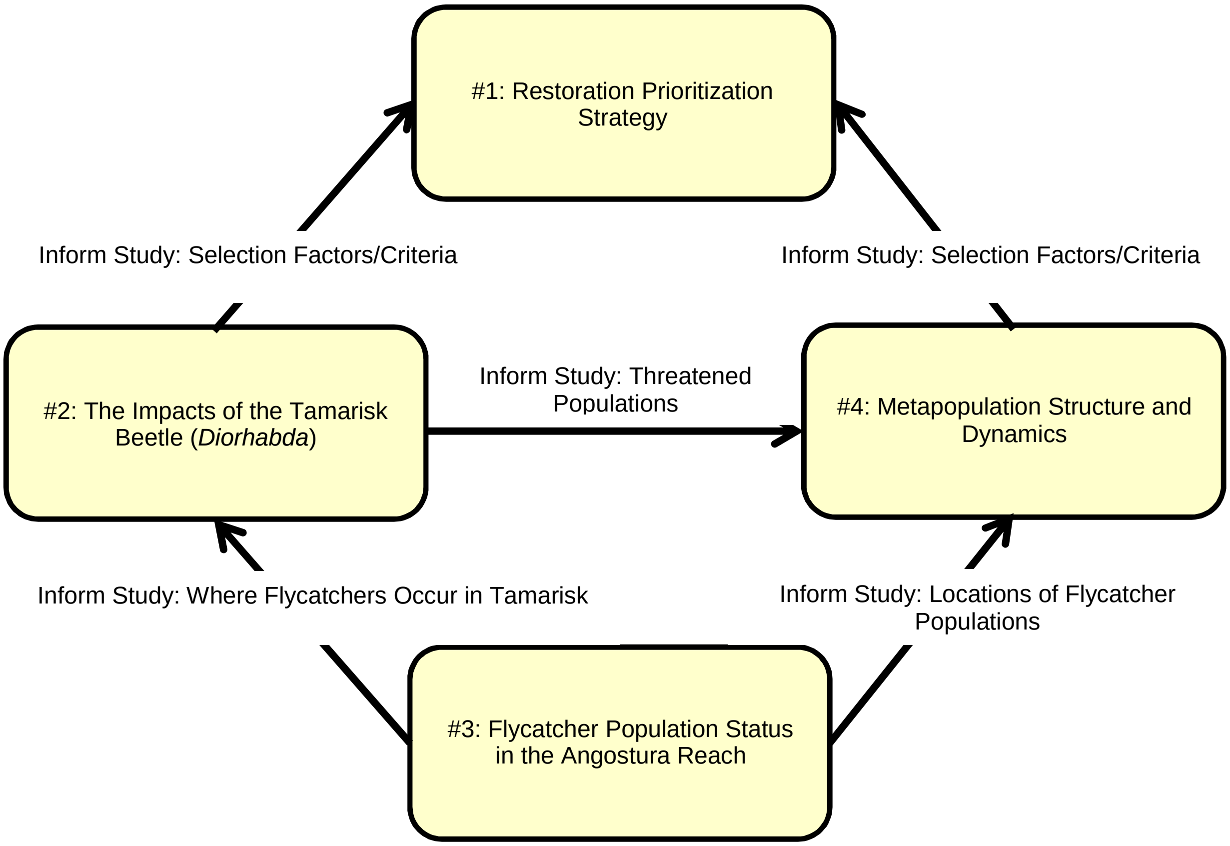

Figure 15. Relationships among critical scientific uncertainties of the Southwestern Willow Flycatcher in the Middle Rio Grande, New Mexico.

Other Critical Scientific Uncertainties

The six scientific questions listed below in no particular order were identified as a lower priority for study and funding than the top five critical scientific uncertainties (see Appendix C-1 for original, unrevised wording):

- Does the number of standardized protocol surveys conducted affect SWFL nest success?
- Do prey composition and availability limit SWFL colonization of restoration sites in the MRG?
- What is the SWFL breeding and migration phenology in the MRG?
- Will climate change result in changes to SWFL phenology, population sizes and distributions, and geographic extent and locations of unoccupied and occupied suitable habitats in the MRG?
- Can information from SWFL research and monitoring performed outside of the MRG be generalized across river basins and applied to the MRG?
- Are SWFL populations threatened by contaminants and disease in the MRG?
- What are SWFL stopover patterns in the MRG? Specifically, what habitats do SWFLs use during stopover and where are they located in the MRG? Furthermore, to what extent does the availability of stopover habitat limit SWFL populations in the MRG? In addition, what methods and technologies should be employed or developed to monitor trends in SWFL stopover habitat use in the MRG?

CRITICAL SCIENTIFIC UNCERTAINTY #1: RESTORATION PRIORITIZATION STRATEGY

***Study Question*:** What site selection and prioritization procedures contribute to the successful restoration of SWFL breeding habitats along the MRG?

Scientific Relevance

RESTORATION PRIORITIZATION STRATEGY

SCIENTIFIC RELEVANCE

Although restoration projects in the MRG have resulted in the successful creation of native riparian woodlands, less than a handful of restoration sites in the MRG support breeding SWFLs. Furthermore, there is no evidence that there has been sufficient creation of suitable SWFL breeding habitats to offset impacts of management actions and/or protect and stabilize SWFL populations. It is difficult to pinpoint the reason for such limited success in creating suitable SWFL breeding habitats; restoration success is contingent upon a number of interrelated factors, such as adequate funding, strong working partnerships and coordination among stakeholders, and well-designed and well-implemented restoration actions. Nonetheless, future success of the Collaborative Program's habitat restoration program is, in part, dependent upon the development of a scientifically-based habitat restoration prioritization strategy that provides managers with guidance on how best to 1) evaluate the pre-existing conditions of potential sites across the MRG and 2) consistently prioritize for restoration those sites where management efforts have the highest likelihood of successfully creating suitable SWFL breeding habitats. Scientific inquiry will be required to determine which selection factors and criteria pertaining to the SWFL's life history requirements and recovery needs should be included in such a strategy.

The SWFL was federally listed as endangered in 1995 due to population declines, primarily in response to anthropogenic loss, fragmentation, and degradation of required riparian woodlands (USFWS 1995). More than 25 years later, loss, fragmentation, and degradation of SWFL habitats continue due to urbanization, agricultural development, recreational activities, intensive livestock grazing, conversion of native vegetation to exotic woody vegetation, and water management activities that disrupt natural hydrologic processes required for the establishment, development, maintenance, and recycling of native woody riparian vegetation (Knopf et al. 1988, Finch and Stoleson 1999, Marshall and Stoleson 2000, USFWS 2002). Due to the SWFL's dependence on riparian ecosystems, protection and restoration of native riparian woodlands are vital to its recovery (USFWS 2002). Consequently, the USFWS is increasingly requiring water managers to provide mitigation and compliance with the Federal ESA through a habitat-based approach that aims to 1) protect unoccupied and occupied suitable SWFL habitats[3] and 2) create suitable habitats to support expanding SWFL populations (USFWS 2002).

In the MRG, the USFWS (2016) concluded that substantial habitat restoration is necessary to offset the impacts of water management actions on the SWFL and its designated critical habitat. However, although numerous habitat restoration projects anticipated to have ancillary benefits to the SWFL have been completed, are on-going, and are planned in the MRG, only a few completed restoration projects have explicitly focused on restoration of SWFL breeding habitats (USFWS 2016:46-48). To date, these restoration projects – whether they are for the SWFL, RGSM, or other purposes – have not significantly contributed to preserving, protecting, or improving the status of the SWFL; extensive SWFL surveys and monitoring have documented less than a handful of SWFL breeding territories in improved or constructed riparian woodlands as of the end of the 2017 (e.g., Moore and Ahlers 2017, USFWS unpubl. data). Moreover, there is no evidence that restoration efforts have measurably increased or will increase in the near future the amount of suitable SWFL breeding habitat; habitat monitoring suggests only a limited amount of suitable SWFL breeding habitats at MRG restoration sites upstream from Elephant Butte Reservoir (Moore 2009, SWCA 2014, Siegle et al. 2016). Although suitable SWFL breeding habitats might yet develop in some restoration sites, determining if and over what time period this occurs will require implementing well-designed effectiveness monitoring efforts.

It is difficult to pinpoint why restoration efforts in the MRG have had limited success in creating suitable SWFL breeding habitats; restoration success is contingent upon a number of interrelated factors from project conception to implementation and monitoring (Figure 16). Strong working partnerships and coordination among stakeholders undertaking restoration efforts is especially important at the onset, as restoration successes can be hampered by a lack of consistency in and coordination of goals and management actions. Therefore, to ensure consistent and repeatable successes, it is critical that restoration programs unify their diverse partners under a shared vision for habitat restoration and develop guidance documents that facilitate coordinated implementation of science-informed and standardized management actions necessary to successfully restore habitats (SWCA 2014).

In the MRG, managers lack program-wide guidance on habitat restoration actions from start to finish, such as how best to 1) formulate meaningful SWFL breeding habitat restoration goals and measurable targets, 2) design and implement SWFL breeding habitat restoration, and 3) design and implement

[3] From USFWS (2002:16), occupied suitable habitat is that in which flycatchers are currently breeding or have established territories, while unoccupied suitable habitat appears to have physical, hydrological, and vegetation characteristics within the range of those found at occupied sites, but does not currently support breeding or territorial flycatchers.

effectiveness monitoring. As restoration site selection sets the stage for success for all subsequent restoration actions (Figure 17), of utmost importance to the SMEs is the development of a guidance document to help managers identify where in the MRG restoration efforts have the highest prospect of creating suitable SWFL breeding habitats. Neither a MRG-wide habitat restoration prioritization strategy that comprehensively addresses all program needs, such as those for other large ecosystem-level restoration programs (e.g., Lower Colorado Multi-Species Conservation Program [LCRMSCP] 2006, LCEP 2012), nor a MRG-wide restoration prioritization strategy that specifically addresses the needs of the SWFL has been developed. Such a strategy is invaluable to managers because:

- Not all habitats along the Rio Grande were or can be again SWFL breeding habitat, and factors such as climate, elevation, precipitation, water availability, river flows, water use, pre-existing vegetation, and management practices vary across the landscape.
- They enable managers to identify and select for restoration those sites with pre-existing conditions (e.g., low disturbance levels and little deviation from reference or target conditions) that maximize both the ecological benefits and the probability of success while minimizing risks and costs (Thom et al. 2011).

Greater restoration successes are achieved when these strategies are complimented by clearly defined goals and measurable targeted outcomes, science-informed restoration design and implementation, and standardized effectiveness monitoring (Figure 16 and Figure 17).

Several habitat restoration prioritization strategies have been prepared for specific projects in the MRG and they can serve as a starting point for creating a unified strategy (e.g., Parametrix 2011; USBR 2012; Caplan et al. 2014, 2015; GSA 2014; Tetra Tech 2015). Furthermore, the Recovery Plan (USFWS 2002), restoration prioritization strategies of other large ecosystem-level restoration programs (e.g., LCRMSCP 2006, LCEP 2012), and other documents (e.g., USBR 2013; Murray et al. 2011; Thom et al. 2011; USFWS 2013, 2016) provide information useful for adjusting and improving upon existing MRG prioritization strategies to yield greater benefits to the SWFL. Specifically, existing literature (USBR 2013; Murray et al. 2011; Thom et al. 2011; USFWS 2002, 2013, 2016) suggests that a restoration prioritization strategy that promotes objective and consistent selection of sites with the highest SWFL breeding habitat restoration potential should include selection factors (i.e., those elements considered when making a decision) and criteria (i.e., the priority range or threshold of values for each selection factors) that pertain to the following site attributes:

- <u>Size</u>: The geographic extent (size) of restored riparian areas should meet the needs of the SWFL at the individual, population, and metapopulation scales (USFWS 2002). The Recovery Plan (USFWS 2002) recommends that contiguous suitable habitat at sites should be at least 24.9 ha (61.5 acres; which is large enough to support 10 or more breeding territories). In contrast, the 2016 BiOp (USFWS 2016:27) states, “Patch size may be as small as 0.1 ha (0.25 acres) or as large as 70 ha (175 acres)." The 2011 Adaptive Management Plan (Murray et al. 2011:26) identified the minimum size of created habitat as a critical scientific uncertainty.

- Connectivity: Sites should be located near enough to existing SWFL breeding populations (as well as other suitable SWFL breeding habitat) to ensure successful colonization (Task 2.1.1a in USBR 2013:78; USFWS 2002). The 2011 Adaptive Management Plan (Murray et al. 2011:26) identified the minimum distance of created habitat from existing territories as a critical scientific uncertainty; however, scientific evidence (Paxton et al. 2011; USFWS 2002, 2013) indicates that restoration should be sited 30 to 40 km (18 to 25 miles), but no further than 97-120 km (60-75 miles) and no closer than 0.4 km (0.3 mile), from existing SWFL breeding populations.
- Pre-existing Vegetation: Sites with pre-existing plant species composition (floristics) and vegetation structure (physiognomy) or the physical processes (e.g., appropriate river flows and hydrogeomorphic conditions) required to establish and maintain the vegetative conditions required by breeding SWFLs should be prioritized for restoration (USFWS 2002:K-15 to K-17).
- Multiple Spatial Scales: The availability and configuration of suitable SWFL breeding habitats within restoration sites and the surrounding landscape should address the SWFL's habitat needs at multiple spatial scales (i.e., at the landscape/breeding site, macrohabitat/patch, and microhabitat/nest site scales). According to Thom et al. (2011), fundamental considerations are not only those selection factors of the site, but also are those pertaining to the surrounding landscapes.
- Habitat Complexity: Riparian ecosystems are biologically complex and a myriad of components interact synergistically to yield a functioning ecosystem that supports all the elements required by the SWFL (USFWS 2002:K-16). Thus, site selection should not only focus on a small subset of ecosystem features, such as vegetation and hydrology, but should consider the full complement of attributes required by breeding SWFLs (i.e., also should consider availability of a rich arthropod prey base and other life history requirements).

In summary, managers require a MRG-wide decision-making tool that promotes consistent selection and prioritization of sites that are most favorable for restoration and, thereby, increases the probability of successfully creating suitable SWFL breeding habitats. To address this need, the SMEs suggested 1) establishing clearly-defined goals and measurable targeted outcomes for the SWFL, and 2) ensuring that a scientifically-based SWFL breeding habitat restoration prioritization strategy is developed and consistently utilized to select those sites for restoration with the highest likelihood of achieving those goals and outcomes (Noon et al. 2009, Thom et al. 2011, Gama et al. 2013).

Management Application

RESTORATION PRIORITIZATION STRATEGY

MANAGEMENT APPLICATION

Currently, managers lack a MRG-wide decision-making tool for consistently selecting those sites for restoration that have the highest SWFL breeding habitat restoration potential. Results of studies addressing the critical scientific uncertainty will help managers develop a science-based MRG-wide habitat restoration prioritization strategy that 1) facilitates coordinated and repeatable selection for restoration those sites that support the pre-existing conditions necessary for successful creation of suitable SWFL breeding habitats, 2) reduces factors limiting restoration success, and 3) supports Collaborative Program partners' efforts to effectively offset the impacts of management actions on the SWFL.

Habitat protection, creation, and restoration are particularly important in minimizing adverse impacts of water management actions on hydrology, geomorphology, and riparian vegetation. In the MRG, the Collaborative Program is tasked with creating suitable SWFL habitat conducive to territory establishment and nesting success to minimize the impacts of water storage, delivery, and depletions on SWFLs along the approximately 273 km (170 miles) of the Rio Grande stretching between Cochiti and Elephant Butte dams (USBR 2013:51, USFWS 2016:166). To increase the probability of restoration success, the SMEs recommend that the Collaborative Program employ a habitat restoration prioritization strategy that identifies where in the MRG restoration efforts have the highest prospect of creating suitable SWFL breeding habitats.

Several habitat restoration prioritization strategies currently exist for the MRG; however, there is no evidence that existing strategies have been implemented or have resulted in sufficient creation of native riparian woody vegetation suitable for breeding SWFLs. Therefore, managers require rigorous scientific information on how best to improve upon existing strategies to effectively address the SWFL's life history requirements and recovery needs. Once developed, a MRG-wide habitat restoration prioritization strategy will: 1) facilitate coordinated and repeatable selection of sites most favorable for SWFL breeding habitat restoration; 2) reduce factors limiting restoration success (e.g., pre-existing site conditions); and, ultimately, 3) support Collaborative Program partners' efforts to effectively offset the effects of water management actions on the SWFL.

Recovery Application

RESTORATION PRIORITIZATION STRATEGY

RECOVERY APPLICATION

Addressing the critical uncertainty should contribute to recovery of the SWFL. Results of research addressing the critical scientific uncertainty will help managers develop science-driven methods (Recovery Action 6) for identifying and prioritizing for restoration those sites with pre-existing conditions that maximize the probability of successfully creating and improving SWFL habitats (Recovery Action 1: *Increase and improve occupied, suitable, and potential breeding habitat*). When effectively implemented across the MRG, a SWFL habitat restoration prioritization strategy can reduce or remove any influence of poor site-selection on restoration success and, thus, should lead to increased creation of suitable SWFL breeding habitats conducive to occupancy by and maintenance of breeding SWFLs (Recovery Action 2: *Increase metapopulation stability* and Recovery Action 3: *Improve demographic parameters*). By assisting managers in implementing recovery actions 1, 2, 3, and 6, results of habitat restoration prioritization research also will help managers implement laws, policies, and agreements that benefit the SWFL (Recovery Action 8).

The Recovery Plan (Recovery Action 1 and Appendix K in USFWS 2002) recognizes that (to recover SWFL populations threatened by habitat loss, fragmentation, and degradation) habitat restoration is necessary to increase the availability of suitable SWFL breeding habitat. Prior to implementing restoration efforts, the Recovery Plan (USFWS 2002) recommends that management plans be developed that identify and prioritize sites for recovery actions based on rigorous scientific research (Recovery Action 6). The Collaborative Program has not yet developed either a comprehensive or a SWFL-specific habitat restoration prioritization strategy. Therefore, managers in the MRG require a science-driven strategy for identifying and prioritizing for restoration those sites with pre-existing conditions that maximize the probability of successfully creating and improving SWFL breeding habitats. When developed based on sound scientific evidence (Recovery Action 6; Figure 18) and if effectively implemented across the MRG, such a restoration prioritization strategy would reduce or remove any influence of poor site-selection on restoration success, and thus, should lead to increased creation of suitable SWFL breeding habitats (Figure 16).

By contributing to restoration success, a habitat restoration prioritization strategy – implemented in concert with other restoration actions (Figure 3 and Figure 17) – should contribute to recovery of the SWFL. Specifically, any resultant increases in the availability and connectivity of suitable SWFL breeding habitats should, in turn, *increase metapopulation stability* (Recovery Action 2) and *improve demographic parameters* (Recovery Action 3) by engendering increases in:

- Occupancy of restoration sites by breeding SWFLs;
- SWFL population connectivity; and, ultimately,

- SWFL population sizes and stability.

By assisting managers in implementing recovery actions 1, 2, 3, and 6, studies on the critical scientific uncertainty will help managers implement BiOPs resulting from ESA Section 7(a)(2) consultations (Recovery Action 8.2; e.g., USFWS 2016) and support conservation efforts in compliance with ESA Section 7(a)(1) of the ESA (Recovery Action 8.3.1). Furthermore, if the SWFL habitat restoration prioritization strategy can be integrated into a comprehensive habitat restoration prioritization strategy that addresses all or other needs of the Collaborative Program (e.g., addresses both the needs of the SWFL and the YBCU), then the strategy also will help managers implement Recovery Action 8.4: *Integrate recovery efforts with those for other species*.

Study Plan Considerations

The process detailed below and illustrated in Figure 18 is offered for addressing the primary study question, "What site selection and prioritization procedures contribute to the successful restoration of SWFL breeding habitats along the MRG?"

Step 1: Define Restoration Goals and Targeted Outcomes.—Although some broad goals for SWFL breeding habitat restoration are provided in the *Middle Rio Grande Adaptive Management Plan* (Murray et al. 2011:12), no targeted outcomes have been defined that outline the desired optimal future conditions for the SWFL or its habitats in the MRG. As clearly defined goals and objectives are "key requirements for all ecosystem-based management approaches" (LCEP 2012:vi), a necessary first step is to develop these outcomes for the MRG. In order to evaluate if restoration targeted outcomes are achieved, it is crucial that the outcomes be specific and measurable. Possible outcomes include: 1) occupancy of a specified proportion of restoration sites by a quantifiable number of SWFLs (e.g., a single territorial SWFL, a breeding pair of SWFLs, 10 breeding pairs); and 2) a specified proportion of restoration sites or a specified geographic extent supporting quantifiable SWFL breeding habitat types and attributes that confer suitability (e.g., USFWS 2002, 2016; Moore 2009; SWCA 2014; Siegle et al. 2016).

Step 2: Identify and Evaluate Previously Developed and Utilized Restoration Prioritization Strategies.—Several restoration prioritization strategies have been proposed in MRG restoration planning reports (e.g., Parametrix 2011, USBR 2012, Tetra Tech 2015), but it is unclear whether and to what degree these strategies have been employed in the implementation of actual restoration projects. This step should involve inventorying existing restoration prioritization strategies, evaluating the line of scientific evidence for which selection factors (i.e., those elements considered when making a decision) and criteria (i.e., the priority range or threshold of values for each selection factor) are included in each strategy (Figure 18), and documenting which restoration projects, if any, have utilized restoration prioritization strategies in the planning phase.

Step 3: Explore Relationships Between Restoration Prioritization Strategies and Successful Restoration Outcomes.—For those restoration projects that have employed restoration prioritization strategies during the project planning phase, it is useful to determine if the strategies were correlated with successful creation and restoration of suitable SWFL breeding habitats, as well as other defined goals and objectives for the SWFL. A number of statistical tests, modelling approaches, and software programs are available to analyze the relationships between restoration outcomes and utilized strategies. Prior to conducting these analyses, standardized methods should be developed to assess the effectiveness of restoration projects in achieving the targeted outcomes for both the SWFL and it habitats established above in Step 1 (SWCA 2014). SWFL outcomes at restoration sites can be ascertained from completed and on-going standardized surveys and monitoring efforts (e.g., Moore and Ahlers 2017; Appendix C-2, *Flycatcher Critical Scientific Uncertainty #3*); however, additional surveys and nest monitoring studies likely are necessary to obtain sufficient data on SWFL presence, reproductive success, and survivorship. Similar to habitat assessments described in *Appendix D-2, Cuckoo Critical Scientific Uncertainty #1:Study Plan Considerations*, quantifying habitat outcomes should involve both field-based assessments and remote sensing monitoring (e.g., LIDAR, Landsat Thematic Mapper) of key ecosystem attributes at restoration sites, such as vegetation composition and structure, patch size, and surface water and groundwater dynamics. Wherever possible, data on habitat conditions at restoration sites should be obtained from completed and on-going restoration assessments (e.g., Moore 2009, SWCA 2014, Siegle et al. 2016); however, habitat conditions at some restoration sites will need to be reassessed to obtain accurate and current data as vegetation characteristics (e.g., vegetation structure, plant species composition, distribution, geographic extent) change over time. It is essential that data on habitat outcomes be contemporary to data on SWFL outcomes (e.g., occupancy by breeding SWFLs).

Step 4: Conduct Efficacy Analyses of Restoration Prioritization Strategy Elements.—To help identify which selection factors and criteria contribute most or least to a successful restoration prioritization strategy, the selection factors and criteria included in strategies utilized in successful restoration projects should be compared and contrasted with those of strategies utilized in less or unsuccessful projects.

Step 5: Improve Restoration Prioritization Strategy.—Step 5 involves identifying how existing restoration prioritization strategies can be improved to yield the maximum benefits for the SWFL. Specifically, constructing a final SWFL habitat restoration prioritization strategy for the MRG requires:

- Building upon the results of Step 4 and identifying those selection factors and criteria of existing prioritization strategies that should be excluded or retained;
- Determining if criteria in existing prioritization strategies should be adjusted; and
- Determining if additional selection factors and criteria should be included (Figure 18).

The last two bullets above likely will involve literature review, data mining, and original quantitative research studies (Figure 18). Valuable sources for literature review and data mining efforts include scientific and gray literature on SWFL life history requirements and recovery needs (e.g., USFWS 2002, 2013), existing SWFL habitat suitability models (e.g., Siegle et al. 2013, Hatten 2016), and habitat restoration prioritization strategies currently implemented in other large ecosystem-level restoration programs (e.g., the LCRMSCP [2006]). There is much flexibility and variety in the types of research studies undertaken and methods employed to investigate which selection factors and criteria should be included in a restoration prioritization strategy for the MRG: studies can be empirical (i.e., collection of observational data, field-based AM experiments), theoretical (i.e., involve modelling), or both.

To illustrate the types of research studies that could be conducted, an investigation of the question, "Does inclusion of the section factor *distance of restoration sites to existing SWFL breeding populations* in a SWFL habitat restoration prioritization strategy increase probability of occupation by breeding SWFLs?" could involve:

- Analyzing correlations between successful SWFL occupancy of completed restoration projects and distance to existing breeding populations; and/or
- Completing an AM experiment that entails 1) gleaning from the scientific literature the maximum and optimal distances between metapopulations to promote metapopulation dynamics, as well as the optimal distance that restoration should be completed away from existing breeding SWFLs to avoid take of SWFLs or their eggs; 2) using the results of the literature review to design and implement restoration at variable distances from existing SWFL breeding populations; and, then, 3) assessing SWFL occupancy and other population metrics over a predetermined timeframe (e.g., one, five, and 10 years after restoration).

Aspects such as logistics, cost, study duration, and training and permit requirements will depend on the types of studies conducted and methods employed. Field-based research likely will require specialized training and permits (e.g., SWFL survey, detection, and nest monitoring training and ESA Section 10a permits), and data collection over multiple years.

<u>Step 6: Finalize Restoration Prioritization Strategy</u>.—A formal MRG-wide SWFL habitat restoration prioritization strategy should be constructed using the information from Step 5 on which selection factors and criteria ought to comprise the strategy. Once finalized, the restoration prioritization strategy, along with all instructions and tools necessary for implementing the strategy, should be made available to all managers in the MRG.

<u>Step 7: Apply Restoration Prioritization Strategy to MRG</u>.—After completing Step 6, potential restoration sites along the MRG should be assessed using the finalized restoration prioritization strategy to determine pre-existing conditions and then those sites with the most favorable conditions should be selected and prioritized for restoration efforts, such as habitat enhancements or creation. Sites also can be assessed to determine if actions other than restoration, such as protection, should be implemented. Generated products useful to managers should include GIS databases of sites, their pre-existing conditions, and their restoration attributes (e.g., high priority for restoration, low restoration potential).

Next Steps: Complete Restoration, Monitoring, Evaluation, and Adjustment.—In order to determine whether the restoration prioritization strategy designed through the above described process effectively promotes restoration and achievement of targeted outcomes of the SWFL and its habitats, managers should:

1) Design and implement restoration at the priority sites based on the best available science;
2) Monitor using standardized protocols the status and trends of the SWFL and ecosystem conditions;
3) Evaluate whether targeted outcomes are met; and
4) Determine if and how future management actions should be adjusted through the AM process.

As water resources and funding are limited and managers must balance the habitat needs for multiple species of conservation concern, managers also might want to evaluate whether the SWFL habitat restoration prioritization strategy acts as an “umbrella” for other species of concern, promoting restoration successes for such species as the YBCU and the RGSM, or if is strategically advantageous to integrate the SWFL habitat restoration prioritization strategy into a comprehensive habitat restoration prioritization strategy for the MRG.

Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 1* priority (Table 9) and was ranked #1 of the top four SWFL critical scientific uncertainties identified by the SMEs.

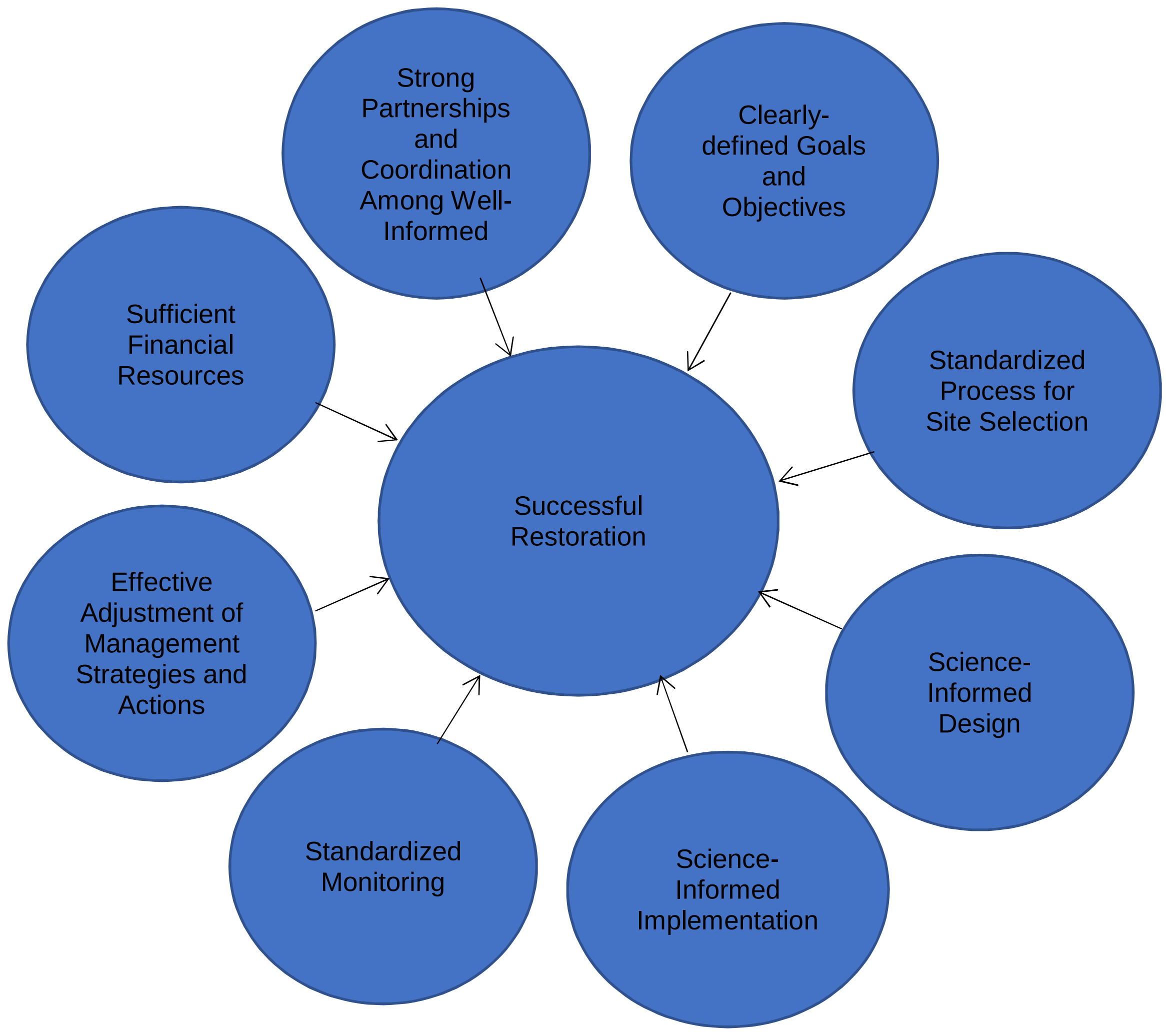

Figure 16. Examples of factors that contribute to habitat restoration success.

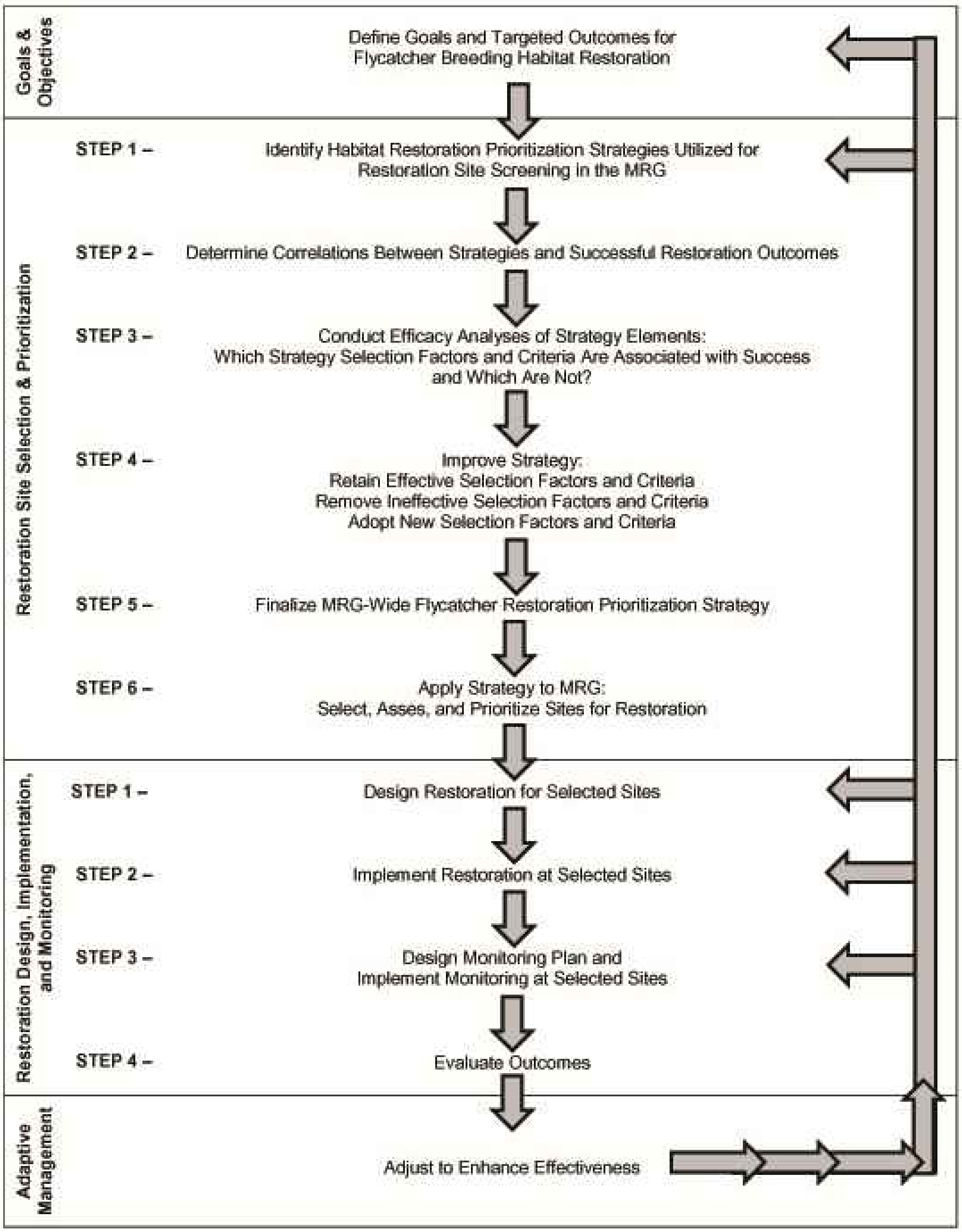

Figure 17. Middle Rio Grande-wide Southwestern Willow Flycatcher habitat restoration prioritization strategy development process, and how this process feeds into other habitat restoration actions and adaptive management.

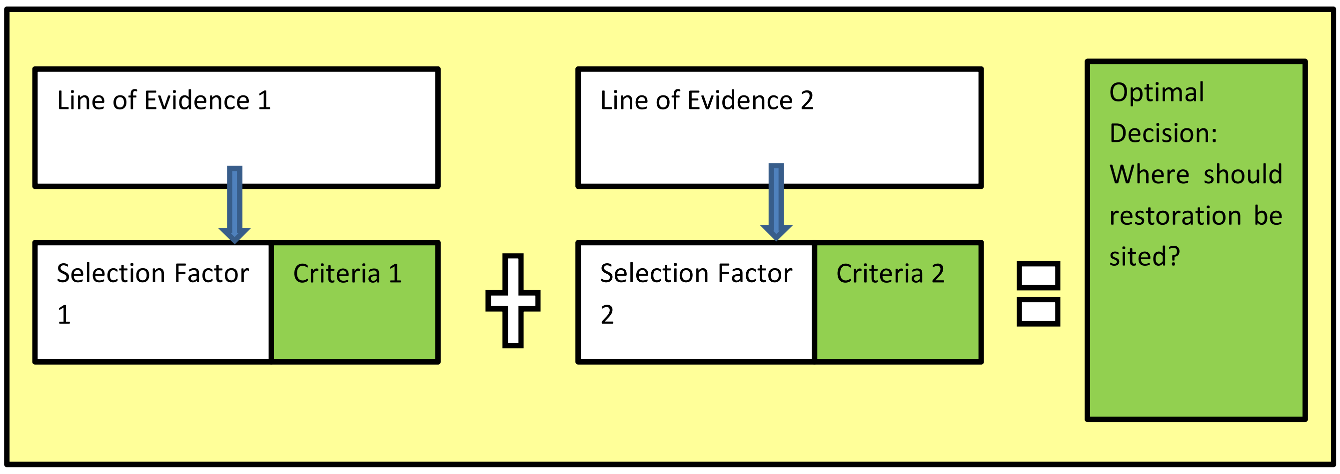

Figure 18. Multi-criteria Habitat Restoration Prioritization Strategy*.

*Model (adapted from the Lower Columbia Estuary Partnership [LCEP 2012]) showing how optimal decisions regarding evaluation and prioritization of restoration projects are based on inclusion of selection factors and criteria that are derived from rigorous scientific information about the life history requirements and recovery needs of the southwestern willow flycatcher (Line of Evidence).

CRITICAL SCIENTIFIC UNCERTAINTY #2: THE IMPACTS OF THE TAMARISK BEETLE

Study Question 1: What are the impacts of the tamarisk beetle (*Diorhabda*) on SWFLs and suitable SWFL breeding habitats in the MRG?

Study Question 2: Which unoccupied and occupied suitable SWFL breeding habitats in the MRG are most threatened by *Diorhabda* in the near- and long-term?

Scientific Relevance

THE IMPACTS OF THE TAMARISK BEETLE

SCIENTIFIC RELEVANCE

The establishment and spread of *Diorhabda* in the MRG could negatively impact breeding SWFLs by altering the composition and abundance of the arthropod prey community, decreasing SWFL nest success, and reducing the availability and suitability of SWFL nesting substrates and habitats. However, the actual impacts of *Diorhabda* on SWFLs and suitable SWFL breeding habitats are largely unknown and little studied. As a large proportion of SWFLs nesting in the MRG could be negatively impacted by *Diorhabda* defoliation and resultant dieoffs of tamarisk, scientific studies are needed to improve our understanding of the ecological impacts of *Diorhabda* on the SWFL.

About 54% of all SWFL nesting attempts across the Southwest up until 2007 and 34% of all SWFL nesting attempts in the MRG from 1999 to 2014 were in mixed native and exotic vegetation or in exotic-dominated vegetation (Durst et al. 2008, Moore and Ahlers 2016). In addition, 49% of all SWFL nests located in the MRG from 1999 to 2014 were placed in an exotic plant (Moore and Ahlers 2016). The predominant exotic plant used by the SWFL is tamarisk or saltcedar, a long-lived (50-100 years) deciduous tree native to arid regions of the Eastern Hemisphere that was first introduced into the United States in the early 1800s for stabilization of eroding stream banks and for use as both ornamentals and windbreaks (DeLoach 1997, Durst et al. 2008, Moore and Ahlers 2016). Introduced tamarisk is now a dominant plant species in most southwestern riparian ecosystems at elevations below 1,500 m (4,921 ft), where it often forms large monotypic stands to the exclusion of native plants (DeLoach 1997, Friedman et al. 2005). Tamarisk is of management concern in the Southwest because it can alter ecosystem function (e.g., the natural fire regime), create unsuitable growing conditions for other plants, and restructure native southwestern animal communities (DeLoach 1997; Walker 2006, 2008).

In an effort to control the spread of tamarisk in the Southwest, a chrysomelid leaf beetle, *Diorhabda*, was released beginning in 2001 in Colorado, Nevada, California, Utah and other states, with the restriction that release sites be more than 322 km (200 miles) from any known SWFL breeding territory

(Dudley et al. 2001, Dudley and Bean 2012). In New Mexico, *Diorhabda* was released only in the eastern part of the state; it was released at several sites along the Rio Puerco from about 2003 to 2007, which resulted in local large-scale defoliation, and at Holloman Air Force Base, Otero County in 2008 and 2009 (D. Thompson and K. Gardner, NMSU, pers. comm.). However, by 2009, *Diorhabda* populations originally established in 2001 in the Four Corners region of Utah and Colorado had spread into northwestern New Mexico (Tamarisk Coalition 2016). On 26 August 2010, H. Walker (then with NMDGF) and D. Hill (USFWS) followed up on a report of *Diorhabda* at Morgan Lake, San Juan County, and found the beetles at the lake and other locales in San Juan County (Fruitland, Kirkland, Farmington, and Bloomfield), as well as along Hwy 550 about 32 km (20 miles) west of Cuba, Sandoval County. By September 2011, *Diorhabda* was documented along the Rio Jemez and Rio Grande on the Pueblo of Santa Ana, Sandoval County (G. Harper, Pueblo of Santa Ana, pers. comm.), and several other locales along the Angostura Reach, Sandoval and Bernalillo counties (pers. obs.). Subsequently, the beetle continued to disperse rapidly and it is now considered to be present throughout the MRG (Johnson and Jamison 2015, Tamarisk Coalition 2016, BEMP 2016).

As *Diorhabda* is now firmly established in the MRG and its spread is unchecked, it can potentially have substantial impacts on tamarisk vegetation and the SWFLs that use it. Understanding these impacts was identified as a critical scientific uncertainty in the Adaptive Management Plan Version 1 (Murray et al. 2011:27), and there remains much uncertainty regarding the impacts of the tamarisk beetle on the SWFL and its habitats in the MRG and elsewhere in the Southwest. Since the first known instance of tamarisk beetle herbivory occurring in a SWFL nesting site on the Virgin River near St. George, Utah in 2008, several studies have documented how SWFL habitats are affected by tamarisk beetle larvae defoliation of trees and resultant death of trees after several years of defoliation (e.g., Hatten 2016, Tracy et al. *in prep*). In the MRG, the 1) geographic distribution and abundance of *Diorhabda,* and 2) timing and extent of *Diorhabda*-caused tamarisk defoliation and refoliation currently are being tracked at both SWFL breeding sites and unoccupied sites (Johnson and Jamison 2015, BEMP 2016, Dillon and Ahlers 2017, Tamarisk Coalition 2016, USFWS unpubl. data). However, no comprehensive, rigorous quantitative scientific studies have been completed in the MRG or elsewhere to address the multitude of ways that *Diorhabda* can positively and negatively impact the SWFL and its required habitats. Much of what is known about the potential impacts of *Diorhabda* on SWFLs comes from a meta-analysis by Paxton et al. (2011). From their literature review on the effects of other defoliating insects on birds and their comparative study on the natural history of the tamarisk beetle with that of the SWFL, Paxton et al. (2011) conclude that *Diorhabda*-mediated control of tamarisk can potentially impact the SWFL by altering arthropod prey composition and availability, reproductive success, and suitable habitat availability (Figure 19Figure 8):

- **Arthropod Prey Composition and Availability**

  Diorhabda likely provides a food source for the insectivorous SWFL in the short-term; however, this positive effect likely is temporary and, after an increase in beetle populations, decreases in foliage might result in declines in *Diorhabda* and native foliage arthropods, as well as pollinating arthropods attracted to flowering tamarisk.

- **Reproductive Success**

  In the spring, prior to defoliation, *Diorhabda*-infested tamarisk vegetation can appear suitable to SWFLs arriving on the breeding grounds and, thus, entice SWFLs to establish territories and nest. However, by mid-summer, *Diorhabda* defoliation of tamarisk generally reaches its peak, coinciding with peak SWFL breeding (see BEMP 2016 for data in the MRG). The loss of foliar cover during this critical phase of the SWFL's breeding cycle can reduce SWFL nest success by exposing nests to predators, brood parasitism by the brown-headed cowbird, and comparatively high summer temperatures (which decreases the ability of eggs and young to effectively thermoregulate). As *Diorhabda* defoliation of tamarisk does not result in mortality for several years and *Diorhabda*-infested tamarisk vegetation will appear suitable to breeding SWFLs each year it refoliates, such vegetation can act as an ecological trap for SWFLs that results in multiple years of reduced nest success and potential population declines. (However, studies by Dobbs [2012] suggest that SWFLs can switch their preference from nesting in tamarisk to nesting in native plants after as little as one year of reduced nest success from beetle-caused reductions in foliar cover.)

- **Suitable Habitat Availability**

  Diorhabda defoliation eventually (usually within three to five years) results in mortality of tamarisk, ultimately reducing the availability of nest substrates and the availability and connectivity of suitable SWFL breeding and foraging habitats (see also Tracy et al. *in prep*). The long-term consequences of tamarisk mortality on SWFL population stability and metapopulation structure and dynamics depend on the rate of recovery of suitable vegetation after tamarisk dieoffs and the availability of other suitable vegetation within and adjacent to tamarisk vegetation.

Although Paxton et al. (2011) provides a very thorough review of the potential impacts of *Diorhabda* on the SWFL, understanding the actual impacts of *Diorhabda* on the SWFL and its required breeding habitats in the MRG will require scientific inquiry. Specifically, more information is needed on whether SWFLs and its breeding habitats in the MRG are experiencing the potential impacts bulleted above, and which SWFL populations and suitable breeding habitats in the MRG are most threatened by *Diorhabda* in the near- and long-term.

Management Application

THE IMPACTS OF THE TAMARISK BEETLE MANAGEMENT APPLICATION
Studies investigating this critical scientific uncertainty will meet the Collaborative Program's needs for science-based advancements in our knowledge of the impacts of *Diorhabda* on the SWFL and its habitats. Data from such studies can inform management decision-making approaches to tamarisk removal, native habitat restoration, and other mitigation actions to minimize *Diorhabda* threats to the SWFL. Principally, rigorous quantitative scientific information on how and where *Diorhabda* affects the SWFL and its habitats currently or in the near-future will be useful for developing a strategy for selecting and prioritizing for restoration suitable SWFL breeding habitats that are most at risk of potentially large-scale negative impacts from *Diorhabda* defoliation and resultant dieoffs of tamarisk. Such proactive restoration implemented by Collaborative Program partners is essential to minimizing *Diorhabda* threats to the SWFL.

Despite efforts to protect SWFLs breeding in tamarisk by releasing *Diorhabda* outside of (i.e., greater than 200 miles from) occupied SWFL breeding habitats, *Diorhabda* has spread unaided from release sites into and across the MRG (Tamarisk Coalition 2016). Both the Adaptive Management Plan Version 1 (Murray et al. 2011) and the 2016 BiOp (USFWS 2016) recognize the potential for *Diorhabda* to negatively impact the SWFL and its habitats in the MRG. To better understand and quantify these impacts, the 2016 BiOp (USFWS 2016:116) recommends that BiOp partners continue to work to advance our knowledge about tamarisk issues using the latest science (Conservation Recommendation 14). Similarly, the New Mexico State Wildlife Action Plan (NMDGF 2016) recommends determining *Diorhabda*'s current distribution and their impacts on native species and habitats.

Studies investigating the critical scientific uncertainty will assist managers in meeting recommendations for science-based advancements in our knowledge of the impacts of *Diorhabda* on the SWFL and its habitats. In addition, data from such studies will guide management decision-making approaches to tamarisk removal and native habitat restoration. Principally, quantitative scientific information on how and where *Diorhabda* affects the SWFL and its habitats currently or in the near-future will be useful for developing a strategy for selecting and prioritizing for restoration those habitats suitable for breeding SWFLs that are most at risk of potentially large-scale negative impacts from *Diorhabda* (see Element 2.1, Action 2.1.1, Task 2.1.1a in USBR 2013:39; Conservation Actions in NMDGF 2016:142; see SWFL Critical Scientific Uncertainty #1). Implementation of proactive restoration by Collaborative Program partners is essential to minimizing *Diorhabda* threats to the SWFL, as defined in the 2013 Collaborative Program Recovery Implementation Program: a task of the Collaborative Program partners is to "aim to be proactive in replacing habitat prior to being degraded from salt cedar leaf beetles (*sic*) with native species within the Collaborative Program boundaries" (Task 2.1.1.c; USBR 2013:40).

Recovery Application

THE IMPACTS OF THE TAMARISK BEETLES RECOVERY APPLICATION
Research on the impacts of *Diorhabda* on both the SWFL and tamarisk-dominated vegetation suitable to the SWFL falls within a priority research topic identified in the Recovery Plan, *Identify factors that may be limiting population stability* (Recovery Action 6.7.2). Results of this research will assist managers in implementing recovery actions to: 1) increase and improve suitable and potentially suitable SWFL breeding habitats by managing exotic plant species (Recovery Action 1), and 2) improve demographic parameters (Recovery Action 3). Furthermore, study results will help managers implement laws, policies, and agreements that benefit the SWFL (Recovery Action 8).

Releases of *Diorhabda* in the Southwest began in 2001, about a year prior to the publication of the Recovery Plan (USFWS 2002). The Recovery Plan (USFWS 2002) does not recommend any recovery actions to specifically address any potential issues arising from *Diorhabda* invasion into SWFL habitats, likely because, in an effort to protect SWFLs breeding in tamarisk, release of the beetle was restricted to sites that were greater than 200 miles from any known SWFL breeding territory. Instead, the Recovery Plan (USFWS 2002) solely recommends that the siting restrictions on *Diorhabda* releases be strictly adhered to (Recovery Action 1.1.3.2.6.2). Nonetheless, studies on the impacts of *Diorhabda* on the SWFL and tamarisk-dominated vegetation suitable to the SWFL in the MRG will assist managers in implementing a number of recovery actions listed in the Recovery Plan (USFWS 2002), including:

- Addressing a priority research topic relevant to recovery efforts, *Identify factors that may be limiting population stability* (Recovery Action 6.7.2);
- Increasing and improving suitable and potentially suitable SWFL breeding habitats by managing exotic plant species (Recovery Action 1.1.3.2); and
- Improving demographic parameters (Recovery Action 3).

Specifically, as described above in Management Application, the research will provide information useful in designing and implementing tamarisk removal and native habitat restoration efforts aimed at preventing or mitigating potentially large-scale negative impacts to the SWFL (e.g., reduced survival, reduced nesting success) resulting from *Diorhabda* defoliation and resultant tamarisk dieoffs.

By assisting managers in implementing recovery actions 1, 3, and 6, results from studies on the impacts of *Diorhabda* on the SWFL and SWFL breeding habitats in the MRG will help managers implement BiOps resulting from ESA Section 7(a)(2) consultations (Recovery Action 8.2; e.g., USFWS 2016) and support conservation efforts in compliance with ESA Section 7(a)(1) of the ESA (Recovery Action 8.3.1).

Study Plan Considerations

The critical scientific uncertainty is a complex topic and it, along with the two study questions, should be addressed by adopting an integrative research strategy that involves answering a number of interrelated questions. Specifically, it is necessary to ascertain where *Diorhabda* are and where they will be, how *Diorhabda* alter their environment, and what vegetation will remain after *Diorhabda*–caused tamarisk defoliation and mortality. The geographic distribution and abundance of *Diorhabda* and the timing and extent of tamarisk defoliation by *Diorhabda* and refoliation currently are being tracked in the MRG (e.g., Johnson and Jamison 2015, BEMP 2016, Tamarisk Coalition 2016, Dillon and Ahlers 2017) and are incidentally recorded during standardized SWFL surveys (USFWS unpubl. data). However, these efforts should be expanded to encompass the entire MRG and to address questions specific to the critical scientific uncertainty, such as:

- What proportions of unoccupied and occupied suitable SWFL breeding habitats in the MRG are currently or will be in the near future infested with *Diorhabda*?
- Does the timing of tamarisk defoliation by *Diorhabda* in the MRG coincide with SWFL nesting?

Concurrent or consecutive to *Diorhabda*–specific studies, the impacts of *Diorhabda* on the SWFL and its required habitats should be evaluated where *Diorhabda* occurs in unoccupied and occupied habitats suitable to breeding SWFLs. This evaluation likely is best accomplished by conducting separate, but complimentary, rigorous quantitative studies investigating interactions of multiple trophic levels and multiple ecosystem components across multiple temporal and spatial scales. Priority questions for study include:

- What are the relationships of *Diorhabda* abundance and tamarisk defoliation with SWFL nest success in the MRG?
- How does *Diorhabda* defoliation and resultant dieoffs of tamarisk alter prey composition and availability in SWFL breeding habitats in the MRG?
- How does *Diorhabda* defoliation and resultant dieoffs of tamarisk alter microhabitat and patch characteristics of unoccupied and occupied suitable SWFL breeding habitats in the MRG?
- Is passive revegetation of native vegetation occurring in areas where *Diorhabda* defoliation has resulted in tamarisk dieoffs and, if so, is this vegetation suitable or projected to become (i.e., potentially) suitable for breeding SWFLs?
- Does *Diorhabda* significantly reduce SWFL breeding habitat suitability and availability in the MRG?

Studies addressing the critical scientific uncertainty should utilize existing datasets, as well as build on and augment completed and on-going work (see Appendix C-2, *Flycatcher Critical Scientific Uncertainty*

#3). For example, data on the distribution of suitable SWFL habitats and SWFL populations in the MRG can be compiled from existing literature (e.g., Siegle et al. 2013, Tetra Tech 2015, Hatten 2016, Tracy et al. *in prep*) and standardized SWFL survey reports (e.g., Moore and Ahlers 2017) and databases (e.g., USFWS unpubl. data).

The integrative research strategy required for answering the critical scientific uncertainty necessitates knowledge of a diversity of disciplines (e.g., ornithology, entomology, botany, demography, community ecology), sampling techniques and technologies (e.g., nest monitoring, arthropod collection, vegetation sampling), data analysis and modelling methods (e.g., analyzing large, multivariate datasets), collection and management of large ecological datasets, and data collection over multiple years. Aspects such as logistics, cost, study duration, and training and permit requirements will depend on the types of studies conducted and methods employed.

Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 2* priority (Table 9) and was ranked #2 of the top four SWFL critical scientific uncertainties identified by the SMEs.

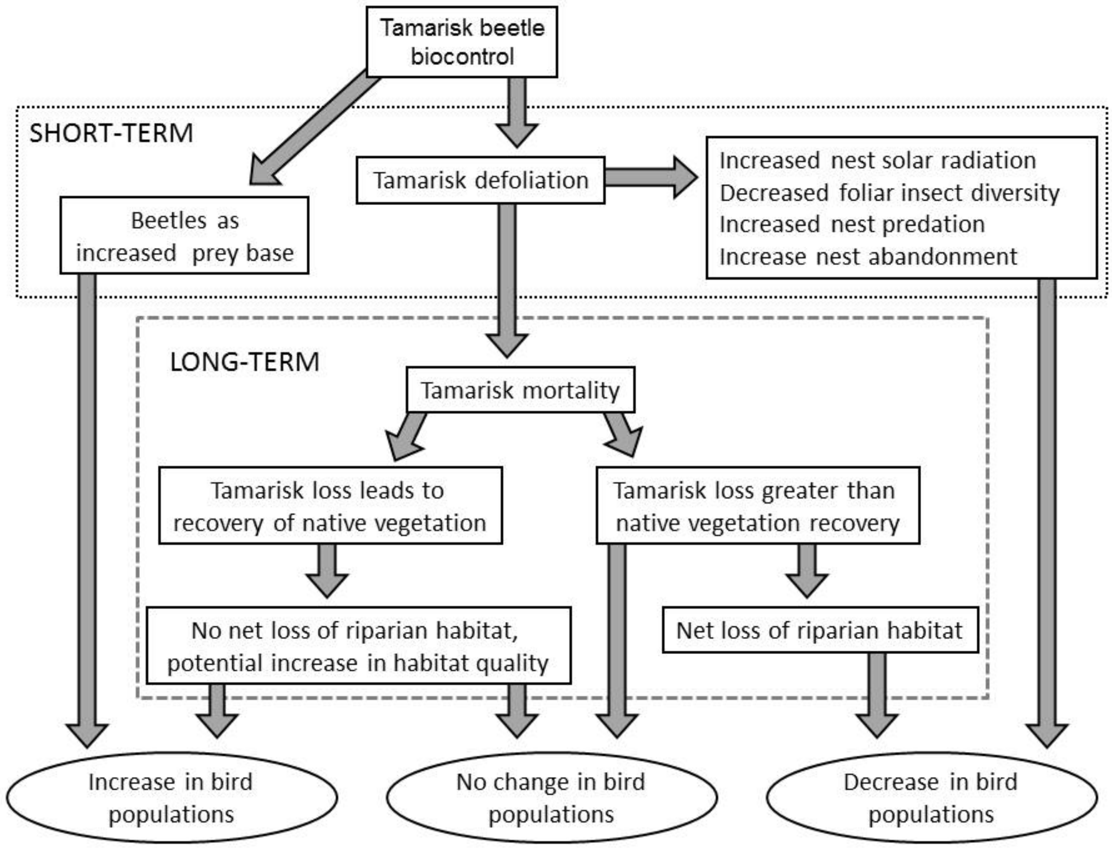

Figure 19. Hypothesized Model of Effects on Tamarisk Beetle on Birds*.

*Hypothesized model of three primary ways that biocontrol of tamarisk trees by the tamarisk beetle can affect avian populations in riparian systems (reproduced with permission from Paxton et al. [2011:258]). In the short term, prior to the trees' death, tamarisk beetles could provide a food source for insectivorous birds as beetle populations expand. Defoliation and mortality of tamarisk, however, will eventually reduce habitat quality by reducing abundance of other insect prey dependent on foliage and by removing canopy cover critical for reducing exposure of nests to predators, brood parasites and the extreme temperatures typical of the southwestern United States. The long-term consequences of tamarisk mortality will depend on the rate of vegetation recovery after the tamarisk dies; these consequences might range from no net loss of habitat if native vegetation recovers at the same rate as tamarisk dies to net loss of habitat when tamarisk mortality is not followed by regrowth of other riparian vegetation.

CRITICAL SCIENTIFIC UNCERTAINTY #3: SOUTHWESTERN WILLOW FLYCATCHER POPULATION STATUS IN THE ANGOSTURA REACH

Study Question: What are the sizes, distributions, and trends of SWFL breeding populations along the Angostura Reach?

Scientific Relevance

SOUTHWESTERN WILLOW FLYCATCHER POPULATION STATUS IN THE ANGOSTURA REACH

SCIENTIFIC RELEVANCE

SWFL survey and monitoring efforts are extensive in the MRG. However, suitable SWFL breeding habitats in some areas along the Rio Grande have never been surveyed, have not been surveyed recently, or have been surveyed inconsistently. Thus, it is challenging to compute an accurate MRG-wide population estimate. In order to improve population estimates for the MRG, additional surveys are needed where efforts are outdated, inconsistent, minimal, or absent. Most importantly, concurrent and repeated standardized SWFL surveys should be conducted within all suitable SWFL breeding habitats along the Angostura Reach. Results of these surveys will help to determine with better accuracy if and where the SWFL is present in the reach, as well as the sizes and trends of any located SWFL breeding populations. To identify which factors affect SWFL breeding populations in the reach, survey efforts should be augmented by scientific investigations on potential limiting factors, such as those on habitat availability, prey composition and availability, and nest success.

Starting about the time of the proposed federal listing of the SWFL as endangered in 1991 and the eventual federal listing of the SWFL as Endangered in 1995 (USFWS 1995), SWFL survey and monitoring efforts substantially increased across the SWFL's range and are now extensive in New Mexico, particularly along the Rio Grande (USFWS 2002, Durst et al. 2008). Survey protocols were developed and subsequently revised to facilitate standardized SWFL population data collection, integration, and reporting (Tibbitts et al. 1994; Sogge et al. 1997, 2010; USFWS 2000). The USFWS and NMDGF compile the survey data annually (Durst et al. 2008, USFWS unpubl. data) to determine if recovery criteria established in the Recovery Plan (USFWS 2002) are being met. Recent survey data indicate that the numerical recovery criteria of 100 for the MRG Management Unit are currently surpassed, primarily due to high numbers of breeding SWFLs along the San Marcial Reach near Elephant Butte Reservoir (USFWS 2002, Moore and Ahlers 2016). Thus, the current status of the SWFL within the MRG is considered stable (Moore and Ahlers 2016, USFWS 2016). However, developing an accurate MRG-wide population estimate is challenging because 1) SWFL populations change numerically and spatially over time, 2) not all suitable SWFL habitat has been surveyed, and 3) population estimates are composites of population estimates derived from multiple years as not all sites are surveyed concurrently within a given year

(USFWS 2002). In order to improve population estimates for the MRG, additional surveys are needed where efforts are outdated, inconsistent, minimal, or absent.

One such reach where additional survey effort is needed is the Angostura Reach, which runs from Angostura Diversion Dam, Sandoval County south through Bernalillo County to Isleta Diversion Dam, Valencia County. Examination of results for all survey sites along the Angostura Reach over the past two decades indicate that SWFLs regularly migrate through the reach, but that breeding in the reach is likely limited to small populations located on Pueblo lands (USFWS unpubl. data). However, population estimates for this reach are based on outdated and incomplete data; standardized SWFL surveys have not been conducted in the reach for 10 of the past 21 years, much of the reach has not been surveyed recently, and coverage of suitable SWFL breeding habitats in the reach within any given year has been incomplete and fragmented (USFWS unpubl. data) (Figure 3). Specifically, much of the vegetation on the west side of the Rio Grande between the Highway 550 and Alameda Boulevard bridges and several sites on both banks of the river south of the Rio Bravo Boulevard bridge have not been surveyed since 1996 or earlier (USFWS unpubl. data) (Figure 20). In addition, the stretch of the reach south of the Rio Bravo Boulevard SW bridge has received inconsistent survey effort over the past 21 years; of the 17 sites surveyed, about half (nine) haven't been surveyed in 12-16 years, while the rest (eight) were surveyed in 2016.

To resolve issues in data collection and quality for the Angostura Reach, there is a need for standardized SWFL surveys conducted concurrently, repeatedly, and within all suitable SWFL breeding habitats, particularly those proposed for biotic, geomorphologic, and hydrologic alterations. Results of these surveys will help to determine with better accuracy where SWFLs are present and SWFL population sizes and trends in both the reach and the MRG. To identify which factors affect SWFL breeding populations in the reach, it is essential that survey efforts be augmented by scientific investigations on potential limiting factors (e.g., availability of suitable habitat, nest predation, human disturbance, *Diorhabda*, river flows).

Management Application

SOUTHWESTERN WILLOW FLYCATCHER POPULATION STATUS IN THE ANGOSTURA REACH

MANAGEMENT APPLICATION

Concurrent and repeated standardized SWFL surveys within all suitable SWFL breeding habitats along the Angostura Reach, particularly those proposed for biotic, geomorphologic, and hydrologic alterations, will provide managers with the data necessary for effectively planning and assessing their actions in the reach.

The Angostura Reach has experienced substantial anthropogenic biological, hydrological, and geomorphological alterations in the past two decades, and a number of management actions (e.g., exotic plant removal, planting of native vegetation, and construction of ephemeral channels, backwater channels and embayments) are ongoing and proposed (USFWS 2016:46-48). Section 7(a)(2) of the ESA requires that all agencies involved in federally authorized, funded, or implemented water management actions in the MRG must ensure that those actions do not jeopardize the SWFL's continued existence or result in the destruction or adverse modification of the SWFL's critical habitat. To assure compliance with the ESA, the 2016 BiOp (USFWS 2016) requires that the USBR, BIA, NMISC, and other BiOp partners fully implement Reasonable and Prudent Measures and Conservation Measures, including securing data on locations of breeding SWFLs and their nests to determine the anticipated level of incidental take from management actions (USFWS 2016: Reasonable and Prudent Measures 7.4 & 7.9), as well as if and what mitigation is required (USFWS 2016: Conservation Measure 61).

Sogge et al. (2010:1) state, "Sound management and conservation of an endangered species like the [SWFL] requires current, detailed information on its abundance and distribution. This requires, among other things, identifying where SWFLs are and are not breeding, and annual monitoring of as many breeding areas as possible." Currently, managers lack such information needed for sound management and conservation in the Angostura Reach due to the fact that SWFL survey efforts in the reach have been incomplete geographically and inconsistent temporally. Concurrent and repeated standardized SWFL surveys within all suitable SWFL breeding habitats along the Angostura Reach, particularly those proposed for biotic, geomorphologic, and hydrologic alterations, will provide managers with the data necessary for effectively mitigating and assessing the effects of their actions on SWFLs in the reach. Principally, survey data on locations of breeding SWFLs will inform siting of management actions in the following ways:

- Projects that benefit the SWFL (e.g., planting native vegetation) can be sited near existing SWFL populations; and
- Projects that jeopardize the SWFL (e.g., vegetation removal) can be sited away (e.g., greater than 0.4 km [0.25 mile]) from breeding territories and nest sites.

Furthermore, data on where SWFL populations are declining and which factors are limiting or threatening SWFL populations can help managers determine which and where management actions should be implemented to improve the status of the SWFL. Finally, survey data collected before, during, and after implementation of management actions can help managers evaluate the effects of their actions on SWFLs and implement AM.

Recovery Application

SOUTHWESTERN WILLOW FLYCATCHER POPULATION STATUS IN THE ANGOSTURA REACH

RECOVERY APPLICATION

Results from standardized SWFL surveys along the Angostura Reach will assist mangers in implementing the Recovery Plan's standardized approach to 1) surveying and monitoring SWFL populations, 2) assessing the status of and dynamics (e.g., dispersal, colonization) in SWFL populations, and 3) determining the effects of management on SWFL populations (Recovery Action 5). In addition, survey results will inform siting of recovery actions to benefit and avoid jeopardy to the SWFL (recovery actions 1 and 3). Similarly, studies on which factors limit SWFL populations in the reach will address a priority research topic (Recovery Action 6.7.2: *Identify factors that may be limiting population stability*), and will provide data essential for determining where and which recovery actions should be implemented to improve the status of the SWFL (Recovery Action 6.7.2: *Identify factors that may be limiting population stability*). By assisting managers in implementing recovery actions 1, 3, 5, and 6, studies on the critical scientific uncertainty will help managers implement laws, policies, and agreements that benefit the SWFL (Recovery Action 8).

The Recovery Plan (USFWS 2002) recommends that SWFL breeding populations and suitable SWFL breeding habitats in the Southwest be surveyed and monitored to assess population status and trends, and track recovery progress (Recovery Action 5: *Survey and Monitor*). Completing comprehensive SWFL surveys in the Angostura Reach can contribute to these recovery efforts by helping to determine with greater accuracy if recovery criteria are being met for the Middle Rio Grande Management Unit, the Rio Grande Recovery Unit, the State, and rangewide (Recovery Action 5.1.3). Furthermore, when surveys are repeated in the reach over multiple years, they can help to document dispersal movements, colonization events, and population changes (Recovery Action 5.3). In addition, surveys conducted before and after implementation of recovery actions can be used to assess the efficacy of such actions (recovery actions 5.2, 5.2.1).

As described above in Management Application, survey results, such as locations of breeding SWFLs and their nests, also are useful for informing siting of recovery actions. In particular, survey results can help to ensure that recovery actions, such as habitat restoration, are sited sufficiently near existing SWFL breeding populations to benefit the SWFL (Recovery Action 1: *Increase and improve currently suitable and potentially suitable habitat*), but are not sited too close to existing SWFL breeding populations that they jeopardize SWFLs or their nests (Recovery Action 3.1.2: *Reduce direct impacts that topple or otherwise destroy nests*). Similarly, studies on which factors are limiting or threatening SWFL populations in the reach – a priority research topic identified in the Recovery Plan (Recovery Action 6.7.2: *Identify factors that may be limiting population stability*) – can provide data essential for determining where and which recovery actions should be implemented to improve the status of the SWFL.

By assisting managers in implementing recovery actions 1, 3, 5, and 6, studies on the critical scientific uncertainty will help managers implement BiOPs resulting from ESA Section 7(a)(2) consultations (Recovery Action 8.2; e.g., USFWS 2016) and support conservation efforts in compliance with ESA Section 7(a)(1) of the ESA (Recovery Action 8.3.1).

Study Plan Considerations

Addressing the critical scientific uncertainty involves data mining, standardized protocol surveys (e.g., Sogge et al. 2010), nest searching and monitoring, and, possibly scientific research. Specifically, determination of historical and recent SWFL population sizes and distributions along the Angostura Reach requires extensive data mining of hardcopies of survey forms dating back at least 20 years, as well as cross-checking survey form entries with corresponding information in the USFWS database (unpubl. data). Investigation of current SWFL population sizes and distributions entails 1) verifying and mapping locations of previous survey routes to ensure consistency in site-naming and to establish and name new survey routes, 2) coordinating standardized protocol surveys and data reporting among any and all agencies and organizations involved in on-going surveys of the reach, and 3) completing standardized protocol surveys (e.g., Sogge et al. 2010) in those areas not covered by existing surveys. All sites along the reach should be surveyed concurrently within each year of the study to ensure that survey results are comparable within and among years. In addition, multiple years of surveys are necessary to assess SWFL population trends in the Angostura reach and whether population sizes are increasing, decreasing, or remaining stable.

To identify which factors affect SWFL breeding populations in the reach, it is essential that survey efforts be augmented by scientific investigations on potential limiting factors, such as those on habitat availability, prey composition and availability, and nest success. These investigations likely involve time- and labor-intensive fieldwork conducted over multiple years. Therefore, separate studies likely will be necessary to investigate each factor. Wherever possible, data should be obtained from completed and on-going complimentary studies (e.g., see SWFL critical scientific uncertainties #2 and 4). If resources are limited, surveys are a priority over investigations on potential limiting factors.

Field studies will require permission to access survey sites from a multitude of landowners (municipal, county, state, federal, and tribal) and any work entailing SWFL surveys, monitoring, and handling will necessitate obtaining specialized training and permits (e.g., SWFL survey, detection, and nest monitoring training and ESA Section 10a permits).

Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level* 2 priority (Table 9). It was ranked #3 of the top four SWFL critical scientific uncertainties identified by the SMEs, but the ranking was nearly tied for second place with the Critical Scientific Uncertainty #2 *The Impacts of the Tamarisk Beetle*.

ID	Last Year Surveyed	Site Name
1	1996	Bernalillo Islands
2	2015	NM 550 Bridge
3	2004	Rio Rancho Bosque Preserve
4	2016	IC (Corrales)
5	2011	Corrales Burn
6	2004	Corrales Cabezon Rd to Alemeda
7	2016	South Corrales
8	2005	Paseo del Norte Diversion Site
9	2004	BE01: Calabacillas Arroyo North
10	1996	Calabacillas Islands
11	2004	BE02: Calabacillas Arroyo South
12	2004	BE03: Los Ranchos Site
13	2004	Paseo del Norte Mitigation
14	2013	Montano Southwest - Graham Property
15	2004	Side Channel at Oxbow Mitigation
16	2016	San Antonio Oxbow
17	2008	Rio Grande Nature Center
18	2001	ALB01/Montano to I-40 Eastside
19	2004	Campbell Pipeline (west)
20	2004	Campbell Pipeline (east)
21	1996	I-40 Central Bridge
22	2015	Central Wasteway
23	1997	Central Ave. Sand Bar (west)
24	2004	Central Ave. Bridge
25	2004	BE04: Southeast Side of Central Ave. Bridge
26	2016	Central Ave SE (Rt. 66)
27	2003	Zoo Bar
28	1996	Tingley Beach
29	2016	Tingley Bar
30	2004	BE05: Tingley Bar
31	2004	BE06: Hispanic Cultural Center
32	2004	BE07-08: Glass Gardens North
33	2004	BE09: Glass Gardens South
34	2004	BE10: Northeast of Rio Bravo
35	2016	Rio Bravo Northeast
36	2004	BE11: Southeast of Rio Bravo
37	2016	Rio Bravo SE (4B)
38	2004	BE12: Near Wastewater Treatment Plant
39	2016	South Division Channel (4C)
40	2004	BE13: South Diversion Channel, North Side
41	2004	BE14: South Diversion Channel, South Side
42	2016	Durand Outfall
43	2016	Site 5B - south of SDC, east side of river
44	2016	Brown Burn
45	2016	5C - west of Valle de Oro
46	2002	State Land Office Bosque
47	2005	Price's Dairy
48	2004	BE15: Price's Dairy
49	2004	BE16: North of I-25
50	2016	I-25 West
51	2004	BE17: South of I-25

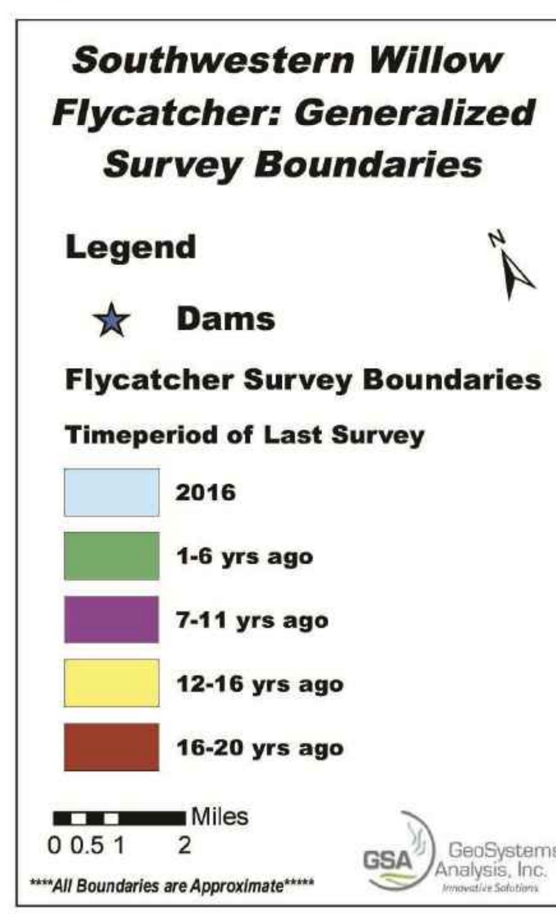

Figure 20. Southwestern Willow Flycatcher Survey Sites Since 1996*.

*Sites within the Angostura Reach of the Rio Grande, from Angostura Diversion Dam to Isleta Diversion Dam, that have been surveyed for southwestern willow flycatchers since 1996 based on data in the USFWS southwestern willow flycatcher standardized survey results database (unpubl. data). Those sites that did not have geographic locality data in the database were not mapped. Shape of survey sites are not representative of the actual survey areas and are, instead, linear representations based on the start and end points provided in the database. Sites that were partly or entirely located within tribal lands are not shown.

CRITICAL SCIENTIFIC UNCERTAINTY #4: SOUTHWESTERN WILLOW FLYCATCHER METAPOPULATION STRUCTURE AND DYNAMICS

Study Question: What is the connectivity among SWFL populations in the MRG?

Scientific Relevance

SOUTHWESTERN WILLOW FLYCATCHER METAPOPULATION STRUCTURE AND DYNAMICS

SCIENTIFIC RELEVANCE

No SWFL metapopulation studies have been completed in New Mexico. Existing SWFL survey and monitoring efforts in New Mexico primarily document territory locations and do not provide data on connectivity and stability of populations. Information gained from studies conducted outside of the State, such as those in Arizona, cannot be directly applied to the MRG as both metapopulation structure and dynamics are influenced by local population sizes and the spatial arrangement of SWFL breeding habitats at local and landscape scales. Thus, MRG-specific information is needed as to whether populations in the MRG function as metapopulations, which populations are sources and which are sinks, and how changes in one population affect other populations. In addition, information specific to the MRG is needed to determine if and how SWFL metapopulation structure and dynamics will be affected by any future loss, fragmentation, degradation, and restoration of riparian woodlands.

In general, riparian areas that support breeding SWFLs are characterized by the presence of the following (USFWS 2002, Sogge et al. 2010):

- Dense and expansive tree or shrub cover that is three m (10 ft) tall or higher (with or without a higher overstory layer);
- Dense twig structure;
- High levels of live green foliage;
- Adjacent lentic (slow-moving, swampy, or still) surface water;
- Moist or saturated soil; and
- Willow, tamarisk, or both.

The distribution of the SWFL's preferred breeding habitats varies spatially across the floodplain in response to the presence and persistence of surface water, saturated soils, and groundwater; suitable breeding habitat is patchily distributed along slow-moving, low-gradient reaches, as well as along river backwaters, swampy abandoned channels and oxbows, marshes, beaver ponds, and river inflows into reservoirs (e.g., Elephant Butte Reservoir) (USFWS 2002). In addition, the distribution of the SWFL's preferred breeding habitats varies temporally due to within and between year variation in river flows and precipitation, disturbance events (e.g., fluctuating reservoir levels, fire, or high magnitude floods that result in scouring), and natural succession, maturation, and degradation of riparian vegetation (USFWS 2002).

SWFLs in the MRG and across the Southwest are well adapted to surviving and reproducing within diverse and dynamic riparian ecosystems, easily moving within and among breeding sites within and among years in response to local conditions (Kenwood and Paxton 2001, USFWS 2002, Paxton et al. 2007). As a result of the comparatively high level of vagility in the SWFL, the species persists across southwestern riparian landscapes as discrete (spatially separate) local subpopulations that are connected as metapopulations by movement (i.e., immigration and emigration) (USFWS 2002). The topic of SWFL metapopulation structure (i.e., the number, size, and distribution of metapopulations) and dynamics (i.e., the processes that connect and effect metapopulations, such as extinction and colonization through immigration and emigration) is well-studied and thoroughly reviewed by both USFWS (2002) and Paxton et al. (2007). The below bulleted conclusions can be derived from the two respective works:

- SWFL breeding populations are connected by dispersal both within and between drainages and within and between years (USFWS 2002, Paxton et al. 2007).
- There is higher connectivity among SWFL breeding sites within the same drainage; however, rare between-drainage dispersal events likely sustain between-drainage genetic connectivity and could be important for the periodic colonization of unoccupied drainages (Paxton et al. 2007).
- Metapopulations tend to be connected by dispersing adults that have experienced poor reproductive success in the previous year and by dispersing young birds (Paxton et al. 2007).
- Metapopulation structure and dynamics are influenced by the distribution of available suitable habitats (Paxton et al. 2007).
- Large (more than 10 territories), centrally-located populations contribute most to metapopulation stability, especially if other breeding populations are nearby, because they persist longer than small ones and produce more dispersers emigrating to other populations or colonizing new areas (USFWS 2002).
- Smaller populations can contribute to metapopulation stability when arrayed in a metapopulation matrix with high connectivity (USFWS 2002).

- Increases or decreases in one population affect other populations (USFWS 2002).
- Those landscapes that support features (e.g., linear water courses) that promote the connection (by immigration and emigration) of geographically separate (but within 30 to 40 km [18 to 25 miles] of each other) and relatively large SWFL breeding populations are most likely to support stable and persistent SWFL breeding populations (USFWS 2002, Paxton et al. 2007).
- Metapopulation stability is more likely to improve by adding more breeding sites rather than adding more individuals to existing sites (USFWS 2002).

The above conclusions are derived from data collected in Arizona, California, Nevada, and southeast Oregon; no metapopulation studies have been completed in New Mexico. The USFWS (2013) contends that, as Paxton et al. (2007) analyzed data collected both during a 10-year SWFL study in central Arizona and from numerous other SWFL studies, conclusions presented in Paxton et al. (2007) extend beyond a localized, regional area. Nonetheless, Paxton et al. (2007:75) state, “Flycatcher dispersal tendencies are influenced by the geographic distribution of habitat at the reach, drainage, and landscape scales.” Thus, results from Paxton et al. (2007) cannot be directly applied to SWFL breeding populations in the MRG. Furthermore, they do not provide information on the connectively of SWFL populations specific to the MRG. Therefore, rigorous scientific inquiry in the MRG is required to understand whether populations within the MRG function as metapopulations, which populations are sources and which are sinks, how changes in one population affect other populations, and if and how SWFL metapopulation structure and dynamics will be affected by any future loss, fragmentation, and degradation of riparian woodlands (see Murray et al. 2011:26).

Management Application

SOUTHWESTERN WILLOW FLYCATCHER METAPOPULATION STRUCTURE AND DYNAMICS

MANAGEMENT APPLICATION

To offset the effects of water management actions on the SWFL and its habitat, managers must protect, restore, and create riparian vegetation that is occupied by breeding SWFLs and promotes flourishing and stable SWFL metapopulations in the MRG. To this end, managers require, in part, effective and MRG-specific restoration siting criteria. Such criteria can be crafted, to some extent, based on the results of studies on SWFL metapopulation structure and dynamics; these studies yield useful data on 1) at what distance efforts to establish, develop, and maintain suitable SWFL breeding habitats in the MRG should be sited from existing SWFL breeding populations to ensure successful colonization of restoration sites, and 2) how best to geographically distribute restoration efforts across the MRG to connect spatially disjunct SWFL breeding populations and promote metapopulation dynamics. In addition to informing management decision-making approaches to siting habitat restoration efforts, SWFL metapopulation studies should help to determine where and which management actions should be implemented and the effects of these actions on the status of the SWFL in the MRG by providing data on SWFL population responses to landscape changes and

Habitat restoration is a vital management strategy for species of conservation concern that experience loss, fragmentation, and/or degradation of their habitat. However, there is no evidence that on-going and completed restoration of native riparian woodlands in the MRG has successfully offset SWFL breeding habitat loss and degradation resulting from water management (SWCA 2014, USFWS unpubl. data). To achieve future SWFL habitat restoration successes, MRG managers must not only create sites that support abiotic and biotic features required by breeding SWFLs, but must ensure that restoration sites are:

- Established close enough to existing SWFL breeding sites to promote rapid and successful colonization; and
- Geographically distributed in such a way that spatially disjunct SWFL breeding populations function as metapopulations (i.e., are connected by immigration and emigration).

Recent data derived from an extensive color-marking study conducted in Arizona suggest that restoration sites should be no more than 97-120 km (60.3-74.6 miles) from and within 30-40 km (18.6-25.9 miles) of an existing SWFL breeding population (Paxton et al. 2007, USFWS 2013). However, managers require MRG-specific information on effective project siting criteria (see SWFL Critical Scientific Uncertainty #1); SWFL dispersal tendencies are influenced by the spatial arrangement of breeding habitats at local and landscape scales (Paxton et al. 2007) and no data exist from the MRG on SWFL dispersal and breeding metapopulation connectivity.

SWFL metapopulation dynamics studies in the MRG will provide MRG-specific information on at what minimum and maximum distances restoration sites need to be from existing SWFL populations and other restoration sites in order to 1) ensure successful colonization, 2) connect isolated suitable habitat to breeding populations, and 3) increase population sizes to achieve metapopulation stability. Therefore, study results should help to inform efforts to successfully site restoration projects, such as efforts to develop a habitat restoration prioritization strategy (see Flycatcher Critical Scientific Uncertainty #1). Furthermore, if metapopulation studies investigate SWFL population responses to landscape changes (e.g., habitat loss) and management actions (e.g., habitat restoration), they will provide data essential to AM efforts by informing where and which management actions should be implemented and the effects of these actions on the status of the SWFL in the MRG.

Recovery Application

SOUTHWESTERN WILLOW FLYCATCHER METAPOPULATION STRUCTURE AND DYNAMICS

RECOVERY APPLICATION

Research on SWFL metapopulation structure and dynamics, particularly on dispersal, is identified as a priority in the Recovery Plan (Recovery Action 6). Results from this priority research can assist managers in implementing the Recovery Plan's spatially explicit approach to recovery, which involves increasing metapopulation stability and reducing the chances of extinction due to genetic isolation and catastrophic events (Recovery Action 2). Research results also can help managers implement laws, policies, and agreements that benefit the SWFL (Recovery Action 8).

Research on SWFL metapopulation structure and dynamics, particularly on dispersal, is identified as a priority in the Recovery Plan (Recovery Action 6: USFWS 2002). Results from this priority research can assist managers in implementing the Recovery Plan's (USFWS 2002) spatially explicit approach to recovery, which involves increasing metapopulation stability rather than simply maximizing the number of individuals throughout the SWFL's range (Recovery Action 2; USFWS 2002:100). For example, results of metapopulation research in the MRG can provide local managers with information (e.g., the critical amount and configuration of SWFL habitat that is necessary for long-term metapopulation persistence) useful for promoting SWFL occupation of restoration sites and achieving stable SWFL metapopulations within the Middle Rio Grande Management Unit. In addition, collected data on SWFL population responses to landscape changes and recovery actions can help managers determine where and which recovery actions should be implemented and the effects of these actions on the status of the SWFL in the MRG. By helping managers recover the SWFL, study results also can assist managers in their efforts to implement BiOps resulting from ESA Section 7(a)(2) consultations (Recovery Action 8.2; e.g., USFWS 2016) and comply with ESA Section 7(a)(1) of the ESA (Recovery Action 8.3.1).

Study Plan Considerations

Definitions for metapopulation vary, but they all are in agreement that metapopulations are composed of geographically discrete subpopulations that are connected by dispersing individuals (e.g., Levins 1970, Hanski and Gilpin 1997, Morris and Doak 2002, Newton 2004). Thus, as movement of organisms among habitat patches is a key aspect of metapopulation structure and dynamics, metapopulation study generally involves quantifying dispersal patterns and dynamics. This is true for the SWFL, where metapopulation structure and dynamics have been documented primarily by tracking movements and site fidelity in color-banded and radio-telemetered birds along the Gila, San Pedro, Colorado, and Salt rivers in Arizona – as well as elsewhere in Arizona, California, Nevada, and southeast Oregon (Cardinal et al. 2006; Koronkiewicz et al. 2004, 2006; McLeod et al. 2008; Paxton et al. 2007; Sedgwick 2004). Data on the age and sex of tracked birds (from blood samples and morphological data collected from banded birds), habitat characteristics of source and dispersal populations, availability and distribution of suitable habitats, and nest success provide evidence as to which factors influence movement and site fidelity (e.g., Paxton et al. 2007).

Although substantial information on metapopulation structure and dynamics has been gained from SWFL dispersal studies in Arizona, such efforts have involved labor-intensive fieldwork to obtain sufficient sample sizes; for example, Paxton et al. (2007) banded and tracked 1,080 adults and 498 nestlings from 1996 to 2005. Because collecting movement data is both time- and money-intensive, models addressing dispersal can provide vital alternatives to fieldwork that are more time- and cost-effective (Akcakaya et al. 2007). Modelling can be used to look at the following:

- Patterns of SWFL population synchrony and rates of extinction and recolonization, and the extent to which the populations operate as metapopulations.
- How SWFL inhabit networks of habitat patches in fragmented landscapes, and the relationship among population dynamics, movement, and landscape features.
- Possible SWFL population responses to landscape changes and management actions at multiple spatial scales.
- The critical amount and configuration of SWFL habitat that is necessary for long-term metapopulation persistence.
- How SWFL populations can persist over a network of habitat patches of specified sizes and distances.
- The dependence of SWFL extinction risk on subpopulation sizes and the degree of connectivity among subpopulations.

In the MRG, the primary study question is "What is the connectivity among SWFL populations in the MRG?" In addition, there are at least three subquestions of interest: 1) At what minimum and maximum distances are SWFL breeding populations connected by metapopulations dynamics?; 2) Which SWFL populations in the MRG are sources and which are sinks, and how do changes in one population affect other populations?; and 3) How does loss, fragmentation, and degradation of riparian habitats – and, conversely, restoration and creation of habitats – affect metapopulation structure and dynamics in the MRG? Given the different approaches available to understanding metapopulation structure and dynamics, there is much flexibility and variety in the types of studies undertaken and methods employed to address the study questions. Studies can be empirical (i.e., collection of observational data, field-based AM experiments), theoretical (i.e., modelling), or both. In addition, studies can use a multitude of methods to assess dispersal and factors influencing movement (e.g., tracking individuals, genetic analyses, isotope analyses, satellite models). Aspects such as logistics, cost, study duration, and training and permit requirements will depend on the types of studies conducted and methods employed. Any work entailing SWFL surveys, monitoring, and handling will necessitate obtaining specialized training and permits (e.g., SWFL survey, detection, and nest monitoring training and ESA Section 10a permits).

Priority Ranking

Addressing this critical scientific uncertainty was ranked #4 of the top four SWFL critical scientific uncertainties identified by the SMEs, and is considered a Level 3 priority (Table 9).

Table 9. Study framework attributes for critical scientific uncertainties for the Southwestern Willow Flycatcher.

Uncertainty Statement/ Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Priority
The strategy for prioritizing sites for SWFL habitat restoration in the MRG. • What site selection and prioritization procedures contribute to the successful restoration of SWFL breeding habitats along the MRG?	• Promote successful occupancy by/maintenance of breeding populations on restoration sites • Ensure the MRGGESCP cost-effectively and successfully offsets effects of water management actions in compliance with the ESA	Data mining: • Scientific and gray literature on SWFL life history requirements and recovery needs • Existing SWFL habitat suitability models • Strategies currently implemented in MRG and other large ecosystem-level restoration programs Original quantitative field-based and remote sensing scientific studies: • Strategies currently being utilized in MRG • Efficacy of MRG strategies • Selection factors and criteria that should be included in SWFL strategy	• Efficacy of MRG strategies • Selection factors and criteria: o Landownership o Land use o Habitat features including vegetation floristics and structure, o Geographic extent of habitat o Proximity/connectivity to existing high quality riparian habitat o Presence/proximity to existing SWFL populations o Processes that promote PCEs, e.g., hydrogeomorphic elements, groundwater depth, and river flows o Threats to SWFL populations	• Multi-year • MRG	• Collecting large datasets • Qualified and permitted personnel • Integrative research strategy that synthesizes results of a number of interrelated studies	Level 1
The impact of the tamarisk beetle (*Diorhabda*) on SWFL breeding habitats in the MRG. • What are the impacts of the tamarisk beetle (*Diorhabda*) on SWFLs and SWFL breeding habitats in the MRG? • Which unoccupied and occupied suitable SWFL breeding habitats in the MRG are most threatened by *Diorhabda* in the near- and long-term?	• Minimize threats and create/restore SWFL breeding habitats	• Data mining • Literature reviews • Modelling • Field surveys and observations	*Diorhabda*: • Distribution and abundance • Direction and rate of spread • Timing of defoliation • Presence in suitable SWFL habitat SWFL: • Availability and distribution of suitable breeding habitats • Prey composition and availability • Nest success Habitat where *Diorhabda* absent and present: • Vegetation floristics, structure, and other features • Microclimate and other microhabitat features • Occurrence of passive native revegetation suitable for SWFLs	• Multi-year • MRG	• Land access and permission • Qualified and permitted personnel • Collecting large datasets • Investigating interactions of multiple trophic levels and ecosystem components across multiple temporal and spatial scales • Integrative research strategy that synthesizes results of a number of interrelated studies	Level 2

Table 9. Study framework attributes for critical scientific uncertainties for the Southwestern Willow Flycatcher.

Uncertainty Statement/ Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Priority
SWFL presence, population size, and population status along the Angostura Reach. • What are the sizes, distributions, and status of SWFL populations along the Angostura Reach?	• Assess and monitor effects of management actions • Ensure MRGESCP cost-effectively and successfully offsets effects of water management actions in compliance with the ESA o Site beneficial projects (e.g., planting native vegetation) near existing SWFL populations o Site jeopardizing projects (e.g., vegetation removal) away from SWFL breeding territories and nest sites to avoid take	Data mining: • Forms of previous SWFL surveys submitted to USFWS Literature Review: • Recent reports on SWFL population size, distribution, and status/trends Field Surveys: • Current distribution • Population size • Population status/tends • Nest monitoring	• Distribution • Population sizes • Population trends • Nest success	• Multi-year • Angostura Reach	• Land access and permission • Qualified and permitted personnel • Obtaining hardcopies and electronic copies of previous (> 20 yrs) surveys • Ensuring continuity and consistency in data collection over multiple years • Ensuring all survey sites are completed concurrently within each year of the study	Level 2
SWFL metapopulation structure and dynamics in the MRG. • What is the connectivity among SWFL populations in the MRG?	• Identify at what distance to site habitat restoration projects from existing SWFL breeding populations: o Increase successful near-term occupancy o Achieve long-term metapopulation stability • Assess success of habitat creation/restoration efforts to increase metapopulation stability • Develop a coordinated restoration strategy to promote/maintain flourishing and stable SWFL metapopulations	Much flexibility and variety in study types and methods: • AM experiments • Tracking of individuals • Genetic analyses • Isotope analyses • Satellite models	• Distances among breeding populations • Dispersal distances and rates • Age and sex • Breeding site connectivity • Reproductive success • Suitable habitat distribution • Population size • Annual population changes • Population longevity	• Multi-year • MRG	• Considerations, including logistics, cost, study duration, and training and permit requirements, depend on the types of studies conducted and methods employed	Level 3

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Appendix D-1: Yellow-Billed Cuckoo Workshop Summary Notes

MIDDLE RIO GRANDE ADAPTIVE MANAGEMENT FRAMEWORK
WESTERN YELLOW-BILLED CUCKOO
Technical Workshop

October 26, 2016
The Artichoke Café, Albuquerque, NM MEETING SUMMARY

Goals and Objectives *(from the agenda)*:

- Learn and discuss the state of the science for the YBCU.
- Develop a list of key *management-relevant* scientific uncertainties for each species in the Middle Rio Grande, and prioritize the group's top five.

1. Action Items and Next Steps

- ALL – Submit relevant YBCU journal articles, agency reports, etc. to Debbie Lee at dlee@west-inc.com for inclusion in the AMT Wiki site (https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/Adaptive%20Management%20Team.html).
- GEOSYSTEMS ANALYSIS TEAM – Define and re-submit top five uncertainties to workshop attendees for additional review.
- GEOSYSTEMS ANALYSIS TEAM – Develop study plan frameworks to address top five uncertainties. Circulate draft study plan frameworks to workshop participants for review and comment prior to presenting to the Program AMT and EC.

2. Meeting Notes

Welcome and Introductions

Debbie Lee (WEST) opened the meeting by welcoming participants and inviting them to introduce themselves. Representatives from the following organizations were in attendance (a full attendee list is located at the end of this summary):

- Albuquerque-Bernalillo County Water Utility Authority (ABCWUA)
- Assessment Payers Association (APA)
- Bureau of Indian Affairs (BIA) Southwest Regional Office (BIA SWRO)
- City of Albuquerque Open Space Division (COA OSD)
- Middle Rio Grande Conservancy District (MRGCD)
- New Mexico Interstate Stream Commission (NMISC)
- Pueblo of Sandia
- Pueblo of Santa Ana
- US Army Corps of Engineers (USACE)
- US Bureau of Reclamation (USBR)
- US Fish and Wildlife Service (USFWS)
- US Forest Service – Rocky Mountain Research Station (USFS-RMRS)

Additionally, individuals from the GSA team (composed of GSA, WEST, and Kearns & West) participated in the meeting.

Todd Caplan, the project manager from GSA, reviewed meeting goals and emphasized, by the end of each day of the workshop, the primary goal is to develop a list of five key *management-relevant* scientific uncertainties that will be used to craft study plan frameworks. GSA and the consultant team will work to refine these five uncertainties, vet them with workshop participants, and use them to develop study plan frameworks that will be reviewed by both workshop participants and the AMT before being submitted to the Collaborative Program EC. These study plan frameworks will address key elements of a study plan needed to address monitoring and research questions for each species. The intent is that the Collaborative Program will utilize the study plan frameworks to solicit proposals and detailed study plans from the scientific community.

Key Scientific Uncertainties

The following five key scientific uncertainties for the YBCU were identified by workshop participants. Note that related sub-questions and sub-topics are detailed under *Key Scientific Uncertainties Discussion* below. Additional thoughts and questions related YBCU scientific uncertainties that arose during the workshop are catalogued below under the sub-heading *Additional Scientific Uncertainties, Questions, and Suggestions for Further Study.* The GSA project team will work to refine these five key scientific uncertainties, vet them with workshop participants, and use them to develop study plan frameworks that will be reviewed by both workshop participants and the AMT before being submitted to the Collaborative Program EC. The purpose of the study plan frameworks is to aid in solicitation and prioritization of proposals and detailed study plans from the scientific community.

1. *YBCU movement within and among breeding seasons (when, to where, and how far), and drivers (e.g., water, vegetation, prey, etc.)*
2. *Degree of overlap in SWFL and YBCU habitat requirements*
3. *Which abiotic and biotic variables predict suitable and unsuitable YBCU habitats across multiple spatial and temporal scales*
4. *The size and distribution of YBCU populations within the MRG and how they change over time*
5. *The timing and availability of YBCU prey and which factors influence both*

***PRESENTATION*: Dave Moore – Western Yellow-billed Cuckoo in the Middle Rio Grande** Dave Moore, USBR, presented on the western YBCU, summarizing the state of the science by reviewing the following six topics: (1) description; (2) taxonomy and ESA listing; (3) breeding biology and life history; (4) habitat requirements; (5) survey methods; and (6) status, trends, and threats. The presentation is available on the AMT Wiki website (https://webapps.usgs.gov/MRGESCP/Wiki/mainSpace/Adaptive%20Management%20Team.html).

3. Yellow-Billed Cuckoo Discussion

Throughout Mr. Moore's presentation, workshop participants discussed the state of the science with respect to the YBCU in the MRG. The following section summarizes this discussion and is organized by presentation topic.

Taxonomy and ESA Listing

Ms. Ryan commented that USFWS is experiencing challenges finalizing critical habitat designations for New Mexico and Arizona, and she was unable to predict when critical habitat designations for the YBCU would be released.

Breeding Biology and Life History

Mr. Moore commented that there is limited YBCU nest site data from the MRG, and that most YBCU nest site data come from the LCR. Mr. Caplan noted that YBCU are responding quickly to artificial habitat created on irrigated farmland along the LCR as part of the LCR Multi-Species Conservation Program, and Mr. Ahlers added that nest success data from artificially restored sites demonstrate what can be expected on the MRG if restoration and water management are implemented.

Dr. Walker noted that migrating YBCU will stop along their migration route and breed if prey is available and that YBCU are flexible in where and when they will breeding according to prey availability.

Mr. Ahlers added that limited data are available on the migration and wintering phases of the YBCU that breed along the MRG, and only slightly more data is available on MRG home-range/site-specific patterns. Banding efforts have yielded no returns, and radio telemetry offers few data points. Mr. Moore commented that site fidelity information is primarily based on data from the LCR, but even LCR sample sizes are small.

Habitat Requirements

Ms. Nishida noted that the YBCUs were present on restoration sites within the Pueblo of Santa Ana in 2016 and, though she was not surveying explicitly for the YBCU, she detected them on numerous occasions, confirming some by sight and others by call. The YBCUs were observed in mixed aged stands of native-exotic riparian vegetation. Other participants commented on hearing signature YBCU calls in spring and summer of 2016 in various locations in New Mexico.

Participants discussed vegetation characteristics of YBCU nest sites. Dr. Walker shared that she has observed YBCU in monotypic Russian-olive stands adjacent to cottonwood gallery forest, while Ms. Nishida commented that YBCUs on the Pecos used to be found in tamarisk in greater numbers than are found today. Mr. Ahlers and Mr. Moore emphasized that while YBCU are found in exotics including tamarisk, they are more commonly found in habitats with some native vegetation component.

Mr. Moore cautioned that sample sizes of YBCU studies are small.

Dr. Marcus asked to clarify if YBCUs were commonly spotted on a channel boundary or riparian vegetation boundary. Mr. Moore responded that they tended to be found on ‘edge’ territory, whether it be the edge of a riparian patch, the channel, a bluff, or cattails along a marsh. Ms. Ryan confirmed that ‘edge’ siting seems to be a range-wide pattern as similar associations were observed in California YBCU.

Mr. Moore noted that vegetation associated with territories and nest sites placement generally contained a native canopy layer, but data also indicate YBCU prefer to place their territories and nests in multi-structured vegetation patches. Mr. Caplan suggested that the group should consider distinguishing the attributes and spatial scales of habitats currently occupied by breeding YBCU along the MRG from those occupied at LCR restoration sites, as the LCR restoration sites are considerably smaller. Ms. Nishida noted that the YBCUs she observed occupied areas with a distinct canopy and sub-canopy, and that the YBCUs appeared to be moving among patches on both sides of the river, suggesting connectivity. Mr. Ahlers observed that not many YBCU occupy riparian habitat adjacent to farmland until native vegetation becomes established, but that YBCU do occupy similar riparian habitats where adjacent habitats are other than farmland.

Dr. Walker initiated a discussion on landscape-scale habitat considerations and asked the question: *what factors predict YBCU presence at multiple spatial scales, from the landscape scale to the nest site?* Mr. Ahlers responded that restoration efforts try to spread out patches within land available to them, but that generally there is not sufficient space to manage restoration on a landscape scale. In response to a question from Dr. Cartron about YBCU presence on the LRG where riparian vegetation is limited, Mr. Ahlers responded that not many are found on the LRG. Mr. Caplan considered Dr. Walker’s question in the context of adjacent habitat, suggesting that urban areas make for poor adjacent habitat, agriculture makes for moderate adjacent habitat, and native vegetation makes for the best adjacent habitat. Dr. Walker replied, indicating adjacent habitat is important but that YBCU process visual cues at a landscape level that dictate where the species stop to establish nest sites or search for prey. Mr. Moore emphasized the importance of core breeding habitats where YBCU spend up to 95% of their time and which tend to have a greater proportion of native canopy, native understory, and exotic understory than has other nearby habitat.

<u>Survey Methods</u>
Ms. Ryan commented that there are tradeoffs in survey methods, and the potential disturbance to YBCU caused by a fifth survey might not merit the marginal increased 1% detection payoff.

Mr. Moore stated the opinion that the current standard survey protocol has been refined over a decade and that it should be finalized, and that collected data should be compiled in a central database. Ms. Ryan informed the participants the USFWS is developing a database for this purpose. Mr. Ahlers commented that not all YBCU detections should be used to identify key habitat features for restoration purposes, because outlier YBCU observations (i.e., non-breeding pair individuals) are commonly recorded and these outlier observations do not help identify breeding habitat. Ms. Ryan said that these outlier detections are valuable for other purposes such as foraging information. Mr. Ahlers commented on the process used by USBR to confirm possible or probable breeding pairs documented during surveys, and Ms. Ryan noted that USBR's additional confirmation of possible or probable breeding pairs is not a required part of the standard survey protocol. Dr. Walker suggested that incidental YBCU detections also should be databased.

In response to a comment from Dr. Cartron on the apparent difficulty of locating YBCU nests given the larger sample size produced from work in that area, Mr. Moore responded that the LCR nests were identified through nest searching and radio telemetry, and that nest searching is not part of USBR's scope of work. Dr. Cartron emphasized the value of increasing MRG YBCU nest site sample sizes.

Status, Trends, and Threats

Mr. Caplan asked what the major differentiators are among river reaches that affect YBCU populations; what are the limiting factors in each reach? Mr. Moore suggested that reaches with lower YBCU numbers could be explained by floodplain land use; for example, the urbanized and agriculture-rich floodplains exhibit lower populations than do the more native reaches downstream. Mr. Moore also noted that the hydrology, habitat availability, and width of the floodplain changes among reaches.

Mr. Ahlers observed that, as the Elephant Butte Reservoir dropped, vegetation expanded and YBCU detections were all recorded along the peripheral edge of the floodplain, suggesting that adjacent uplands are important for prey. Mr. Ahlers also noted that the recession of the reservoir demonstrates how quickly riparian habitat can develop under dynamic hydrological conditions and how quickly the YBCU will take residence in new riparian habitat. Mr. Moore commented that there is risk to YBCU populations if the reservoir rises, but that dislocation of reservoir YBCU populations could cause increases in nearby populations. *Participants recognized changes in Elephant Butte Reservoir as a key uncertainty in YBCU management.* Mr. Caplan commented that the potential impact on riparian habitat resulting from changes in reservoir levels highlights the value of upstream restoration that would create habitat to accommodate displaced reservoir populations. Mr. Ahlers noted that vegetation that has matured beyond that required by the SWFL habitat is suitable habitat for YBCU.

Participants identified past and present YBCU survey efforts and catalogued the following:

- USBR has conducted formal surveys south of Isleta since 2006; population and abundance data are available
- The Pueblo of Santa Ana conducted surveys from 2005-2009 before using the formal survey protocol; surveys at the time were shorter in duration.
- The Pueblo of Sandia conducted formal surveys in 2016 and anticipates conducting formal surveys in 2017.

- USACE is performing formal surveys at restoration sites and will survey all current restoration sites in 2017.

4. Priority Key Scientific Uncertainties Discussion

Through thoughtful discussion, workshop participants identified the top five key scientific uncertainties detailed above. Participants discussed and elaborated on each of these, noting monitoring and research considerations for each of the top five scientific uncertainties that will inform development of study plan frameworks:

1. YBCU movement within and among breeding seasons (when, to where, and how far), and drivers (e.g., water, vegetation, prey, etc.)

- Addressing this uncertainty might be achievable within a breeding season.
- Banding has historically yielded limited results; gathering 'among season breeding' data would, therefore, pose a greater challenge and require greater resources than gathering 'within breeding season' data.
- Increased banding and survey efforts should yield an increased understanding of YBCU movement patterns.
- Should 'among breeding seasons' be a top five priority relative to other priorities?
- Can inter-annual movement be assessed through extrapolation of annual breeding data from specific river reaches?
- Telemetry is a feasible method for gathering 'within breeding season' data.
- USBR has funded a multi-year telemetry study.
- For what area do we answer this research question?
    - Restoration projects could be located in areas where YBCU populations are low, but the potential for YBCU occupation after restoration is high.
    - Researchers could identify 'functionally similar' habitats, currently occupied by YBCU, to inform potential restoration sites where YBCU are not currently found.
    - The limitations of restoration locations should be considered with respect to potential future changes in Elephant Butte/MRG levee locations.
    - Though on-the-ground restoration projects are confined to specific areas due to permitting, scientific studies could feasibly be performed on territory outside of the designated restoration area boundaries.

2. Degree of overlap in SWFL and YBCU habitat requirements (No additional discussion was held on this uncertainty.)

3. Which abiotic and biotic variables predict suitable and unsuitable YBCU habitats across multiple spatial and temporal scales

- Reference the table created for the YBCU questionnaire that provides specific variables.
- Consistency in terminology is important, and the following are a preliminary foundation for consistent terminology with respect to YBCU habitat areas:
    - Nest Site = location of nest and immediate surroundings
    - Core Use Area = nesting site + core breeding patch (50%; approximately seven hectares [ha])
    - Home Range = nesting site + core breeding patch + extended foraging
    - Landscape/Floodplain (to be defined by the GSA team, with input from the SMEs)
- Parameters for these distinct spatial scales can be weighted in a habitat suitability model to reflect importance to site selection.
- Information from California indicates that the SWFL cues in on different habitat parameters at different spatial scales.
- There is a need for more nest searches to be able to characterize nest sites with greater accuracy.
- Data collection methods used to answer this question could overlap with methods identified in Uncertainty #1, #3, #4, and #5.
- This uncertainty could be informed by data from both created/restored sites *and* natural sites.
- This uncertainty can help inform the development of a study plan to determine which characteristics of active restoration sites attract the YBCU.

4. The size and distribution of YBCU populations within the MRG and how they change over time

- More surveys and nest monitoring is needed to refine the existing understanding of YBCU population distributions and sizes.
- Many parameters could impact population fluctuations (e.g., proximity to/presence of water, vegetation structure, depredation, prey availability, etc.).
- Habitat factors are less likely to impact population fluctuations than other parameters, because habitat factors do not fluctuate as dramatically as YBCU populations.

- The geographic scope will impact which population trends can be identified (e.g., river reach vs. MRG).
- A potential follow-up question is: what is causing identified changes to YBCU population distribution and sizes?

5. *The timing and availability of YBCU prey and which factors influence both*

- Reference: Smith, D. M., J. F. Kelly, and D. M. Finch. 2006. Cicada emergence in southwestern riparian forest: influences of wildfire and vegetation composition. Ecological Applications 16: 1608-1618.

Additional Scientific Uncertainties, Questions, and Suggestions for Further Study Importantly, other scientific uncertainties and topics of interest were identified throughout the workshop beyond the top five key scientific uncertainties. These are catalogued here by topic, question, and goals (some of these questions could be nested under the top five key scientific uncertainties):

5. Breeding and Migration

1. Migration Patterns
   - *Question:* What is the timing of arrival to and departure from Middle Rio Grande breeding sites?
   - *Question:* What are the YBCU migratory routes and stopover locations?
     - *Goal:* Inform timing of monitoring and siting of restoration projects
2. Prey Availability
   - *Question*: How is timing and location of breeding linked to prey availability/emergence?
     - *Goal:* Inform restoration siting and design
3. Nesting Variables
   - *Question:* What are the key factors contributing to nesting success/failure (e.g., depredation, proximity to water, etc.)?
     - *Goal*: Inform restoration siting and design
4. Other
   - Survivorship/Demographics
   - Site Fidelity and Dispersal

6. Habitat Requirements

1. Core Habitat Patch vs. Surrounding Habitat

- *Question:* What are the key habitat characteristics of a 'core patch' versus 'surrounding habitat/overall patch/adjacent habitat'?
- *Question*: How are these two sub-habitats spatially defined?
- *Question*: Is there sufficient MRG data to identify and weigh habitat attributes to support a Habitat Suitability Model?
- *Question*: What are the limiting factors in YBCU habitat selection (i.e., which habitat parameters are most important in breeding site selection)?
- *Question*: How can we increase sample sizes?
  - *Goal:* Inform restoration siting and design

2. Connectivity/Landscape Scale

- *Question*: What is the importance of landscape-scale attributes to YBCU breeding site selection/habitat occupancy given the mobility of the YBCU (i.e., how does diversity of topography, size of floodplain, length of habitat 'edge,' etc. affect YBCU site selection/behavior)?
- *Question:* Site fidelity – how far will a YBCU travel among sites?
- *Question:* How will climate change impact habitat connectivity for the YBCU?
  - *Goal*: Inform restoration siting and design

3. Vegetative Structure

- *Question*: What vegetative compositions and features (plant species, structure, etc.) comprise preferred YBCU breeding habitats?
- *Question*: What is the longevity/persistence of YBCU habitats (e.g., how long will habitats remain suitable to the YBCU)?
- *Question*: What are the potential effects of *Diorhabda* on the vegetative structures of potential YBCU habitat/restoration sites?
  - *Goal*: Inform restoration siting and design

4. Hydrology

- *Question:* What is the importance of hydrology in YBCU habitat?
  - *Goal*: Inform restoration siting and design

5. Nest Sites
   - *Question:* Where are YBCUs nesting and what are the key habitat features of nest sites?
     - *Goal*: Inform restoration siting and design and population estimates

7. **Survey Methods**
   1. Sensitivity to Disturbance
      - *Question:* Can YBCU surveys be combined with SWFL surveys to minimize disturbance?
        - *Goal*: Inform survey/monitoring protocol
   2. Sample Size
      - *Question:* How can we increase sample sizes via surveys, etc. to inform restoration?
        - *Goal*: Increase data availability to inform restoration planning
   3. Other
      - Finalize survey forms and data reporting
      - Statewide/range database to be compiled (USFWS is developing…)
      - Reporting consistency/subjectivity

8. **Status/Trends and Threats**
   1. Sensitivity to Disturbance
      - *Question*: What are YBCU sensitivities to human disturbance and how do they manifest in YBCU behavior?
   2. Survey Data
      - *Question*: What additional data collection is needed and from where should these data come (e.g., upstream of Isleta Diversion Dam)?
        - *Goal*: Increase data availability to inform restoration planning
   3. Population Fluctuations
      - *Question*: What are the causes of YBCU population fluctuations (e.g., immigration/emigration, survival, habitat variability, prey availability, etc.)?
        - *Goal*: Increase understanding of population trends

4. Genetic Diversity

- *Question:* Is there sufficient genetic diversity in the MRG population to prevent bottlenecking?
  - *Goal*: Increase understanding of population trends

5. Restoration

1. *Question:* What is the variability in habitats of restored sites and occupied YBCU breeding sites, and what is the suitability of each habitat type and what are the commonalities in attributes among them?
2. *Question:* What are the characteristics of active restoration sites attracting the YBCU?
   - *Goal*: Inform prioritization of future restoration sites

Middle Rio Grande Adaptive Management Framework

TECHNICAL WORKSHOP ATTENDEES
October 25 - 26, 2016

SOUTHWESTERN WILLOW FLYCATCHER WORKSHOP	**WESTERN YELLOW-BILLED CUCKOO WORKSHOP**
Darrell Ahlers – USBR	Darrell Ahlers – USBR
Jean-Luc Cartron – DB Stephens & Associates, NMISC, ABCWUA	Jean-Luc Cartron – DB Stephens & Associates, NMISC, ABCWUA
Dave Hawksworth – USFS-RMRS	Dave Hawksworth – USFS-RMRS
Mike Marcus – APA	Joe Jojola – BIA SWRO
Dave Moore – USBR	Mike Marcus – APA
Yasmeen Najmi – MRGCD	Dave Moore – USBR
Cathy Nishida – Pueblo of Santa Ana	Cathy Nishida – Pueblo of Santa Ana
Matthew Peterson – City of Albuquerque, Open Space Division (COA, OSD)	Stephen Ryan – USACE
Stephen Ryan – USACE	Vicky Ryan – USFWS
Vicky Ryan – USFWS	Kenneth Richard – NMISC
Kenneth Richard – NMISC	Matt Schmader – COA OSD
Michael Scialdone – Pueblo of Sandia	Dale Strickland – WEST
Lori Walton – USBR	Lori Walton – USBR
ADAPTIVE MANAGEMENT PROCESS LEADS AND SUPPORT STAFF	
Todd Caplan – GSA Hira Walker - GSA Debbie Lee –WEST Briana Seapy – Kearns & West	

Appendix D-2: Detailed Technical Discussion: Critical Scientific Uncertainties for the Yellow-Billed Cuckoo

CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE YELLOW-BILLED CUCKOO

Listing History, Recovery, and Population Status

The YBCU is a neotropical migrant landbird that breeds in wet habitats from temperate North America south to Mexico and the Greater Antilles, and winters primarily in South America east of the Andes (Hughes 1999). Breeding YBCU populations in the US west of the Continental Divide are separated geographically from those in eastern North America by high mountains, extensive desert, and ecological deserts (i.e., areas absent of habitat), with the shortest separation between western and eastern breeding populations occurring across 257 km (160 miles) of desert between the Pecos River and Rio Grande in southern New Mexico and western Texas (see Figure 2 in USFWS 2013b). Over the past 100 years, western populations have been extirpated or have undergone catastrophic declines in western states primarily due to loss, degradation, and fragmentation of required riparian breeding habitats resulting from anthropogenic activities such as dam construction and operations, groundwater pumping, water diversions, stream channelization and stabilization, livestock grazing, and urban development (Howe 1986, Center for Biological Diversity 1998, Hughes 1999, USFWS 2013b). Losses in native riparian habitats in the three western states with the highest historical numbers of YBCUs – Arizona, California, and New Mexico – are estimated to be 90-99% and population declines in core breeding areas in these states have been documented in the past two decades (USFWS 2013b).

Based on the determination that loss of the western population would result in a significant gap in the range of the taxon, the USFWS designated all YBCU populations west of the Continental Divide as a DPS and placed the DPS on the candidate species list on 25 July 2001, later uplisting it to threatened on 3 October 2014 (USFWS 2000, 2001, 2013b, 2014b). Prior to listing the YBCU as threatened, approximately 221,094 ha (546,335 ac) were proposed for designation as critical habitat for the western DPS on 15 August 2014; despite subsequent extension of the public comment period on 12 November 2014 and a public hearing on 18 December 2014 in Sacramento, California, there has been no final rule issued for critical habitat (USFWS 2014a, 2014c, 2014d). There is no federal recovery plan for the YBCU and, thus, population goals and recovery actions for recovery have not yet been established. In general, however, a recovery goal for all listed species is to restore the listed species “to a point where they are secure, self-sustaining, and functioning components of their ecosystems” (USFWS 2013b). To achieve this goal, recovery actions can include habitat restoration (e.g., native vegetation planting), research, captive propagation and reintroduction, and outreach and education. A standardized survey protocol for the YBCU has been developed and standardized survey should yield information useful in developing a federal recovery plan, such as 1) YBCU breeding population sizes, distributions, and trends; and 2) possible threats to YBCU survival and recovery (Laymon 1998, Halterman 1999, Halterman et al. 2016).

The YBCU is not listed as threatened or endangered under the New Mexico Wildlife Conservation Act, but it is listed in the State Wildlife Action Plan as a *Species of Greatest Conservation Need* (NMDGF

2016). Although the loss of 90% of native riparian habitats in the state due to extensive anthropogenic changes to rivers and associated ecosystems certainly has threatened the persistence of YBCU populations, 15% of all proposed YBCU critical habitat (33,349 ha [82,408 ac]) is located in New Mexico, 75% of which (25,074 ha [61,959 ac]) occurs along the MRG (Howe 1986, USFWS 2014a). Furthermore, New Mexico is presumed to support some of the only healthy YBCU populations remaining in the western US. The USFWS (2013b) estimated that New Mexico supports 100 to 155 of the estimated 350 to 495 YBCU breeding pairs thought to be occurring north of the Mexican border; however, New Mexico likely supports much higher numbers of YBCUs as recent USBR surveys of approximately 208 km (129 mi) of the approximately 273-km- (170-mi-) long MRG found 116 territories in 2016 and an average of 100 territories from 2009-2016 (Dillon et al. 2017). West of the eastern boundary of the Rio Grande drainage (the dividing line between the two DPSs in New Mexico), YBCUs are primarily concentrated within New Mexico's major lowland river valleys along reaches of the Rio Grande and Gila, as well as along the San Francisco, San Juan, and Mimbres rivers, with the largest YBCU populations occurring along the San Marcial (primarily in the exposed pool of Elephant Butte Reservoir, Sierra County) and Escondida segments of the MRG and along the upper Gila (Bailey 1928, Hubbard 1971, Hubbard 1978, Egbert 1982, Howe 1986, CBD 1998, Woodward et al. 2003, USFWS 2013b, Dillon et al. 2017). It is thought that the status of the YBCU in the MRG is stable (USFWS 2016); however, obtaining accurate population size, distribution, and trend estimates will require the completion of long-term standardized protocol surveys of the entire MRG (see Cuckoo Critical Scientific Uncertainty #2).

Middle Rio Grande Management Actions

Although operations managers along the Rio Grande began consultation with the USFWS under Section 7 of the ESA for the SWFL and RGSM beginning in 1998 and the memorandum of understanding to develop the Collaborative Programwas executed in 2000, the YBCU generally was not a focus of restoration and other recovery efforts undertaken by Collaborative Program partners prior to its federal listing as a candidate in 2001.

Under the Collaborative Program, various agencies and organizations have contributed over the past decade and a half to water management, habitat restoration, research, and monitoring activities prescribed in a 2003 BiOp to protect listed species (USFWS 2016). Currently, a number of Collaborative Program-signatories, including USBR, BIA, MRGCD, and NMISC, are involved in completing three tasks required in the most recent BiOp (USFWS 2016) to offset the potentially negative effects of proposed and on-going water management and river maintenance activities on the YBCU and proposed YBCU critical habitat (USFWS 2016): 1) implementing BMPs to minimize take of the YBCU as well as minimize the effects of water management actions and habitat restoration activities on the YBCU; 2) YBCU population and habitat surveys, monitoring, and research; and 3) YBCU breeding habitat protection, creation, and restoration. There are several guidance documents for implementation of tasks #1 and #2, namely 1) the 2016 BiOp, which clearly outlines the BMPs for the YBCU (Conservation Measures 51, 54-55, 58-59, 61, 64, and 80; USFWS 2016:162-169), and 2) the standardized survey protocol for the YBCU (Halterman et al. 2016). In the absence of a federal recovery plan, recommendations in documents such as proposed critical habitat (USFWS 2014a) and the 2016 BiOp (USFWS 2016) can guide habitat protection, creation, and restoration efforts. For example, the primary constituent elements (PCEs) of YBCU proposed critical habitat can inform managers on which physical and biological elements are required to provide for life-history processes and are essential to the conservation of the YBCU (USFWS 2014a). The PCEs of YBCU proposed critical habitat relate to nesting and foraging habitat, food resources, and river dynamics and processes (USFWS 2016:29).

Critical Scientific Uncertainties

Federal, state, tribal, and private land and water managers require practical scientific information necessary for making well-informed management decisions – including developing alternative actions and evaluating effects of actions – for the YBCU within the MRG while implementing management actions. When identifying and selecting the best management strategy, managers are required to use the best scientific information available; however, in many cases, there is a lack of appropriate scientific data and information that cover all management objectives, are relevant to the specific location in question, and/or are peer-reviewed. Thus, to facilitate boots-on-the-ground management, there must be a cross-linkage between work completed by the scientific community on the YBCU and the information needs of the management community. Specifically, scientific experts should facilitate the AM process by helping to develop and describe the details of the design, implementation, and evaluation process for YBCU-related studies that address management uncertainties.

As discussed in Section 2.2.3, a team of SMEs met in Albuquerque, New Mexico on 26 October 2016 to learn and discuss the state of the science for the YBCU and to identify where there are critical scientific uncertainties in our scientific knowledge for the YBCU. There was general consensus among the agency SMEs that increased scientific inquiry on the YBCU in the past two decades, as well as more recent extensive surveys along the MRG and across the YBCU's range, have advanced our knowledge of the YBCU's natural history requirements, breeding population status, threats, and response to management efforts. However, the SMEs concluded that there remains much about the YBCU that is not well understood. Specifically, the SMEs delineated approximately 15 scientific topics that were less studied and less understood, and they identified the top five scientific uncertainties that affect management decisions for the YBCU and, thus, should be the focus of future scientific efforts (Appendix D-1). After the conclusion of the meeting, via email correspondence, the SMEs ranked the top five critical scientific uncertainties to determine which should be given the highest priority for scientific inquiry, management action, and funding. During the meeting and subsequent review of the literature, questions were identified as a priority for study to address each key scientific uncertainty. The primary objectives of identifying the critical scientific uncertainties and questions are to: 1) contribute to scientific knowledge; 2) ensure that Collaborative Program-funded monitoring, research, and experiments reduce management uncertainties; and 3) improve the rigor of the science informing those management decisions and actions directed at protecting the YBCU and restoring habitats without jeopardizing existing and future water uses and rights.

This appendix provides in-depth reviews of the scientific relevance, management application, and recovery application for each critical scientific uncertainty; brief overviews of these topics are provided in Section 5. Study plan considerations for each critical scientific uncertainty also are offered both in this appendix and in Section 5 to guide Collaborative Program signatories with soliciting detailed *Requests for Proposals* from the scientific community.

Identified Critical Scientific Uncertainties

The agency SMEs prioritized the following four critical scientific uncertainties for scientific study (ranked 1 = Highest to 4 = Lowest):

5) The abiotic and biotic variables that predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales.
6) YBCU breeding population sizes, distributions, and trends in the MRG.
7) Similarity in YBCU and SWFL breeding habitat requirements in the MRG.
8) Spatial behavior patterns of YBCUs that breed in the MRG within and among years, and drivers.

Ranked fifth was “the timing and availability of YBCU prey in the MRG and which factors influence both;” however, this topic does not receive expanded review and consideration in the following sections because it was ranked as a significantly lower priority than the four critical scientific uncertainties listed above. The SMEs also identified nine additional scientific uncertainties that were considered lower priority at this time (see Other Critical Scientific Uncertainties).

Connectivity Among Critical Scientific Uncertainties

The top four critical scientific uncertainties for the YBCU are interconnected; research on one uncertainty informs research (e.g., provides similar or baseline data) on other uncertainties (Figure 21). More specifically, all four critical scientific uncertainties relate in some degree to where YBCUs are on the landscape, the sizes and trends of YBCU breeding populations, YBCU breeding habitat requirements, and YBCU spatial behavior patterns.

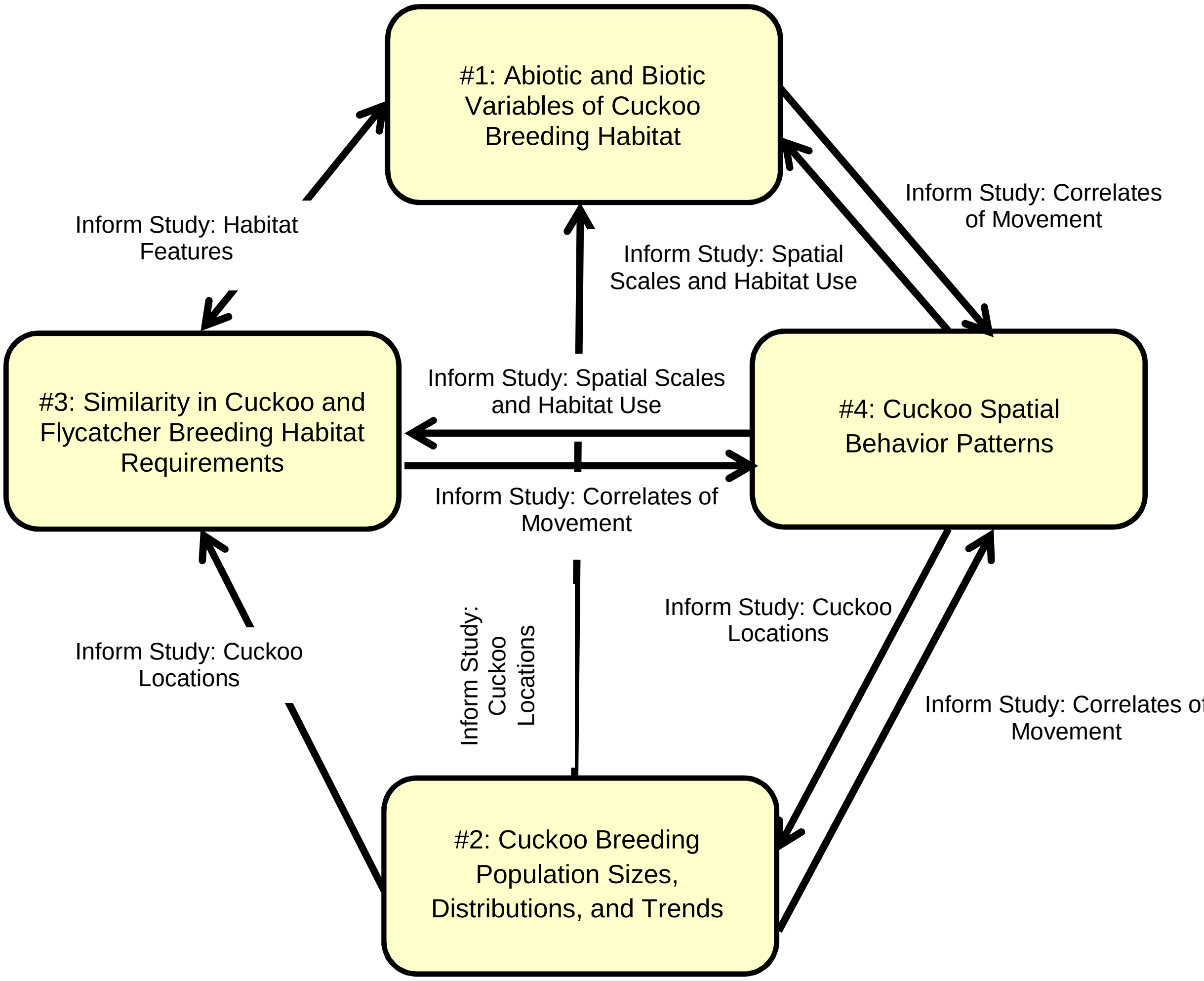

Figure 21. Relationships among critical scientific uncertainties of the Yellow-Billed Cuckoo in the Middle Rio Grande, New Mexico.

Other Critical Scientific Uncertainties

The nine scientific questions listed below in no particular order were identified as a lower priority for study and funding than the top five critical scientific uncertainties (see Appendix D-1 for original, unrevised wording):

- What is the timing of YBCU arrival to and departure from MRG breeding sites?
- What are the YBCU migratory routes and stopover locations in the MRG?
- What are YBCU survivorship and demographics in the MRG?
- What factors (e.g., depredation, proximity to water, etc.) contribute to YBCU nesting success in the MRG?
- How can increases in sample sizes of YBCU studies be achieved?
- What are the potential effects of *Diorhabda* on unoccupied and occupied suitable YBCU breeding habitats in the MRG?
- Can YBCU surveys be combined with SWFL surveys to minimize disturbance?
- How sensitive are YBCUs to human disturbance and what are the effects of disturbance on YBCU behaviors?
- Is there sufficient genetic diversity in YBCU breeding populations in the MRG to prevent bottlenecking?

CRITICAL SCIENTIFIC UNCERTAINTY #1: ABIOTIC AND BIOTIC VARIABLES OF YELLOW-BILLED CUCKOO BREEDING HABITATS

***Study Question*:** Which abiotic and biotic variables predict suitable cuckoo breeding habitats in the MRG across multiple spatial and temporal scales?

Scientific Relevance

ABIOTIC AND BIOTIC VARIABLES OF

YELLOW-BILLED CUCKOO BREEDING HABITATS

SCIENTIFIC RELEVANCE

YBCUs make decisions about where to breed at multiple spatial scales; as they migrate north, they make decisions on where they stop to breed (the landscape or breeding site), where within the landscape they regularly travel to meet life history requirements (the patch, also termed “territory” or “home range and core use area”), and where they build their nests (the nest site). Required breeding habitat attributes, such as geographic extent of vegetation, vegetation floristics and physiognomy, and distance to surface water, all can differ among these different spatial scales. In addition, the geographic distribution and the abiotic and biotic features of YBCU breeding habitats can vary temporally due to within and between year variation in river flows and precipitation, disturbance events, and natural succession, maturation, and degradation of riparian vegetation. In the MRG, no rigorous scientific inquiry has been completed to determine landscape requirements, only limited data exist on patch requirements, and very limited data exist on nest site requirements. Furthermore, although information exists as to the seral stage of vegetation in YBCU breeding patches, studies have not been completed to determine how YBCU breeding habitats change temporally. Therefore, further scientific research is essential to accurately characterize YBCU breeding habitats in the MRG; studies are needed to determine which spatial and temporal scales are biologically relevant to the YBCU and which abiotic and biotic variables predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales.

YBCUs begin arriving in New Mexico as early as late April and typically by mid-May (Williams and Travis 2003). Similar to other neotropical migrant landbirds, as YBCUs migrate north, they make decisions on where to stop and breed (the “landscape” or “breeding site”), where within the landscape they regularly travel to meet life history requirements (the “patch,” also referred to as the “home range and core use area[4]," or "territory"), and where they build their nests (the "nest site"). Required breeding habitat attributes, such as geographic extent of vegetation, vegetation floristics (species composition) and physiognomy (structure), and presence of surface water, all can differ among these different spatial scales (Girvetz and Greco 2009, Johnson et al. 2017). In addition, the geographic distribution and the abiotic and biotic features of YBCU breeding habitats can vary temporally due to within and between year variation in river flows and precipitation, disturbance events (e.g., fluctuating reservoir levels, fire, or high magnitude floods that result in scouring), and natural succession, maturation, and degradation of riparian vegetation (USFWS 2014a). Thus, determinations of YBCU breeding habitat must involve consideration of habitat requirements at multi-spatial and temporal scales (Meyer and Thuiller 2006, Girvetz and Greco 2009, Johnson et al. 2017).

Landscapes supporting breeding YBCUs tend to be characterized by: 1) hydrologically connected floodplains; 2) low-gradient perennial rivers and streams with dynamic hydrologic regimes that promote establishment, development, maintenance, and recycling of mosaics of riparian vegetation; 3) a large geographic extent; 4) moderate terrain ruggedness (e.g., not flat); and 5) large patches of dense, structurally diverse, and floristically uniform native riparian vegetation (Gaines and Laymon 1984; Greco 2008, 2012; Halterman 1991; Hughes 1999; Johnson et al. 2012; Laymon 1998; USFWS 2014a, 2014b). In addition, YBCUs tend to breed in landscapes that support contiguous or near-continuous suitable habitat patches that provide movement corridors for foraging (YBCUs rarely traverse distances across unwooded spaces greater than 0.62 km [0.25 mi)] while foraging) and post-breeding dispersal (USFWS 2014a). In New Mexico, the YBCU breeds primarily in open riverine valleys below 1,500 m (4,921 ft) and the largest YBCU breeding population occurs largely within in the elevational range of 1327 to 1,335 m (4,355 to 4,380 ft) of the exposed pool of Elephant Butte Reservoir in the San Marcial Reach of the Rio Grande (Dillon et al. 2017). Landscape features associated with YBCU breeding sites are unknown for the MRG as no landscape-scale habitat studies have been completed in New Mexico.

Within the landscape, YBCUs tend to use large patches of woody riparian vegetation; there is a significant relationship between the size of a breeding habitat patch and the likelihood of it being occupied (USFWS 2014a). YBCUs rarely use habitat patches smaller than 3 ha (7.4 ac; Hughes 1999); suitable habitat patches across the YBCU's breeding range are generally greater than 81 ha (200 ac) in size and at least 100-m (325-ft) wide (USFWS 2014a). Recent work by Johnson et al. (2017) found that a patch size of 72 ha (178 ac) was most predictive of YBCU presence along the LCR. In addition to being large in size, suitable YBCU breeding patches are characterized by vegetative, hydrologic, and food conditions that promote conditions necessary for successful foraging and nesting (USFWS 2014a). More

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[4] *Home range* is defined as the area regularly travelled to meet life history requirements) and *core use area* is defined as a portion of the home range that is utilized more thoroughly and frequently (Hughes 1999).

specifically, YBCUs prefer habitat patches that occur along water courses and other areas with hydrologic conditions (e.g., surface water, saturated soils, and low groundwater elevations) that promote production of required woody riparian vegetation and large invertebrate and vertebrate prey (USFWS 2014a). Areas that experience prolonged inundation or desiccation are not favorable for the YBCU as these conditions can reduce prey availability and can result in reduced vigor and increased mortality of required riparian woody vegetation (USFWS 2014a). Where hydrological conditions support patches of woody riparian vegetation of sufficient extent, YBCUs prefer to nest and forage in those patches with heterogeneously dense and native (primarily cottonwood [*Populus*] and willow [*Salix*]) vegetation with a developed canopy (canopy closure greater than 70%; USFWS 2014a, Johnson et al. 2017). Although exotic plants, such as tamarisk (*Tamarix*) and Russian-olive (*Elaeagnus angustifolia*), can be dominant components of YBCU breeding habitat patches, YBCUs have been found to avoid stands of monotypic exotic vegetation (USFWS 2014a). For example, on the LCR, YBCU occurrence is negatively correlated with the amount of tamarisk cover (Johnson et al. 2017).

Very limited information exists on attributes of YBCU breeding habitat patches in the MRG. Nonetheless, it can be concluded from the best scientific information available (e.g., Howe 1986, Travis 2003, Sechrist et al. 2013, Dillon et al. 2017) that YBCUs use a variety of vegetation community types, generally are associated with habitats with mature trees and a developed shrub layer, and do not avoid exotic tamarisk vegetation in the MRG to the degree found elsewhere in the YBCU's breeding range (see USFWS 2014a and Johnson et al. 2017). Good reference information on vegetation floristics and physiognomy of YBCU breeding sites along the Rio Grande from Espanola, Rio Arriba County south to La Joya, Socorro comes from Howe (1986), who found that YBCUs used cottonwood/coyote willow (*P. deltoides* var. *wizlensii*/*S. exigua*), cottonwood/Russian-olive, and cottonwood/juniper (*Juniperus monosperma*) vegetation community types that varied in structure from primarily shrubs to tall mature trees, and from only having a shrub layer to lacking an understory. The vegetation community type used varied geographically, with YBCUs primarily found in stands with intermediate-sized cottonwood trees and a well-developed Russian-olive understory from Espanola south to Bernalillo, Sandoval County, intermediate-sized cottonwood trees and a well-developed coyote willow understory from Bernalillo south to Bosque Farms, Valencia County, and tall, mature cottonwood trees and a well-developed coyote willow understory from Bosque Farms south to La Joya (Howe 1986). Later work by Sechrist et al. (2013) and Dillon et al. (2017) similarly documented breeding YBCUs in vegetation with a developed native-dominated canopy and exotic-, native-, or mixed vegetation-dominated understory in areas just upstream of the pool of Elephant Butte Reservoir, Sierra County (Sechrist et al. 2013) and in areas north of Elephant Butte Reservoir to the southern boundary of the Pueblo of Isleta in Valencia County (Dillon et al. 2017). Native canopy plant species included Rio Grande cottonwood, coyote willow, and Gooding's willow (*S. gooddingii*), while native coyote willow and exotic tamarisk and Russian-olive were the common understory plant species. Dillon et al. (2017) conclude that understory is a vital component of YBCU breeding habitats in the MRG, likely for foraging and nest concealment, as 26% of YBCU detections were in areas that supported understory but no overstory vegetation, and core use areas were comprised of about 33% understory-only vegetation. It is notable that, although Sechrist et al. (2013) and Dillon et al. (2017) are the principal sources of quantitative, research-based information on vegetation floristics and physiognomy of YBCU breeding habitat patches in the MRG, neither had sufficient data to reject the hypothesis that YBCUs use vegetation in proportion to their availability.

YBCUs are thought to breed in habitat patches with moist soils or near surface water, but it is unclear to what degree these habitat features are utilized by YBCUs in habitat selection. Along the LCR, McNeil et al. (2013) did not find a significant relationship between YBCU nest sites and soil moisture and Johnson et al. (2017) did not find a significant relationship between YBCU occupancy of a patch and distance to surface water. In New Mexico, Travis (2003) mentioned that flowing, standing, or nearby water is not characteristic of all occupied habitats in New Mexico, but he did not specify the hydrologic conditions at any particular breeding location. Interestingly, Howe (1986) mentioned that Albuquerque is the only city along the Rio Grande where YBCUs can be found breeding outside of the riparian zone, where they use large-sized planted cottonwoods in the older sections of the city.

Within a habitat patch, both members of a YBCU pair build their open cup nest (a loose, flat, oblong platform of dry twigs) in vegetation: 1) with a dense sub-canopy and overstory (mean canopy cover = 89%); 2) that is located in proximity to slow or standing water; and 3) that has relatively low daytime temperatures and high day and night humidity levels (Laymon et al. 1997, Hughes 1999, Johnson et al. 2008, McNeil et al. 2013, USFWS 2014a). YBCUs possibly require the specific microclimate conditions found near river bottoms, ponds, oxbow lakes, marshes, swampy areas, and damp thickets for successful hatching and rearing of young in the mid-summer heat and dryness of the western US (Hamilton and Hamilton 1965, Gaines and Laymon 1984, Rosenberg et al. 1991, Johnson et al. 2008). Nests are built 1-22 m (4-73 ft) above the ground and average 7 m up (22 ft) on well-foliaged horizontal branches or in vertical forks of trees or large shrubs that are protected from inclement weather by thick overhanging branches (Hughes 1999, USFWS 2014a). Reflecting the range in nest heights, the nest trees range 3-30 m (10-98 ft) in height and average 11-m (35-ft) tall. The majority of nests throughout the range of the western DPS are placed in willow trees, but nests can also be placed in other plant species, such as cottonwood and tamarisk (USFWS 2014a). Limited data exist on nest site requirements in the MRG, but Travis (2003) states that Russian-olive is the major nest tree in the MRG and Walker et al. (2002) found YBCUs nesting 2.4-6.3 m (7.8-20.7 ft) up in Russian-olive. Travis (2003) also mentions that YBCUs will nest in mulberry (*Morus*) and Siberian elm (*Ulmus pumila*), the later in residential areas. Two YBCU nests monitored in the MRG in 2017 were both located in Gooding's willow (Darrell Ahlers, pers. comm., 12 February 2018).

In summary, little is known regarding which spatial and temporal scales are biologically relevant to the YBCU and how abiotic and biotic variables of suitable YBCU breeding habitat differ across multiple scales. In the MRG, no rigorous scientific inquiry has been completed to determine landscape requirements (e.g., elevation, geographic extent, topographic diversity), only limited data exist on patch requirements (e.g., Sechrist et al. 2013, Dillon et al. 2017), and very limited data exist on nest site requirements (e.g., Walker et al. 2002). Furthermore, although information exists as to the seral stage of vegetation in patches (e.g., the maturity of the cottonwood overstory), studies have not been completed to determine how YBCU breeding habitats change temporally. Therefore, more study is needed to accurately characterize YBCU breeding habitat requirements in the MRG.

Management Application

ABIOTIC AND BIOTIC VARIABLES OF CUCKOO BREEDING HABITATS

MANAGEMENT APPLICATION

Managers can offset threats to cuckoo breeding habitats in the MRG by controlling exotic vegetation, planting native vegetation, improving geomorphological conditions, and adaptively managing water flows to create the conditions necessary for cuckoo breeding habitat establishment, development, maintenance, and recycling. Unfortunately, the successful design and implementation of cuckoo breeding habitat restoration has been limited by the lack of information on multi-scale cuckoo breeding habitat requirements. Therefore, to improve the success of cuckoo breeding habitat restoration efforts, managers require more accurate data on 1) restoration targets, such as patch size, configuration, and vegetation composition and structure, 2) which habitats are unsuitable or marginally suitable (e.g., monotypic tamarisk stands) for breeding cuckoos and, thus, a priority for restoration, and 3) which river processes and active and passive management actions promote cuckoo breeding habitats. If conducted in both naturally occurring habitats and restoration sites in the MRG, research on which spatial and temporal scales are biologically relevant to the cuckoo and how abiotic and biotic variables of suitable cuckoo breeding habitats differ across multiple scales can provide managers with the required scientific data. Furthermore, research results can be useful to formulating and standardizing conservation measures necessary to effectively offset short-term decreases in available cuckoo breeding habitats resulting from water management and river maintenance activities in the MRG.

The YBCU's dependency on large patches of native riparian vegetation with high abundances of large invertebrate prey and a dense sub-canopy and canopy for nesting and foraging confers a dependency on active river channel processes that promote establishment, development, maintenance, and recycling of mosaics of riparian vegetation (Greco 2008, 2012; Laymon 1998). Thus, any alteration to the hydrologic regime necessary to establish and maintain YBCU breeding habitats can threaten YBCU breeding populations (USFWS 2013b). Specifically, loss and degradation of YBCU breeding habitats can arise when water diversion and dam and reservoir management results in unnatural rates of flow – that is, flows at inappropriate times of year, inappropriate intervals (too frequent or infrequent), or inappropriate levels (too high or low) – and, thus, leads to flooding or desiccation beyond the tolerance limits of native riparian vegetation, conversion of riparian vegetation to that dominated by drought-tolerant and exotic vegetation, and accumulation of fire-prone woody and herbaceous debris (Poff et al. 1997, Greco 1999, USFWS 2013b). Improvement of geomorphological conditions and AM of water flows can be effective methods for offsetting negative impacts of water use on YBCU breeding habitats (USFWS 2014b, 2016).

In particular, one method is the implementation of large-scale river channel modifications (e.g., widening the river channel, increasing meanders, lowering banks and berms) in the active floodplain. Another effective method is management of the timing, magnitude, and duration of water releases to mimic natural hydrological regimes which can synergistically create the conditions necessary for YBCU breeding habitat establishment, development, maintenance, and recycling (e.g., expansive floodplain inundation through overbank flooding, sufficient depth to groundwater and wetted soil conditions; USFWS 2014b, 2016). Furthermore, when the appropriate physical processes are present, they provide favorable conditions for management actions such as exotic vegetation control and native vegetation plantings.

To date, the success of habitat restoration efforts has been limited by the lack of information on YBCU breeding habitat requirements and, despite expansive restoration efforts completed in the western US over the 25-30 years, it appears that most efforts have not affected stabilization and recovery of the YBCU (USFWS 2014b). Although the YBCU breeds across its range in sites supported by supplemental water, including dam outflows, reservoirs (e.g., the largest YBCU breeding population in the MRG occurs within the exposed pool of Elephant Butte Reservoir), and irrigation and diversion ditches, YBCU breeding habitats at these sites are often an incidental result of water management (USFWS 2014b, Dillon et al. 2017). Recommendations in recent documents such as proposed critical habitat (USFWS 2014a) and the 2016 BiOp (USFWS 2016) can guide future habitat protection, creation, and restoration efforts. For example, the primary constituent elements of YBCU proposed critical habitat can inform managers on which physical and biological elements are required to provide for life-history processes and are essential to the conservation of the YBCU (USFWS 2014a). However, managers require more accurate data on 1) restoration targets, such as patch size, configuration, and vegetation composition and structure, 2) which habitats are unsuitable or marginally suitable (e.g., monotypic tamarisk stands) for breeding YBCUs and, thus, a priority for restoration, and 3) which river processes and active and passive management actions promote YBCU breeding habitats. To obtain the required scientific data, research should be conducted on which spatial and temporal scales are biologically relevant to the YBCU and how abiotic and biotic variables of suitable YBCU breeding habitats differ across multiple scales in both naturally occurring habitats and restoration sites in the MRG. Furthermore, research results (e.g., a YBCU breeding habitat suitability model) will be useful to formulating and standardizing conservation measures necessary to effectively offset short-term decreases in available YBCU breeding habitats resulting from water management and river maintenance activities in the MRG (see USFWS 2016).

Recovery Application

ABIOTIC AND BIOTIC VARIABLES OF YELLOW-BILLED CUCKOO BREEDING HABITATS

RECOVERY APPLICATION

Results of studies characterizing multi-scale YBCU breeding habitat requirements will provide information useful in accurately identifying the primary constituent elements of critical habitat, determining which and where habitats in the MRG should be designated as critical, and making a final ruling on critical habitat. In addition, study results will provide information vital to YBCU recovery efforts, such as on potential threats to YBCU breeding habitats (e.g., invasion of exotic plant species), and on which habitats should be a priority for protection and restoration.

On 15 August 2014, approximately 221,094 ha (546,335 ac) of riparian vegetation were proposed for designation as critical habitat for the western DPS of the YBCU, 15% of which (33,349 ha [82,408 ac]) is located in New Mexico (USFWS 2014a). The three primary constituent elements (PCEs) of proposed YBCU critical habitat are considered essential to the conservation of the species and relate to nesting and foraging habitat, food resources, and river dynamics and processes (USFWS 2014a:48586):

i. **Riparian woodlands**. Riparian woodlands with mixed willow cottonwood vegetation, mesquite-thorn forest vegetation, or a combination of these that contain habitat for nesting and foraging in contiguous or nearly contiguous patches that are greater than 100 m (325 ft) in width and 81 ha (200 ac) or more in extent. These habitat patches contain one or more nesting groves, which are generally willow dominated, have above average canopy closure (greater than 70%), and have a cooler, more humid environment than the surrounding riparian and upland habitats.

ii. **Adequate prey base**. Presence of a prey base consisting of large insect fauna (for example, cicadas, caterpillars, katydids, grasshoppers, large beetles, dragonflies) and tree frogs for adults and young in breeding areas during the nesting season and in post-breeding dispersal areas.

iii. **Dynamic riverine processes**. River systems that are dynamic and provide hydrologic processes that encourage sediment movement and deposits that allow seedling germination and promote plant growth, maintenance, health, and vigor (e.g., lower gradient streams and broad floodplains, elevated subsurface groundwater table, and perennial rivers and streams). This allows habitat to regenerate at regular intervals, leading to riparian vegetation with variously aged patches from young to old.

Results of studies characterizing multi-scale YBCU breeding habitat requirements will provide information useful in refining the PCEs of critical habitat and identifying which and where habitats in the MRG should be delineated as critical. In addition, results of such studies will assist in the recovery planning and implementation by identifying unoccupied and occupied suitable YBCU breeding habitats for protection, and potential threats to YBCU breeding habitats, such as expansion and invasion of exotic plant species or defoliation of tamarisk by the tamarisk beetle (*Diorhabda*).

Study Plan Considerations

The first step in addressing the critical scientific uncertainty is to define suitable YBCU breeding habitat. Although occupancy by breeding YBCUs generally infers that the habitat is suitable (e.g., Johnson et al. 2017), YBCUs can occupy unsuitable, low quality habitat. Thus, metrics other than occupancy likely are more biologically meaningful in defining suitability, such as YBCU reproductive success, YBCU survivorship, and high use (USFWS 2002). Once it is determined which YBCU metrics indicate suitability, occupied suitable YBCU breeding habitats in the MRG should be delineated and mapped. Existing literature (e.g., Sechrist et al. 2013, Dillon et al. 2017) and standardized YBCU survey forms for the MRG submitted to the USFWS (USFWS unpubl. data) can provide useful data on YBCU detection and nest site locations during the breeding season, but additional surveys and nest monitoring studies likely are necessary to obtain sufficient data on YBCU presence, reproductive success, and survivorship in the MRG (see Cuckoo Critical Scientific Uncertainty #2).

The next step to addressing the critical scientific uncertainty is to quantify the abiotic and biotic habitat variables that predict occupied suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales. There is some evidence that three spatial scales are of biological importance to the YBCU: the landscape (also termed the "breeding site"), the patch (also termed the "territory," or the "home range and core use area"), and the nest site (e.g., Girvetz and Greco 2009, Johnson et al. 2017). Nonetheless, definitions of these spatial scales vary among studies and are largely lacking for the MRG (e.g., Sechrist et al. 2013, Johnson et al. 2017). The spatial scale of habitat measurements should match the spatial scale at which organisms use habitat as habitat features exhibit changing patterns when measured at different scales (Meyer and Thuiller 2006, Girvetz and Greco 2009, Seavy et al. 2009). Furthermore, the more vagile a species is, the more important it is to measure habitat at multiple spatial scales (Meyer and Thuiller 2006). Therefore, it is essential that the following two questions be answered prior to conducting habitat assessments:

1. What are biologically relevant definitions of spatial habitat terms, such as landscape, patch, home range, core use area, territory, and nest site?
2. Which spatial scales are biologically relevant to the YBCU in the MRG?

Our increasing understanding of YBCU spatial behavior patterns (see Cuckoo Critical Scientific Uncertainty #4) should refine spatial-scale definitions for the YBCU for the MRG specifically and rangewide.

Once the geographic units of measurement are identified and standardized, those habitat features considered most predictive of suitable YBCU breeding habitats must be identified. Determining which abiotic and biotic variables predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales likely will require an iterative process of collecting habitat data at a subset of occupied YBCU sites, modelling habitat suitability, and testing the predictability of habitat suitability models across all occupied sites in the MRG. After the appropriate compliment of habitat variables are selected for measurement, habitat quantification and characterization of occupied suitable habitats can be completed in a variety of ways. Due to the YBCU's large home range, it can be logistically difficult to obtain detailed field-based measurements of habitat features – such as vegetation structure, floristic composition, geographic extent of the floodplain and vegetation communities, and proximity to surface water – at scales considered to be biologically meaningful for the YBCU. To avoid the constraints of fieldwork or compliment field-based habitat assessments, it is valuable to explore the predictive power of complex multi-scale habitat suitability models based on remote sensing data (e.g., LIDAR, Landsat Thematic Mapper, aerial photographs), statistical models, or a combination of both (Girvetz and Greco 2009, Johnson et al. 2017). Whether habitat data are collected in the field or remotely, it is essential that data on habitat features be contemporary to data on suitability (e.g., occupancy by breeding YBCUs) because both change over time. Furthermore, to quantify the temporal changes, data should be collected over multiple years.

The collected YBCU suitability (e.g., occupancy) and habitat data should be analyzed to address the primary study question associated with the critical scientific uncertainty, "Which abiotic and biotic variables predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales?" In addition, data should be analyzed to answer the following five subquestions:

1) Where are unoccupied and occupied suitable YBCU breeding habitats located in the MRG?
2) Which vegetation community types provided suitable habitat for the YBCU?
3) How are key features of naturally occurring suitable YBCU breeding habitats similar and/or different from those of occupied restoration sites in the MRG?
4) In the MRG, to what degree do breeding YBCUs use exotic vegetation, particularly tamarisk, for foraging and nesting?
5) How do features (e.g., hydrologic conditions, vegetation structure) of YBCU breeding habitats in the MRG vary temporally and what is the longevity/persistence of YBCU breeding habitats in the MRG?

Knowledge of a diversity of disciplines, sampling techniques and technologies, and data analysis and modelling methods are required as successfully addressing the critical scientific uncertainty involves adopting an integrative research strategy that investigates multiple ecosystem components across multiple temporal and spatial scales. Any work entailing YBCU surveys or monitoring will necessitate obtaining specialized training and permits (e.g., YBCU survey, detection, and nest monitoring training and ESA Section 10a permits).

Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 1* priority (Table 10) and was ranked #1 of the top four YBCU scientific uncertainties identified by the SMEs.

CRITICAL SCIENTIFIC UNCERTAINTY #2: YELLOW-BILLED CUCKOO BREEDING POPULATION SIZES, DISTRIBUTIONS, AND TRENDS

***Study Question*:** What are YBCU breeding population sizes, distributions, and trends in the MRG?

Scientific Relevance

YELLOW-BILLED CUCKOO BREEDING POPULATION SIZES, DISTRIBUTIONS, AND TRENDS

SCIENTIFIC RELEVANCE

In the past two decades, formal YBCU survey efforts have provided estimates of YBCU breeding population sizes, distributions, and trends in the MRG. However, evaluation of survey results from this period has been complicated by the fact that survey areas and methods have not been consistent within and among survey efforts. In addition, despite consistent and comparable surveys by the USBR since 2009 south of the Pueblo of Isleta, there has been limited survey data from the Cochiti and Angostura reaches. Therefore, to obtain accurate YBCU breeding population estimates for the MRG, there is a need for standardized YBCU surveys conducted concurrently and repeatedly within all suitable YBCU breeding habitats along the entire length of the MRG. Furthermore, scientific investigation is needed to identify which factors affect YBCU breeding population sizes, distributions, and trends in the MRG.

Over the past 120 years, documentation of YBCU breeding population sizes, distributions, and trends in the MRG has transitioned from bird collections and observations during early explorations of New Mexico to general avian surveys to recent formal targeted surveys. The earliest records provide some limited evidence on YBCU distributions in the MRG, such as the presence of breeding YBCUs at Elephant Butte Reservoir, Sierra County (Bailey 1928) and general descriptions of the Rio Grande as a “main” YBCU breeding area within the State (Hubbard 1978). Subsequent general avian surveys and incidental YBCU detections during SWFL surveys helped to identify specific YBCU breeding populations in the MRG and generate initial estimates of YBCU breeding population sizes. For example, relying heavily on the results of Hink and Ohmart (1984), Howe (1986) estimated 159 YBCU pairs at various locales along the stretch of the Rio Grande from Bernalillo, Sandoval County south to La Joya, Socorro County. Within the last 20 years or so, formal surveys conducted for the YBCU has resulted in more rigorous estimates of YBCU breeding population sizes, distributions, and population trends in the MRG (e.g., Dillon et al. 2017; Lehmann and Walker 2001a, 2001b; Travis 2003, 2004, 2005).

Although formal surveys over the past two decades have provided the most rigorous YBCU population estimates, evaluation of survey results has been complicated by the fact that survey areas have not been consistent within and among survey efforts. Furthermore, survey methods also have not been consistent due to significant advancements in both survey protocols and methods for estimating numbers of breeding territories (Halterman et al. 2016). For example, Hink and Ohmart's (1984) estimate (which is reproduced in Howe 1986) of 54 YBCU breeding territories along the Rio Grande from Bernalillo, Sandoval County south to Bernardo, Socorro County in 1981-82 is likely inflated due to a now known incorrect method for estimating YBCU breeding territories (USFWS 2014b). Thus, Travis (2003, 2004, 2005) possibly came to an erroneous conclusion that there were significant declines in YBCU numbers in the area when he located only six YBCUs along this same stretch of the Rio Grande in 2002. Also, as an example, year-to-year comparisons of YBCU survey data collected since 2006 by the USBR in a significant portion of the MRG south of the southern boundary of the Pueblo of Isleta, Valencia County are confounded by annual incremental increases in the size of the survey area, increases in the number of surveys completed per year, and modifications to methods for estimating numbers of YBCU breeding territories (Dillon et al. 2017).

Since 2009, the USBR's YBCU survey efforts have remained relatively consistent and, thus, provide solid information on YBCU breeding population sizes, distributions, and trends for areas of the MRG south of the Pueblo of Isleta. During this eight-year period, an average of 100 YBCU breeding territories have been detected along approximately 208 km (129 mi) of the Rio Grande riparian corridor from the southern boundary of the Pueblo of Isleta downstream to Elephant Butte Reservoir, Sierra County (Dillon et al. 2017). The largest and second largest YBCU breeding populations were found along the San Marcial and the Escondida reaches, respectively, with the exposed pool of Elephant Butte Reservoir in the San Marcial Reach possibly supporting the largest breeding population in New Mexico (Dillon et al. 2017). However, population estimates fluctuated within and among survey reaches over the past eight years, and estimates of the total number of YBCU breeding territories within the entire survey area ranged from a low of 73 (2011) to a high of 116 (in 2016) (Figure 22). Despite annual fluctuations, Dillon et al. (2017:37) made the determination that the YBCU breeding population within the MRG "appears to be generally stable overall." This assertion was upheld in the 2016 BiOp (USFWS 2016:35).

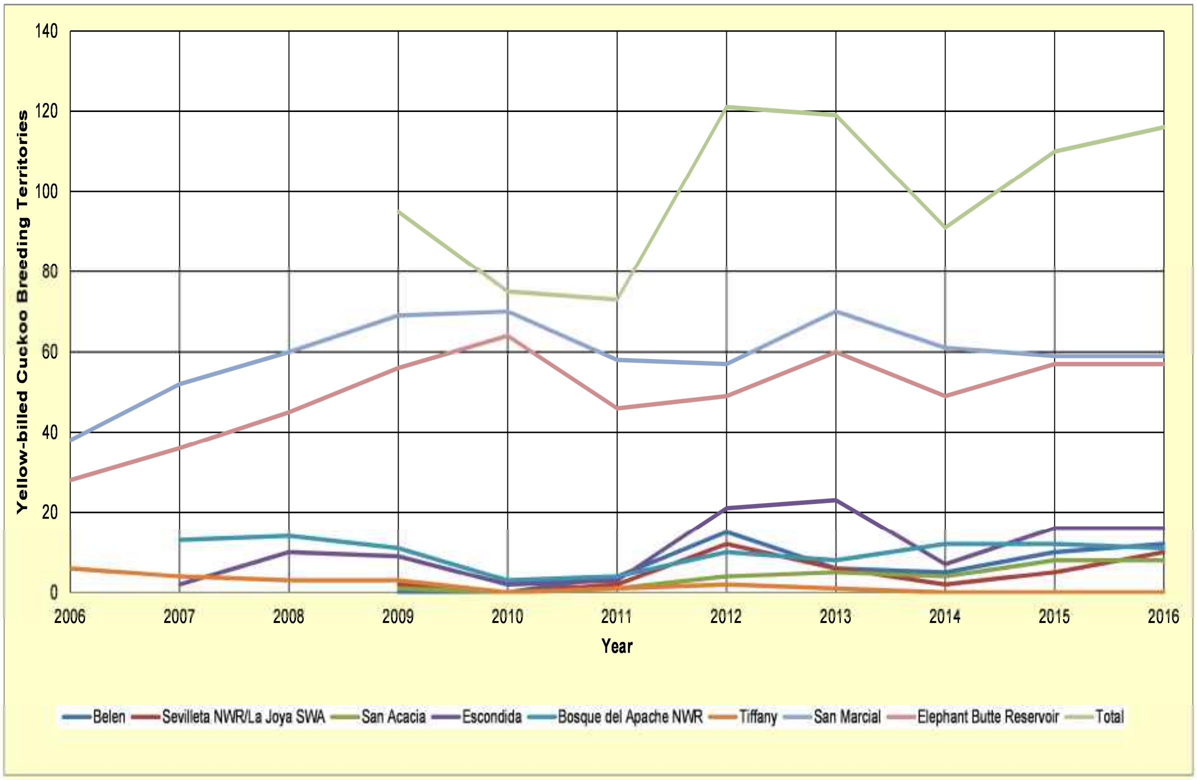

Figure 22. Yellow-Billed Cuckoo breeding territories within river reaches in the MRG from 2006 to 2016 (adapted from Dillion et al. 2017).

It is notable that the USBR's surveys do not extend north of the southern boundary of the Pueblo of Isleta and YBCU breeding population sizes, distributions, and trends from the Pueblo of Isleta north to Cochiti Dam, Sandoval County are largely undocumented and/or unknown due to spotty survey efforts and the fact that survey data from Pueblos are largely proprietary to the Pueblos (e.g., Lehmann and Walker 2001a). Nonetheless, there are some data available from this section of the Rio Grande. Howe (1986:6) claimed that the YBCU was a "fairly common summer resident in the extensive cottonwood/willow [*Populus*/*Salix*] woodland from Bernardo north to Espanola," and estimated a maximum of 19 breeding territories specifically around Bernalillo, Sandoval County and Albuquerque, Bernalillo County. Subsequent survey data have not supported Howe's (1986) claims that YBCUs are common along this stretch of the Rio Grande. When Thompson et al. (1994) conducted general avian surveys in the area from 1992 to 1993, they located only two YBCUs. Furthermore, no YBCUs were detected in 2001 during surveys of four USFS RMRS fuels reduction study sites along the Rio Grande in Bernalillo County (Lehmann and Walker 2001b). Travis (2003, 2004, 2005) also did not locate any YBCUs around Bernalillo and Albuquerque during surveys conducted from 2002-2004, but he did report incidental sightings in 2002 and 2003. Again, no YBCUs were detected in 2016 during formal surveys of eight restoration sites near Corrales, Sandoval County and Albuquerque conducted by USACE (USFWS unpubl. data). Without consistent surveys of the Cochiti and Angostura reaches, it is unclear whether the limited numbers of YBCU detections within the past 15 years indicate a real population decline since Howe (1986).

To obtain accurate estimates of YBCU breeding population sizes, distributions, and trends in the MRG, there is a need to resolve the lack of data collection in the Cochiti and Angostura reaches and elsewhere in the MRG by implementing standardized YBCU surveys concurrently and within all suitable YBCU breeding habitats along the entire length of the MRG, particularly in areas proposed for biotic, geomorphologic, and hydrologic alterations. Furthermore, there is a need for repeating this survey effort over subsequent years to accurately determine YBCU breeding population trends. In addition, scientific investigations are needed on which factors (e.g., immigration, emigration, habitat availability, prey composition and availability, and nesting success) affect YBCU breeding population sizes, distributions, and trends in the MRG.

Management Application

CUCKOO BREEDING POPULATION SIZES, DISTRIBUTIONS, AND TRENDS MANAGEMENT APPLICATION
Concurrent, repeated, and comprehensive standardized cuckoo surveys in the MRG conducted before and after implementation of management actions will provide managers with the data necessary for effectively assessing and offsetting the effects of their actions on cuckoos in the MRG. Principally, collected data on locations of breeding cuckoos and their nests will inform siting of management actions, ensuring that those projects that might benefit the cuckoo (e.g., planting native vegetation) are sited near existing cuckoo breeding populations and those projects that might jeopardize the cuckoo (e.g., vegetation removal) are sited away (e.g., greater than 0.4 km [0.25 mi]) from breeding territories and nest sites. Studies conducted complementary to surveys will provide information to managers on where cuckoo breeding populations are declining, and which factors (e.g., availability of suitable habitat, nest predation, human disturbance, livestock grazing, river flows) are limiting or threatening cuckoo breeding populations, which is essential for determining where and which management actions could be implemented to improve the status of the cuckoo in the MRG.

Section 7(a)(2) of the ESA requires that all agencies involved in federally authorized, funded, or implemented actions in the MRG must ensure that those actions do not jeopardize the YBCU's continued existence or result in the destruction or adverse modification of the YBCU's proposed critical habitat. To assure compliance with the ESA, the 2016 BiOp (USFWS 2016) requires that the USBR, BIA, NMISC, and other BiOp partners fully implement BMPs as listed in Conservation Measures 51, 54-55, 58-59, 61, 64, and 80 (USFWS 2016:162-169). These measures include securing data on locations of breeding YBCUs and their nests to: 1) effectively evaluate the anticipated level of disturbance and incidental take from management actions; 2) determine if and what mitigation is required; 3) design and implement efforts to improve the status of the YBCU; and 4) assess and monitor the effects of managements actions on YBCUs. Consistent and comparable YBCU surveys by USBR since 2009 provide information useful to managers regarding YBCU breeding population sizes, distributions, and trends along 208 km (129 mi) of the Rio Grande riparian corridor south of the Pueblo of Isleta (Dillon et al. 2017). However, limited YBCU survey efforts have been completed north of the USBR's survey area in the Cochiti and Angostura reaches, as well as elsewhere in the MRG. Only by resolving data gaps on YBCU breeding population sizes, distributions, and trends in the MRG, can managers effectively assess and mitigate (e.g., successfully implement BMPs) the effects of their actions on YBCUs.

Standardized YBCU surveys conducted concurrently and repeatedly within all suitable YBCU breeding habitats (particularly habitats proposed for biotic, geomorphologic, and hydrologic alterations) along the entire length of the MRG from Cochiti Dam south to Elephant Butte Dam can provide managers with information necessary for effectively assessing and offsetting the effects of their actions on YBCUs in the

MRG. Principally, by knowing the locations of breeding YBCUs and their nests, managers can site those projects that might benefit the YBCU (e.g., planting native vegetation) near existing YBCU populations and those projects that might jeopardize the YBCU away from breeding territories and nest sites (e.g., siting projects such as vegetation removal greater than 0.4 km [0.25 mi] from an active nest to avoid take). Furthermore, if surveys are conducted before and after implementation of management actions, survey results can provide managers with data useful in evaluating the effects of their actions on YBCUs and implementing AM. Studies conducted complementary to surveys on population trends can provide data to managers essential for determining where and which management actions could be implemented to improve the status of the YBCU in the MRG, such as where YBCU populations are declining and which factors (e.g., availability of suitable habitat, nest predation, human disturbance, livestock grazing, river flows) are limiting or threatening YBCU populations.

Recovery Application

YELLOW-BILLED CUCKOO BREEDING POPULATION SIZES, DISTRIBUTIONS, AND TRENDS

RECOVERY APPLICATION

Research addressing the critical scientific uncertainty will help to identify the threats to cuckoo breeding populations, ascertain if and where recovery efforts are required, assess the effects of recovery actions on cuckoo breeding populations, and determine if recovery criteria are being met.

Information from research addressing the critical scientific uncertainty will be useful in recovery planning and implementation (USFWS 2014b). More specifically, information on sizes, distributions, and trends of YBCU breeding populations and which factors limit or threaten YBCU breeding populations (e.g., availability of suitable habitat, nest predation, human disturbance, livestock grazing, river flows) will assist managers in identifying the threats to YBCU breeding populations, ascertaining if and where recovery efforts are required, and assessing the effects of recovery actions on YBCU breeding populations. Once a recovery plan is finalized, collected data will be useful in determining if recovery criteria are being met.

Study Plan Considerations

Addressing the critical scientific uncertainty involves data mining, standardized protocol surveys (e.g., Halterman et al. 2016), nest searching and monitoring, field-based research, and, possibly, modeling studies. The first step to understanding YBCU breeding populations in the MRG is to analyze the results of previous survey efforts (e.g., Dillon et al. 2017) to determine historical and recent YBCU breeding population sizes, distributions, and trends in the MRG. Once these baseline data are analyzed, current YBCU breeding population sizes and distributions in the MRG should be investigated by:

1) verifying and mapping locations of established YBCU survey routes to ensure consistency in site naming, as well as establish and name new survey routes,
2) acquiring data from any and all agencies and organizations involved in on-going standardized YBCU protocol surveys in the MRG,
3) completing standardized YBCU protocol surveys (Halterman et al. 2016) in those areas not covered by existing surveys,
4) obtaining multiple years of survey data to assess if and where YBCU breeding population sizes are increasing, decreasing, or remaining stable,
5) securing permission to access survey sites from a multitude of landowners and managers (municipal, county, state, federal, and tribal), and

6) hiring sufficient ESA Section 10a-permitted personnel to ensure that all survey sites along the MRG are completed concurrently within each year of the study.

All survey data, whether obtained from partners or from efforts to specifically address the critical scientific uncertainty, should be analyzed using the appropriate statistical tests and software to determine YBCU breeding population sizes, distributions, and trends in the MRG. As part of these analyses, a rigorous evaluation of the most biologically accurate method for delineating breeding populations should be completed. River reach was used by both Dillon et al. (2017) and the USFWS (2016) as a spatial unit of measurement to evaluate YBCU breeding populations and make determinations regarding stability of breeding populations; however, river reach likely does not reflect how YBCU breeding populations are spatially distributed across the MRG.

Although obtaining and analyzing data on YBCU breeding population sizes, distributions, and trends should be the primary focus of efforts to address the critical uncertainty, it is also valuable to complete scientific investigations to identify which factors affect YBCU breeding populations in the MRG, such as habitat availability, prey composition and availability, and nest success. These investigations likely will involve time- and labor-intensive fieldwork conducted over multiple years. Therefore, separate studies likely will be necessary to investigate each factor. Wherever possible, data should be obtained from completed and on-going complimentary studies (e.g., see Appendix D-2, *Cuckoo Critical Scientific Uncertainties #1* and *3*).

Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 2* priority (Table 10) and was ranked #2 of the top four YBCU scientific uncertainties identified by the SMEs.

CRITICAL SCIENTIFIC UNCERTAINTY #3: SIMILARITY IN YELLOW-BILLED CUCKOO AND SOUTHWESTERN WILLOW FLYCATCHER BREEDING HABITAT REQUIREMENTS

Study Question: How similar are the cuckoo and the SWFL in their breeding habitat requirements in the MRG?

Scientific Relevance

SIMILARITY IN YELLOW-BILLED CUCKOO AND SOUTHWESTERN WILLOW FLYCATCHER BREEDING HABITAT REQUIREMENTS

SCIENTIFIC RELEVANCE

Both the YBCU and the SWFL are migratory landbirds of conservation concern that breed in the Southwest in dense woody riparian vegetation. Despite overlap in YBCU proposed critical habitat and SWFL designated critical habitat, the two species are not always found in similar habitats or locales as a result of differing life history requirements. Little scientific work has been completed to determine similarity in breeding habitat requirements between the two bird species and any comparisons of habitat requirements are hampered by the fact that less is known for the YBCU. To determine how similar the YBCU and the SWFL are in their breeding habitat requirements in the MRG, scientific research is needed to determine which abiotic and biotic breeding habitat features at multiple spatial scales (e.g., landscape, patch, nest site) predict where the YBCU and SWFL co-occur, occur individually, and are absent within the MRG.

Both the federally threatened YBCU and the federally endangered SWFL are migratory landbirds of conservation concern that breed in the Southwest in dense woody riparian plant communities associated with slow moving rivers and streams, lakes, and other lands with moist conditions (USFWS 2013a, 2013b, 2014b). Lentic water and moist or saturated soil, and associated microclimate features (low temperatures and high humidity), found in these areas not only support vegetation required by both species, but support their prey base and the microclimate conditions necessary for successful hatching and rearing of young in the mid-summer heat and dryness of the western US (USFWS 2002, 2014a). Owing to their dependency on riparian ecosystems, both bird species generally are found in landscapes where the floodplain is hydrologically connected to a river with a relatively unconstrained river flow and a hydrologic regime (e.g., scouring floods, sediment deposition, periodic inundation, and groundwater recharge) that promotes establishment, development, maintenance, and recycling of mosaics of riparian woodlands of varying ages (USFWS 2002, 2014a). As water is vital to YBCU and SWFL breeding habitats, both bird species are threatened by alterations to hydrological conditions (i.e., to the frequency, magnitude, duration, and timing of river flow) and, thus, both birds can benefit from conservation measures that protect, restore, and create functioning floodplains and associated riparian woodlands (USFWS 2002, 2013a, 2014b).

Despite overlap and similarities in YBCU proposed critical habitat and SWFL designated critical habitat, these two bird species are not always found in similar habitats or locales (USFWS 2013a, 2014a). Across the Southwest, riparian areas that support unoccupied and occupied suitable breeding habitat for both bird species are most often low elevation floodplains, reservoirs, and dam inflows and outflows that support expansive mosaics of dense and diverse native riparian vegetation (Durst et al. 2008; USFWS 2002, 2013a, 2014a). However, away from these broad floodplains, in areas with a narrow, restricted floodplain and small, linear strips of riparian vegetation, differences in breeding habitat requirements and distributions become apparent. The weakly or non-territorial YBCU breeds in large vegetation patches (often 70-80 ha [173-198 ac] or more in extent) that can support the YBCU's large home range, and it generally avoids small, linear vegetation patches less than 100 m (325 ft) in width (USFWS 2014b, Johnson et al. 2017). According to Laymon and Halterman (1989), YBCUs rarely nest in habitat patches less than 20 ha (50 ac) in size, and patches less than 15 ha (37 ac) are likely unsuitable for nesting. The SWFL, on the other hand, is territorial, requires smaller vegetation patches (median patch size = 1.8 ha [4.4 ac], smallest patch size = 0.8 ha [2.0 ac]), and it can occupy and occur in fairly high densities in very small, isolated habitat patches (Sogge et al. 2010, USFWS 2013a). Validating differences in the two bird species' spatial habitat requirements, Johnson et al. (2017) found that the most important variable in a satellite-based YBCU breeding habitat suitability model for the LCR is the amount of dense vegetation within a 72-ha (178-ac) patch (likely corresponding to the YBCU's home range), while a 4.5-ha-patch variable (likely corresponding to the SWFL's territory) is the most important covariate of the SWFL model (also see Hatten and Paradzick 2003).

In addition to size and shape of required breeding habitat patches, the two bird species differ in their requirements for patch floristics. Generalizing broadly across the Southwest, both the YBCU and the SWFL forage and nest primarily in native-dominated habitats and both avoid monotypic stands of exotic (e.g., tamarisk and Russian-olive; Durst et al. 2008, USFWS 2014b). However, the two bird species appear to differ in their ability to utilize exotic vegetation community types that have replaced native riparian vegetation across the Southwest. When the YBCU forages and nests in exotic-dominated and mixed exotic and native vegetation in the MRG and elsewhere in the Southwest, it is usually in vegetation with a native (e.g., cottonwood and willow [*Salix*]) overstory component (Walker et al. 2002, Dillon et al. 2017). The SWFL, on the other hand, appears to more readily forage and nest in exotic-dominated vegetation community types, particularly those located near moist soils or surface water and are structurally similar to the native vegetation in which they breed (Siegle et al. 2013; Tetra Tech 2015; Walker 2006, 2008; USFWS 2002). About 54% of all SWFL nesting attempts across the Southwest up until 2007 and 34% of all SWFL nesting attempts in the MRG from 1999 to 2014 were in mixed native and exotic vegetation or in exotic-dominated vegetation (Durst et al. 2008, Moore and Ahlers 2016).

The two bird species also differ in their requirements for horizontal and vertical vegetation structure within breeding habitat patches. Although the YBCU and the SWFL both require dense, live foliage, and can use habitats with similar physiognomy, the two species appear to differ in their requirements for understory and overstory vegetation (Sogge et al. 2010; USFWS 2002, 2014a). The YBCU, which is generally dependent on floristically uniform breeding habitat patches, largely depends on structurally complex vegetation (Johnson et al. 2017). Specifically, the YBCU's breeding habitat is typified by tall (e.g., upwards of 30 m [98.4 ft] or more) and mature canopy trees and a multistoried woody understory with a significant shrub layer (USFWS 2014a, Dillon et al. 2017). Although SWFL breeding habitat can include structural elements similar to that of the YBCU, such as a tall canopy, an overstory, and a dense midstory (usually in the 2-5 m [6.6-16.4 ft] range), these elements are not always present and, unlike the YBCU, the SWFL can breed in areas that support only low-statured vegetation (Siegle et al. 2013; Sogge et al. 2010; USFWS 2002, 2013a, 2014a). In general, breeding SWFLs use vegetation characterized by a dense cover of trees or shrubs that are ≥ 3 m (9.8 ft) tall (Sogge et al. 2010).

Differences in habitat requirements, such as patch size, shape, and vegetation composition and structure, correspond in part to differences in foraging and dietary preferences between the YBCU and the SWFL. Both the YBCU and SWFL can employ a "sit and wait" foraging tactic, perching for long bouts and then sallying from the perch briefly to aerial hawk and glean prey items; however, the two bird species differ in the size and composition of preferred prey, foraging micro- and macro-habitat requirements, and primary foraging behaviors (Hughes 1999, Sedgwick 2000, USFWS 2002, Durst 2004, Sogge et al. 2010). The YBCU and its extremely rapid breeding cycle are dependent on short-term abundances of large, nutritious prey, such as sphinx moth larvae (Family Sphingidae), katydids (Family Tettigoniidae), and, in some locales, tree frogs (e.g., *Hyla* and *Pseudacris*; Laymon 1980, USFWS 2014a). The YBCU's preference for foraging in native cottonwood-willow riparian habitat is likely due to the fact that its preferred prey of large caterpillars are dependent on cottonwoods and willows and are not found in exotic tamarisk (USFWS 2014b). Furthermore, the YBCU's preference for large vegetation patches and high connectivity among patches within a landscape is likely due to the fact that the paradoxical YBCU, which can remain nearly motionless for long bouts, traverses large areas (e.g., over 62.0 ha [153.2 ac] in the MRG) in order to locate a sufficient quantity of large prey items to meet their own and their nestling's high energetic needs (Hughes 1999, USFWS 2002, Sechrist et al. 2013). In addition, although YBCUs do forage in shrub vegetation and can drop to the ground to capture grasshoppers and other prey, YBCUs are thought to primarily forage by gleaning insects from vegetation of tall, mature, canopy trees with high foliage volume (Laymon and Halterman 1985, Rosenberg et al. 1991, USFWS 2013b). In contrast to the YBCU, the exclusively insectivorous SWFL tends to be a dietary generalist, consuming a wide range of primarily small insect prey, such as leafhoppers (Homoptera), true bugs (Hemiptera), bees and wasps (Hymenoptera), and flies (Diptera) (USFWS 2002, Sogge et al. 2010). SWFLs are able to meet their energetic needs by foraging for insects within their relatively (compared to the YBCU) small territories, though they can forage in adjacent habitats (e.g., agricultural fields, upland vegetation) upwards of 100 m (330 ft) distant from their territories (Sanders and Flett 1989, Sogge et al. 2010). The SWFL's adaptability in using a variety of vegetation community types is, at least partly, due to the fact that SWFLs are able to obtain sufficient (but compositionally different) food in exotic-dominated, mixed, and native vegetation (Owen and Sogge 2002, Drost et al. 2001). In contrast to YBCUs, SWFLs employ primarily aerial maneuvers while foraging; they aerial glean insects from vegetation while hovering or they hawk insects on the wing by sallying from a perch and capturing prey in flight (Sogge et al. 2010). Furthermore, unlike YBCUs, SWFLs forage primarily at external edges and internal openings within a riparian habitat patch, though they can forage at the top of the upper layer of vegetation or near the ground (Sogge et al. 2010).

In addition to differences in foraging requirements, differences in nest requirements between the two bird species are likely a basis for differences in habitat requirements. Across both bird species' ranges, the two birds most commonly place their nests in native plants such as willow; however, the YBCU appears to nest more frequently in native vegetation, particularly cottonwood and willow (Sogge et al. 2010; USFWS 2002, 2014a). In a review of YBCU nest substrates across its range, the USFWS (2014a) found that only 4% of nests were in exotic tamarisk, while 72% of nests were in willow (e.g., Gooding's willow, red willow [*S. laevigata*], and coyote willow [*S. exigua*]), 13% were in Fremont cottonwood (*P. fremontii*), 7% were in mesquite (*Prosopis*), and 2% were in netleaf hackberry (*Celtis laevigata* var. *reticulata*). Two YBCU nests monitored in the MRG in 2017 were both located in Gooding's willow (Darrell Ahlers, pers. comm., 12 February 2018). Exceptions to these generalities include YBCUs nesting at the Bill Williams Reserve National Wildlife Refuge in Arizona, which most commonly nest in tamarisk (43% of all nests from 2008-2012; McNeil et al. 2013). Furthermore, Walker et al. (2002) found YBCUs nesting in exotic Russian-olive in the MRG. In contrast to the YBCU, the SWFL frequently nests in exotic vegetation, including both tamarisk and Russian-olive (Sogge and Marshall 2000, Stoleson and Finch 2003). In the MRG, 49% of all SWFL nests located from 1999 to 2014 were placed in an exotic plant (47% in tamarisk and 2% in Russian-olive; Moore and Ahlers 2016). Corresponding to the variability in floristics of nest substrates and the height at which each species of plant presents YBCUs and SWFLs with their required nesting structure, nest height for both bird species is variable within and among breeding sites and there is much overlap in nest substrate and nest tree height between the two bird species (Stoleson and Finch 2003, Sogge et al. 2010, USFWS 2014a). However, YBCUs generally nest higher up in taller vegetation than do SWFLs. YBCU nests are built an average of 7 m (22 ft) (range = 1-22 m [4-73 ft]) up in trees that average 11 m (35 ft) in height (range = 3-30 m [10-98 ft]; McNeil et al. 2013, USFWS 2014a). In comparison, SWFL nests are usually built 2-7 m (6.6-23 ft) above ground (range = 0.6-20 m [1.6-65.6 ft]) in trees and shrubs ranging in height from 2-30 m (6.6-98 ft; Sogge et al. 2010; USFWS 2002, 2013a). Both bird species are thought to require moist soils or surface water near nest sites, but these habitat features might be more important for SWFLs. McNeil et al. (2013) did not find a significant relationship between YBCU nest sites and soil moisture and Johnson et al. (2017) did not find a significant relationship between YBCU occupancy of a patch and distance to surface water. In contrast, Moore and Ahlers (2016) found that 91% of nests located in the MRG between 2004 and 2015 occurred within 100 m (328 ft) of surface water, 79% of which were within 50 m (164 ft) of surface water.

In summary, a comparison and contrast of habitat requirements for each bird species completed above reveals that the two bird species' required breeding habitats can overlap in floodplains supporting large, contiguous, structurally heterogeneous patches of native woody riparian vegetation (USFWS 2013a, 2013b, 2014b). However, the SWFL appears to show a greater adaptability in habitat selection, as demonstrated by variability in size, shape, dominant plant species, and vertical and horizontal structure of breeding patches (USFWS 2002, Sogge et al. 2010). Owing largely to the YBCU's dependence on large prey items found in native vegetation landscapes and its proclivity for foraging over large distances and nesting high up in densely foliaged native trees, the YBCU tends to require large patches of tall, structurally complex native-dominated vegetation (USFWS 2013b, 2014a, 2014b). The SWFL, on the other hand, is a dietary generalist, consumes relatively smaller prey than the YBCU, and tends to nest in vegetation layers lower to the ground in smaller territories than the YBCU, and, thus, it can be found in habitats considered unsuitable for the YBCU, such as habitats that are small or linear, or that are dominated by short-statured vegetation, relatively less structurally complex vegetation, or exotic vegetation (Sogge et al. 2010; USFWS 2002, 2013a). Although comparing and contrasting life history requirements of both species is useful in making generalizations about the similarity in YBCU and SWFL breeding habitat requirements in the MRG and across the Southwest, the accuracy of such efforts is limited by the fact that habitat attributes preferred by both species vary across multiple spatial and temporal scales and differ among geographic locations. In addition, far more is known about habitat requirements of the SWFL than the YBCU, partly due to the fact that: 1) the SWFL has been federally listed and, thus, formally surveyed, for a longer period of time; 2) SWFL territories are more easily delineated; and 3) SWFL nests are more easily located. Due to these issues, it is unclear whether similarities or differences in habitat requirements between the SWFL and YBCU are due to averaging habitat attributes over large geographic areas (e.g., averaging nest height across their ranges), small samples sizes for the YBCU at least in some geographic areas, or differences in methods for defining and quantifying habitat attributes. As little scientific work has been completed to determine similarity in YBCU and SWFL breeding habitat requirements (this author only found a single study addressing the topic completed by Johnson et al. [2017]), rigorous scientific research is needed to determine which abiotic and biotic breeding habitat features at multiple spatial scales (e.g., landscape, patch, nest site) predict where the YBCUs and SWFL co-occur, occur individually, and are absent within the MRG.

Management Application

SIMILARITY IN CUCKOO AND FLYCATCHER BREEDING HABITAT REQUIREMENTS

MANAGEMENT APPLICATION

There is no quantitative scientific information available regarding which breeding habitat requirements the cuckoo and flycatcher share in common and which are species-specific. Therefore, it is unclear whether offsetting and conservation measures developed for the flycatcher benefit the cuckoo. Studies characterizing the similarity between cuckoo and flycatcher breeding habitat requirements in the MRG will provide information needed to effectively design and implement offsetting measures for, as well as accurately evaluate the impacts of management actions on, both the cuckoo and the flycatcher and for each species individually.

Currently, in the absence of sufficient information on YBCU breeding habitat requirements at multiple spatial and temporal scales (see Cuckoo Critical Scientific Uncertainty #1: Scientific Relevance), managers are attempting to implement mitigation and conservation measures developed for the SWFL for the benefit of the YBCU (USFWS 2014b, 2016). It is reasonable to assume that the SWFL can be a surrogate for the YBCU because the two birds are both riparian obligates and have some life history requirements in common (see Cuckoo Critical Scientific Uncertainty #3: Scientific Relevance). Specifically, it is reasonable to assume that water management activities (e.g., alterations to river flows) and habitat restoration efforts (e.g., vegetation plantings, exotic vegetation removal, geomorphologic alterations) similarly impact both bird species because 1) the PCEs of proposed YBCU critical habitat and designated SWFL critical habitat are similar; 2) their critical habitats overlap; and 3) both require dynamic river processes that promotes establishment, development, maintenance, and recycling of mosaics of riparian woodlands of varying ages. However, there is no scientific evidence that proves that management actions for the SWFL also benefit the YBCU (USFWS 2014b). In fact, it is likely that SWFL only can be a surrogate for the YBCU only at certain spatial scales, in certain geographic areas, and in certain vegetation community types (see Cuckoo Critical Scientific Uncertainty #3: Scientific Relevance). In particular, restoration sites that support small, linear strips of low-statured riparian vegetation might be suitable for the SWFL, but are likely avoided by the YBCU due to its requirements for substantially larger habitat patches (Laymon and Halterman 1989; Sogge et al. 2010; USFWS 2013a, 2016). In fact, the USFWS (2014b) contends that most habitat protection and restoration efforts completed in the western US over the 25-30 years, including those for the SWFL, have been too small-scaled for the stabilization and recovery of the YBCU. Thus, managers require scientific data on the similarity in YBCU and SWFL breeding habitat requirements to effectively design, implement, and evaluate offsetting measures for both the YBCU and the SWFL and for each species individually.

Recovery Application

SIMILARITY IN CUCKOO AND FLYCATCHER BREEDING HABITAT REQUIREMENTS

RECOVERY APPLICATION

Lacking vital cuckoo life history information and formal guidance from a recovery plan or a federal designation of critical habitat, managers involved in recovery efforts for the flycatcher are attempting to implement the same efforts for the cuckoo based on the assumption that the two riparian obligate bird species are similar in their breeding habitat requirements. However, there is no scientific evidence to support the deduction that recovery actions and conservation measures for the flycatcher benefit either the cuckoo or its habitats. Studies investigating the critical scientific uncertainty not only would provide information on cuckoo-specific breeding habitat requirements at multiple spatial and temporal scales, but also would provide a comparison and contrast with that of the flycatcher. Therefore, such studies will provide information necessary for species-specific, dual-species, and multi-species recovery planning and implementation efforts in the MRG.

Currently, there is no recovery plan for the YBCU, critical habitat has only been proposed not designated (USFWS 2014a, 2014b, 2016), and design and implementation of effective recovery actions are hampered by insufficient information on YBCU breeding habitat requirements at multiple spatial and temporal scales (see Cuckoo Critical Scientific Uncertainty #1). Therefore, managers involved in recovery efforts for the SWFL are attempting to implement the same efforts for the YBCU based on the assumption that the two riparian obligate bird species are similar in their breeding habitat requirements (USFWS 2014b, 2016). As mentioned in the above in Management Application, the USFWS (2014b) states in the federal listing of the YBCU as threatened that it is reasonable to assume that actions for the SWFL can provide protections for and benefits to the YBCU. However, the USFWS (2014b) cautions that there is no scientific evidence to support a position that recovery actions for the SWFL will benefit either the YBCU or its habitats. Furthermore, although multi-species recovery planning and implementation has broader conservation application and are generally more time- and cost-effective than single-species recovery efforts, multi-species recovery efforts tend to be less effective. This is because they, in part, 1) reflect a poorer understanding of species-specific biology and 2) fail to identify and address species-specific threats (Clark and Harvey 2002). Boersma et al. (2001) found that species covered by single-species recovery plans were four times more likely to improve in status than species covered by multi-species recovery plans, and species covered by multi-species recovery plans are significantly more likely to exhibit a declining status trend than species covered by single-species recovery plans. Therefore, in order to maximize benefits for the YBCU, recovery actions must be based on sound quantitative data on which of the YBCU's recovery needs require YBCU-specific action and which can be addressed by a multi-species approach (e.g., for both the YBCU and SWFL).

Studies investigating the similarity in breeding habitat requirements between the YBCU and the SWFL not only provide information on YBCU-specific breeding habitat requirements at multiple spatial and temporal scales (see Critical Scientific Uncertainty #1), but also provide a comparison and contrast with that of the SWFL (see Scientific Relevance above). Therefore, these studies will provide information on the YBCU and SWFL vital to both species-specific and dual-species recovery planning and implementation efforts in the MRG. Specifically, studies addressing the critical scientific uncertainty will assist in this recovery planning process for both bird species by identifying: 1) unoccupied and occupied suitable YBCU and SWFL breeding habitats for protection; 2) restoration targets, such as patch size, configuration, and vegetation composition and structure, specifically for the YBCU, specifically for the SWFL, and both bird species; 3) habitats that are unsuitable or marginally suitable for breeding YBCUs and/or SWFLs, and, thus, a priority for restoration; and 4) potential threats to YBCU and/or SWFL breeding habitats, such as expansion and invasion of exotic plant species or defoliation of tamarisk by the tamarisk beetle (*Diorhabda*).

Study Plan Considerations

Addressing the primary question, “How similar are the YBCU and the SWFL in their breeding habitat requirements in the MRG?” involves answering the following three subquestions:

1) What is the degree of YBCU and SWFL co-occurrence in the MRG? Specifically, at what frequency do YBCUs and SWFLs breed in the same riparian patches in the MRG?
2) Which abiotic and biotic breeding habitat features at multiple spatial scales predict where the YBCU and SWFL co-occur, occur individually, and are absent in the MRG?
3) Which abiotic and biotic breeding habitat features at multiple spatial scales (e.g., landscape, patch, nest site) are similar or dissimilar between suitable YBCU and suitable SWFL breeding habitats? Specifically, which habitat attributes are specific to the YBCU, specific to the SWFL, and shared by both bird species?

Each subquestion can be investigated in separate studies, but they should be addressed in a sequential manner so that study results build upon and augment each other. Determining the degree of YBCU and SWFL co-occurrence in the MRG (*Subquestion 1*) requires first obtaining previously collected data on occurrences of both the YBCU and the SWFL from either targeted surveys and studies or from incidental reports (e.g., YBCU incidentally detected during formal SWFL surveys) to estimate historical and recent co-occurrence. Answering *Subquestion 1* also requires obtaining current YBCU and SWFL co-occurrence data from both on-going work (see Flycatcher Critical Scientific Uncertainty #3 and the Cuckoo Critical Scientific Uncertainty #2) and new survey efforts. Similar to addressing Flycatcher Critical Scientific Uncertainty #3 and the Cuckoo Critical Scientific Uncertainty #2, this entails:

1) verifying and mapping locations of established YBCU and SWFL survey routes to ensure consistency in site-naming, as well as establish and name new survey routes;

2) acquiring data from any and all agencies and organizations involved in on-going standardized YBCU and SWFL protocol surveys in the MRG;
3) completing standardized protocol surveys for the YBCU (Halterman et al. 2016) and the SWFL (Sogge et al. 2010) in those areas not covered by existing surveys;
4) securing permission to access survey sites from a multitude of landowners and managers (municipal, county, state, federal, and tribal); and
5) hiring sufficient ESA Section 10a-permitted personnel to ensure that all survey sites along the MRG are completed concurrently within each year of the study.

Similar to addressing Cuckoo Critical Scientific Uncertainty #1, accurately answering *subquestions 2* and *3* requires the completion of original scientific studies to determine which habitat features are associated with landscapes, habitat patches, and nest sites supporting only breeding YBCUs, only breeding SWFLs, and both bird species. These studies likely will involve fieldwork to collect multi-spatial-scale habitat data; however, mining scientific and gray literature on YBCU and SWFL life history requirements might be a more time- and cost-effective method of obtaining at least some of the required information. Literature useful for data mining efforts includes federal recovery plans and listing documents (e.g., USFWS 2002, 2013a, 2014a, 2014b), YBCU and SWFL monitoring reports (e.g., Dillon et al. 2017, Moore and Ahlers 2017), peer-reviewed publications (e.g., Hughes 1999, Paxton et al. 2007), and the results of studies addressing cuckoo critical scientific uncertainties #1 and #4. Statistical and remote sensing models also can supplement or provide informative alternatives to fieldwork, such the range-wide satellite model for suitable SWFL breeding habitat developed by Hatten (2016), the SWFL habitat suitability model for the MRG developed by Siegle et al. (2013), and aerial-photo and satellite models for the LCR developed by Johnson et al. (2017).

Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 2* priority (Table 10). It was ranked #3 of the top four YBCU scientific uncertainties identified by the SMEs, but the ranking was nearly tied for second place with Critical Scientific Uncertainty #2 *Cuckoo breeding population sizes, distributions, and trends in the MRG*.

CRITICAL SCIENTIFIC UNCERTAINTY #4: YELLOW-BILLED CUCKOO SPATIAL BEHAVIOR PATTERNS

Study Question: What are the spatial behavior patterns of YBCUs that breed in the MRG within and among years?

Scientific Relevance

YELLOW-BILLED CUCKOO SPATIAL BEHAVIOR PATTERNS

SCIENTIFIC RELEVANCE

The vagile YBCU moves within and among breeding sites within and among years in response to local conditions (e.g., availability of preferred prey) and travels complex, long-distance migration routes between breeding sites in the Southwest and wintering sites in South America. Studies employing color banding, radio telemetry, light-level geolocators, and GPS tags conducted in the Southwest over the past two decades have yielded important information on YBCU migration routes, wintering locations, dispersal from natal and breeding areas, site fidelity, and territory use. However, information on the spatial behavior patterns of YBCUs that breed in the MRG is derived primarily from tracking 10 individual YBCUs in two different studies conducted from 2007-2010. Therefore, additional scientific research is needed to elucidate spatial behavior patterns of YBCUs that breed in the MRG.

The YBCU is highly vagile; it moves thousands of miles between its wintering and breeding grounds, and it can move large distances within and among breeding sites within and among years (USFWS 2013b). Specifically, each year, YBCUs breeding in the US west of the Continental Divide migrate upwards of 10,000 km (6,214 mi) to and from wintering grounds primarily in South America east of the Andes (Hughes 1999, Sechrist et al. 2012, McNeil et al. 2015). In addition, YBCUs engage in pre- and post-breeding nomadic movements, likely to locate high quality breeding sites (e.g., those with high invertebrate prey abundances) and to prepare for fall migration, respectively (Hamilton and Hamilton 1965, Laymon 1980, Rappole and Ballard 1987, Hughes 1999, USFWS 2013b). Furthermore, once YBCUs have begun nesting, they move widely, presumably while foraging for preferred prey (Laymon and Halterman 1987, Halterman 2009, Sechrist et al. 2013).

Movement during the non-breeding portion of the YBCU's annual cycle is not well understood (USFWS 2013b), but data collected from two female YBCUs fitted with light-level geolocators and five YBCUs fitted with GPS tags suggest that western YBCUs exhibit a complex loop migration route with multiple stopovers between their breeding grounds in the Southwest and their wintering grounds in South America (McNeil et al. 2015; Parametrix, Inc. and SSRS 2015, 2016a, 2016b; Sechrist et al. 2012). The first documented migration and wintering of an individual YBCU was from a single female equipped with a geolocator on her breeding grounds along the Rio Grande near Elephant Butte Reservoir, Sierra County, New Mexico, and was tracked from 31 July 2009 until she was recaptured approximately 1.4 km from the site of her initial capture on 2 July 2010 (Sechrist et al. 2012). During this time period, the female traveled approximately 9500 km (5903 mi) roundtrip from the MRG to its wintering grounds in eastern Bolivia, southwestern Brazil, Paraguay, and northeastern Argentina. She took a fall migration route through Central America that differed from her spring migration route through portions of the Caribbean, but, apparently, she spent time in northern Mexico both post- and pre-breeding (Sechrist et al. 2012). Interestingly, the female appeared to have migrated during spring and fall through areas in eastern New Mexico and western Texas considered to be in the range of the eastern DPS of the YBCU. Although this female provides the only concrete evidence of where YBCUs breeding in the MRG go during the nonbreeding portion of their annual life cycle, her nonbreeding movement patterns were similar to that of a female YBCU that was captured and fitted with a light-level geolocator on 7 August 2011 at the Palo Verde Ecological Reserve (PVER), along the LCR in California (McNeil et al. 2015). Similar to the MRG female, the PVER bird was tracked a total of approximately 9500–9900 km (5903-6152 mi) as she traveled to her wintering grounds in the Gran Chaco region of northern Argentina and southern Bolivia, and then back to her initial capture site where she was recaptured on 17 July 2012 (McNeil et al. 2015). Also, similar to the MRG female, the PVER bird possibly stopped over in northern Mexico post- and pre-breeding. Although both birds had migration routes through Central America and the Caribbean region, they followed these routes in reverse order of each other, with the PVER female traveling through the Caribbean in fall and Central American in spring. Additional data from five PVER YBCUs fitted with GPS tags in 2014 (N = 3) and 2015 (N = 2) lends support both for wintering grounds in the Gran Chaco region of South America and, similar to Sechrist et al. (2012), a fall migration route through the west coasts of Mexico and Central America (Parametrix, Inc. and SSRS 2015, 2016a, 2016b).

All seven of the YBCUs tracked during the nonbreeding phase of the annual cycle were recaptured at or near the sites where they were initially captured the previous year, suggesting a degree of site fidelity in YBCUs; however, the recapture rate of geolocator-tagged birds was only 8% (1 of 13 birds) in the MRG and 13% (1 of 8 birds) in the LCR (Sechrist et al. 2012, McNeil et al. 2015). These low recapture rates are comparable to the recapture/resight rate of 9.6% (5 of 52 birds) in color-banded YBCUs along the San Pedro River in Arizona (Halterman 2009) and 9.9% in color-banded YBCUs in the LCR (McNeil et al. 2013). In contrast, highlighting how tracking methods can affect recapture and resight rates, the recapture rate was 43% (6 of 14 birds; 1 tag was not retrieved) for birds tagged with GPS units in the LCR in 2014 and 2015 and the recapture/resight rate was 37.7% (23 of 61 birds) for color-banded YBCUs in the LCR in 2016 (Parametrix, Inc. and SSRS 2015, 2016a, 2016b). In general, estimating site fidelity and dispersal from these recapture and resight data is problematic because 1) a majority of marked and tracked birds are not relocated, retrieved (for deceased birds), or recaptured, and 2) it is unknown whether the unencountered birds have dispersed, deceased, or avoided detection. Limiting analyses to only those birds whose fate is known, interannual site fidelity and dispersal information for the MRG is derived from the single female tracked by Sechrist et al. (2012). Thus, the majority of such information comes from tracking studies conducted outside of New Mexico, primarily in California and Arizona. In the LCR, dispersal studies have found that birds that bred in the previous year tended to disperse further than those that hatched the previous year (McNeil et al. 2013). In addition, both breeding and natal dispersal were higher in females than males, though this pattern might be an artifact of small sample sizes (McNeil et al. 2013). Furthermore, although individuals dispersing from breeding and natal sites in the LCR have been tracked to other sites in the LCR, no large-scale dispersal events have been documented in the western DPS, such as among the Kern River, the LCR, the San Pedro River, and the MRG populations (McNeil et al. 2013; S. McNeil, pers. comm., 3 August 2017). One of the larger documented dispersal events in the LCR was a single adult female that was banded at the ‘Ahakhav Tribal Preserve in 2009 and was re-sighted 37.4 km (23.2 mi) north at the Bill Williams River NWR the following year.

In addition to year-to-year movements among breeding sites, YBCUs are weakly or non-territorial and move widely during the breeding season, requiring the use of the terms *home range* (the area regularly travelled to meet life history requirements) and *core use area* (a portion of the home range that is utilized more thoroughly and frequently) to describe YBCU breeding territories (Hughes 1999). Unlike the highly defended breeding territories of SWFLs, home ranges of YBCUs are large, vary greatly among individuals and geographic locations, and overlap greatly both between members of a pair and between neighboring pairs (USFWS 2013b). Two metrics used to quantify home ranges and core use areas are minimum convex polygon (MCP) and kernel-home-range estimates (KHR), both of which involve identifying the spatial structure of localities where an individual is detected (Halterman 2009). Usually 95% and 100% estimates are used to identify home ranges and a 50% estimate is used to identify core use areas. In the MRG, home range size varied widely among radio telemetered individuals, but, on average, was 91.0 ha [224.9 ac] for a 100% MCP estimate and 62.0 ha [153.2 ac] for a 95% KHR estimate (Sechrist et al. 2013). The core use area averaged 10 ha [24.7 ac] for the 50% KHR (Sechrist et al. 2013). These estimates are within the range of those from radio telemetry studies conducted on the San Pedro River, Arizona (95% MCP = 51.1 ± 62.4 ha [126.3 ± 154.2 ac], 95% KHR = 38.6 ± 42.2 ha [95.4 ± 104.3 ac], 50% KHR = 7.5 ± 10.3 ha [18.5 ± 25.5 ac]; Halterman 2009). However, the estimates are larger than those from radio telemetry studies conducted in the Kern River, California (95% KHR = 18.4 ± 2.3 ha [45.5 ± 5.7 ac], 50% KHR = 3.1 ± 0.1 ha [7.7 ± 0.25 ac]; Stanek and Stanek 2013), and in the LCR (100% MCP = 31.3 ± 52.7 ha [77.4 ± 130.2 ac], 95% KHR = 18.4 ± 9.2 ha [45.5 ± 22.7 ac], 50% KHR = 3.6 ± 1.5 ha [8.9 ± 3.7 ac]; McNeil et al. 2013). As well as moving within their home ranges, YBCUs also occasionally move among sites within a breeding season (Sechrist et al. 2012, McNeil et al. 2013). As YBCUs rarely traverse across unwooded spaces greater than 0.62 km (0.25 mi) while foraging, movement is partly dependent on the quality, configuration, and size of corridors of woody riparian vegetation (USFWS 2014b). Perhaps uncharacteristic of within-breeding-season movements in general, the female tracked with a geolocator along the MRG appeared to make some long-distance movements during the 2010 breeding season, travelling over a 9-day period from New Mexico south into the Mexican state of Chihuahua and then back to New Mexico (Sechrist et al. 2012).

In summary, studies employing color banding, radio telemetry, light-level geolocators, and GPS tags conducted in the Southwest over the past two decades have yielded important information on YBCU spatial behavior patterns, including migration routes, wintering locations, dispersal from natal and breeding areas, site fidelity, and territory use (i.e., home ranges and core use areas). However, YBCU movement remains largely unknown primarily due to the fact that conclusions are drawn from very small sample sizes. In the MRG, information on YBCU spatial behavior patterns is derived primarily from a 2007/2008 radio telemetry study on nine YBCUs and a single female fitted with a light-level geolocator in 2009 (Sechrist et al. 2012, 2013). Therefore, understanding spatial behavior patterns of YBCUs that breed in the MRG will require further rigorous scientific inquiry. Specifically, the following information is needed on YBCUs that breed in the MRG: site fidelity, breeding and natal dispersal, correlates of dispersal, locations and habitats used during movements, and connectivity among populations.

Management Application

YELLOW-BILLED CUCKOO SPATIAL BEHAVIOR PATTERNS MANAGEMENT APPLICATION
In the absence of sufficient information on YBCU breeding habitat requirements at multiple spatial and temporal scales, managers are attempting to implement habitat restoration for the YBCU based on the assumption that restoration techniques developed for the SWFL will create suitable YBCU breeding habitats. Although using the SWFL as a surrogate for the YBCU is valuable as a temporary measure, successfully protecting and promoting YBCU breeding populations through habitat restoration require obtaining scientific information specific to the YBCU on restoration targets, such as patch size, configuration, and vegetation composition and structure, and where in the MRG habitat protection and restoration are needed. Researching YBCU spatial behavior patterns is a useful means to obtaining such information.

Currently, in the absence of sufficient information on YBCU breeding habitat requirements at multiple spatial and temporal scales (see Cuckoo Critical Scientific Uncertainty #1), managers are attempting to implement habitat restoration for the YBCU based on the assumption that restoration techniques developed for the SWFL will create suitable YBCU breeding habitats (USFWS 2014b, 2016). Although some restoration sites do support habitats suitable for both the SWFL and the YBCU, the USFWS (2014b) cautions that YBCUs do not always benefit from habitat restoration efforts benefiting the SWFL. This is because the YBCU, while being a riparian obligate like the SWFL, has different ecological requirements, such as larger home ranges and more mature age classes of vegetation (see Cuckoo Critical Scientific Uncertainty #3). In fact, the USFWS (2014b) contends that most habitat protection and restoration efforts completed in the western US over the 25-30 years have been too small-scaled for the stabilization and recovery of the YBCU.

To successfully implement restoration for the benefit of the YBCU now and in the future, managers require scientific information specific to the YBCU on restoration targets, such as patch size, configuration, and vegetation composition and structure, and where in the MRG habitat protection and restoration are needed. Researching YBCU spatial behavior patterns is a useful approach to obtaining such information; by understanding intra- and inter-annual YBCUs movements, information is obtained on the diversity of habitats YBCUs use, YBCU home range requirements, connectivity among YBCU populations, and the locations of key breeding sites (and, possibly, stopover areas and migratory routes) in the MRG. Thus, by reducing uncertainties on a broad range of topics of interest, research on YBCU spatial behavior patterns is helpful for determining where and what management actions could be implemented to offset the negative impacts of water use on the YBCU and improve the overall status of the YBCU in the MRG.

Recovery Application

YELLOW-BILLED CUCKOO SPATIAL BEHAVIOR PATTERNS

RECOVERY APPLICATION

Research on YBCU spatial behavior patterns will yield information useful for recovery planning and implementation. Specifically, by providing information on the diversity of habitats and locations used by YBCUs in the MRG and, possibly, elsewhere, spatial behavior pattern research can inform which and where recovery actions (e.g., habitat restoration) are necessary. Research results also can provide information on connectivity among YBCU populations.

On 3 October 2014, the USFWS made the determination that the western DPS of the YBCU met the definition of threatened based on the immediacy, severity, and scope of the threats to its continued existence (USFWS 2014b). The primary threats to the western DPS are reduced fitness and/or fecundity due to anthropogenic habitat loss, degradation, and fragmentation on the breeding grounds in the western US (USFWS 2014b). In addition, the YBCU spends approximately 80% of its annual life cycle away from its breeding grounds, during which time it is threatened by extensive habitat loss, pesticides, collision with communication towers and other tall structures, and other hazards (USFWS 2014b). In order to develop a YBCU recovery plan, designate critical habitat, and plan and implement effective YBCU recovery efforts that address threats during all phases of the YBCU's annual cycle, it is essential that research be completed on YBCU spatial behavior patterns (USFWS 2014b). Such research can inform which and where recovery actions (e.g., habitat restoration) are necessary by elucidating the habitats and geographic locations used by YBCUs during all phases of their annual cycle. Specifically, YBCU spatial behavior pattern studies can provide the following information useful to recovery: 1) YBCU breeding habitat requirements, such as size and vegetation characteristics, of home ranges and core use areas; 2) habitat requirements during pre- and post-breeding movements in the MRG (and, possibly, migration, and wintering); 3) locations of breeding sites in the MRG and, possibly elsewhere; and, depending on the tracking methods employed (e.g., radio telemetry versus GPS tags), 4) migratory routes, stopover sites, and wintering grounds (USFWS 2014b). Research results also can be useful in assessing connectivity between YBCU populations (e.g., to what degree the range of the western and eastern DPSs overlap during the breeding and nonbreeding seasons).

Study Plan Considerations

Addressing the critical scientific uncertainty involves answering the question, "What are the spatial behavior patterns of YBCUs that breed in the MRG within and among years?" In addition, the following seven subquestions should be answered:

1) What are biologically relevant definitions of spatial habitat terms, such as landscape, patch, home range, core use area, territory, and nest site?
2) What is the spatial structure of YBCU breeding home ranges and core use areas?
3) What are the breeding (and, possibly stopover and wintering) habitats used by YBCUs that breed in the MRG?
4) What are the locations of breeding sites (and, possibly, migratory routes, stopover sites, and wintering grounds) of YBCU that breed in the MRG?
5) What is the degree of YBCU site fidelity in the MRG?
6) How far do YBCU individuals move from source breeding and natal populations within and among years?
7) What is the connectivity among YBCU populations within the MRG, and between the MRG and other breeding sites along the Rio Grande and other stream drainages within and outside of New Mexico?
8) What factors are correlated with YBCU dispersal (e.g., age, sex, climate, geographic distribution of habitat)?

To date, information on YBCU movement has been derived primarily from: 1) color banding and resighting studies conducted along the Kern River in California (e.g., Stanek and Stanek 2013), the San Pedro River in Arizona (e.g., Halterman 2009), and the Lower Colorado River in California, Arizona, and Nevada (Parametrix, Inc. and SSRS 2015, 2016a, 2016b); 2) radio telemetry studies conducted along the Kern River in California (e.g., Stanek and Stanek 2013), in the MRG (Sechrist et al. 2013), and the LCR (McNeil et al. 2013); 3) light-level geolocator studies conducted in the MRG and Pecos River in New Mexico (Sechrist and Best 2012, Sechrist et al. 2012, Dillon et al. 2017) and in the LCR (McNeil et al. 2015); and 4) GPS tag studies in the LCR (Parametrix, Inc. and SSRS 2015, 2016a, 2016b). In addition to tracking movements of individual birds, both colonization events of previously unoccupied YBCU breeding habitats and YBCU population fluctuations not attributable to local demographics can provide indirect evidence of dispersal (Gaines and Laymon 1984, Halterman 2003, Halterman et al. 2016, USFWS 2013b). Thus far, despite investment of significant resources, movement studies have been hampered by small sample sizes because YBCUs are difficult to detect, trap, and observe. More specifically, YBCUs have a secretive nature, often referred to as "bizarre" and "peculiar," that can thwart detection and capture efforts, and they have short legs that are often covered by body feathers that can prevent visual observations of leg bands (Hughes 1999). Study results also have been complicated by the fact that YBCU behaviors vary among individuals, populations, and years.

If sufficient sample sizes are obtained to achieve desired statistical power, radio telemetry can be effective in determining within-season and within-site spatial behavior patterns of YBCUs in the MRG and, thus, a current multi-year radio telemetry study by the USBR's Albuquerque Area Office (L. Walton, USBR, pers. comm.) should inform our knowledge of within-season movements, such as home ranges and core use areas. Although color banding (including resighting and recapturing) individuals and fitting birds with geolocators have been the traditional methods of investigating spatial behavior patterns among years and during the nonbreeding season, studies on these topics should employ newly developed technologies, such as GPS tracking units, which track YBCU movements with greater precision and accuracy, over larger geographic areas (i.e., during all phases of the YBCU's annual cycle), and require smaller sample sizes. To determine correlates of YBCU spatial behavior patterns, data should be collected on the age and sex of tracked birds (from blood samples and morphological data collected from banded birds), habitat characteristics of high use areas, availability and distribution of suitable habitats, availability and phenology of prey, and nest success. Wherever possible, results of completed and on-going habitat, prey, and nest monitoring studies (see cuckoo critical scientific uncertainties 1-3) should be used to investigate correlates of YBCU spatial behavior patterns to limit redundancy and unnecessary expenditure of resources. As investigating spatial behavior patterns is complex, it requires knowledge of a diversity of disciplines (e.g., ornithology, entomology, botany, demography, community ecology), sampling techniques and technologies (e.g., color banding, radio telemetry, nest monitoring, arthropod collection, vegetation sampling), and data analysis and modelling methods. In addition, obtaining sufficient sample sizes will necessitate multiple years of resource- and labor-intensive fieldwork. Surveying for and handling YBCUs require obtaining specialized training and permits (e.g., ESA Section 10a permits).

Priority Ranking

Addressing this critical scientific uncertainty is considered a *Level 2* priority (Table 10). It was ranked #4 of the top four YBCU scientific uncertainties identified by SMEs, but the ranking was nearly tied for second place with Critical Scientific Uncertainty #2 *Cuckoo breeding population sizes, distributions, and trends in the MRG*.

Table 10. Study framework attributes for critical scientific uncertainties for the Yellow-Billed Cuckoo.

Uncertainty Statement/Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Recommended Priority
The abiotic and biotic variables that predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales. • Which abiotic and biotic variables predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales	• Accurately evaluate impacts of management actions • Design, implement, and evaluative offsetting measures (e.g., habitat restoration)	• Data mining: o Scientific and gray literature • Literature Review: o Scientific and gray literature • Field-based, remote sensing, and modeling studies on abiotic and biotic features of breeding habitat: o Multi-spatial scale o Multi-temporal scale	• Landscape features: o Floodplain extent and ruggedness o Vegetation greenness indices o Connectivity, distribution, availability, and composition of vegetation community types • Patch (home range and core use area) features: o Vegetation composition and structure o Presence and proximity to surface water, and saturated/moist soils o Groundwater depth o Size and shape o Composition and availability of prey • Nest site features o Nest tree height and floristics o Surrounding vegetation composition and structure o Microclimate • Temporal changes o Seasonality and persistence of surface water and moist soils o Longevity of suitable vegetation community types	• Multi-year • MRG	• Land access and permission • Qualified and permitted personnel • Collecting large datasets • Time- and labor-intensive fieldwork • Investigating ecosystem components across multiple temporal and spatial scales	Level 1
YBCU breeding population sizes, distributions, and trends in the MRG. • What are YBCU breeding population sizes, distributions, and trends in the MRG?	• Accurately estimate YBCU breeding population sizes, distributions, and trends in the MRG o Where are YBCUs breeding o Where are YBCUs declining • Ensure Collaborative Program cost-effectively and successfully offsets effects of management actions in compliance with the ESA o Proper siting of projects	• Data mining: o YBCU survey data submitted to USFWS • Literature Review: o Recent reports on YBCU breeding population size, distribution, and status/trends • Field-based, remote sensing, and modeling studies	• Historical, recent, and current breeding population sizes and distributions • Annual variation in breeding population sizes and distributions • Breeding population trends • Survey year • Factors that affect breeding population sizes, distributions, and trends: o Im-/emigration o Habitat changes o Changes in prey composition and availability o Nesting success	• Multi-year • MRG	• Land access and permission • Qualified and permitted personnel • Obtaining hardcopies and electronic copies of previous (> 20 yrs) surveys • Ensuring continuity and consistency in data collection over multiple years • Ensuring all survey sites are completed concurrently within each year of the study	Level 2

Table 10. Study framework attributes for critical scientific uncertainties for the Yellow-Billed Cuckoo.

Uncertainty Statement/Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Recommended Priority
Similarity in YBCU and SWFL breeding habitat requirements in the MRG. • How similar are the YBCU and the SWFL in their breeding habitat requirements in the MRG?	• Accurately evaluate and effectively offsets impacts of management actions on both the YBCU and SWFL in compliance with the ESA: o Evaluate impacts o Design, implement, and evaluate offsetting measures (e.g., habitat restoration)	• Data mining: o YBCU and SWFL survey data submitted to USFWS • Literature Review: o Recent reports on YBCU and SWFL breeding population sizes, distribution, and status/trends o Recent reports on individual species occurrence and co-occurrence o Scientific and gray literature on YBCU and SWFL life history requirements and recovery needs o Existing YBCU and SWFL habitat suitability models • Field-based, remote sensing, and modeling studies on abiotic and biotic features of breeding habitat: o Multi-spatial scale o Multi-temporal scale	• Locations of individual species occur and co-occur • Annual variation in occurrences of both species • Habitat features at multiple spatial and temporal scales (see above *The abiotic and biotic variables that predict suitable YBCU breeding habitats in the MRG across multiple spatial and temporal scales*)	• Multi-year • MRG	• Land access and permission • Qualified and permitted personnel • Collecting large datasets • Time and labor-intensive fieldwork • Obtaining hardcopies and electronic copies of previous (> 20 yrs) surveys • Obtaining habitat suitability models for both species • Investigating ecosystem components across multiple temporal and spatial scales • Integrative research strategy that synthesizes results of a number of interrelated studies	Level 2
Spatial behavior patterns of YBCUs that breed in the MRG within and among years, and drivers. • What are the spatial behavior patterns of YBCUs that breed in the MRG within and among years?	• Accurately evaluate and effectively offsets impacts of management actions on the YBCU in compliance with the ESA: o Set restoration targets o Determine focus areas for protection and restoration efforts	• Much flexibility and variety in methods for tracking movements of individuals: o Radio-telemetry o GPS o Light-level geolocators o Stable isotopes o Color-banding • Much flexibility and variety in study types and methods to assess factors influencing movement: o Field-based studies o Remote sensing studies o Modeling studies	• Site fidelity • Natal and breeding dispersal distances and rates • Home range sizes • Core use area sizes • Migration distances and routes • Wintering locations • Habitat characteristics of high use areas • Prey composition and availability • Reproductive success • Connectivity among populations • Age and sex • Suitable habitat availability and distribution	• Multi-year • MRG	• Land access and permission • Qualified and permitted personnel • Collecting large datasets • Time- and labor-intensive fieldwork • Investigating ecosystem components across multiple temporal and spatial scales • Integrative research strategy that synthesizes results of a number of interrelated studies	Level 2

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Appendix E-1: Rio Grande Silvery Minnow Technical Convening Assessment Results Summary

RIO GRANDE SILVERY MINNOW
TECHNICAL CONVENING ASSESSMENT REPORT

Following the General Convening Assessment, the GSA team has focused on the RGSM. The Collaborative Program partners have already spent substantive time, energy, and effort on RGSM; nevertheless the General Convening Assessment results showed that this species is still the subject of considerable scientific debate with no clear consensus on either the science, or how to respond to the species' needs. The GSA team therefore set up a detailed technical assessment process, using a questionnaire and follow-up interview process.

Each of the Collaborative Program partners was given the opportunity to name one or two SMEs to participate in the RGSM TCA. The GSA team developed a technical questionnaire to document the breadth of defensible scientific opinion on an array of issues related to RGSM in the following five areas:

- Life History
- Snowmelt Hydrograph
- River Baseflow
- Habitat Restoration
- Longitudinal Connectivity

The GSA team did not address issues of genetics, captive propagation, or population monitoring, which are being addressed in parallel evaluations. The results of those efforts may be integrated into the AM and scientific review panel processes.

Each SME completed the technical questionnaire, and the GSA team followed up with each SME in one-on-one interviews to explore the rationale behind his or her responses. Following the initial interviews, the GSA team identified one additional SME with expertise and scientific opinions whose work was cited by several SMEs (Dr. David Cowley, NMSU). Accordingly, the GSA team felt that Dr. Cowley's scientific perspectives should be documented through the same TCA process as the other SMEs.

In total, fifteen SMEs participated in the TCA process. Because all SME responses were on the record, each SME is represented by identifiers in the compiled results. These identifiers are noted below in parentheses:

- Thomas Archdeacon, USFWS (**TA**)
- Jennifer Bachus, USBR (**BR**[5])
- Rick Billings, ABCWUA (**RB**)
- Scott Bulgrin, Pueblo of Sandia (**SB**)
- David Cowley, NM State (**DC**)
- Eric Gonzales, NMISC/USBR[6] (**EG**)
- Brian Hobbs, USBR (**BR**)
- Alison Hutson, NMISC (**AH**)
- Joel Lusk, USFWS (**JL**)
- Mike Marcus, APA (**MM**)
- Bill Pine, MRGCD (**BP**)
- Michael Porter, USACE (**MP**)
- David Probst, UNM (**DP**)
- Nathan Schroeder, Pueblo of Sandia (**NS**)
- Rich Valdez, NMISC (**RV**)

During the interviews, the GSA team asked each SME two types of questions:

- The first question focused on areas of potential error in the responses to the questionnaire: where the GSA team thought it was possible that the SME may have misunderstood what the question was asking. SMEs were permitted to amend their responses for these questions.
- The second focused on areas where the SME held a minority opinion, particularly if he or she was a clear outlier. The interview questions focused on eliciting the rationale and scientific basis behind the SME's responses, including asking for citations when available. SMEs were not permitted to amend their responses for these questions.

All individual SME questionnaires are archived at the project wiki (https://webapps.usgs.gov/MRGESCP/Wiki/). If any SME indicated to the GSA team that he or she wished to amend their responses during the interview because of an error, as explained above, that edit is reflected in the final questionnaire as a redline edit.

The compiled results of the questionnaire are presented below.

There is general agreement on some important areas, but there are also areas where there is disagreement or a range in scientific opinion. GSA had identified that in the majority of such cases, disagreement is based on substantive scientific information. Each SME was asked the basis for his or her opinions.

[5] The USBR filled out one questionnaire jointly.
[6] During the course of the TCA, Eric Gonzales changed affiliations, from SWCA (contracting to NMISC) to the USBR.

The interviews helped to identify nuances in the questionnaire responses. While the questionnaires provided a useful overview of areas of agreement, disagreement, and scientific uncertainty, the interviews provided the context for those ranges of opinions. The GSA team will transcribe a record of each interview and post them on the wiki (https://webapps.usgs.gov/MRGESCP/Wiki/).

Generally, we saw a significant range of opinion on the life history of the RGSM, as well as a range of opinion on how and at what scale it is possible to monitor species response to management actions.

Summary of Areas of Agreement

- Spawn is cued by ascending limb of hydrograph
- Peak magnitude and duration are important for promoting larval development
- Larval development and food sources are controlled, in part, by water temperature
- Rate of decline in the descending limb is likely important to reduce larval stranding in nursery habitat
- Lateral floodplain connectivity is highly important
- High priority to better understand details re: larval life-stage and rearing habitat attributes

Summary of Areas which there were Varying Perspectives

- Time frame when ascending limb will trigger meaningful spawn
- Minimum magnitude and duration of peak to optimize larval development
- Role of inundated floodplain in spawning and larval development
- Importance of inundated floodplain for post-spawn adult food/energy demand
- Causal factors driving flow-recruitment relationship
- Adult life span
- Benefits of isolated wetted refugia vs. extensive contiguous perennial flow during summer drought
- Importance of improving longitudinal connectivity
- Monitoring methods and scale to evaluate species use/response to wetted refugia management
- Monitoring approach to evaluate RGSM response to management actions (e.g., monitoring scale, life-stage, existing vs. new methods, etc.)

Next Steps

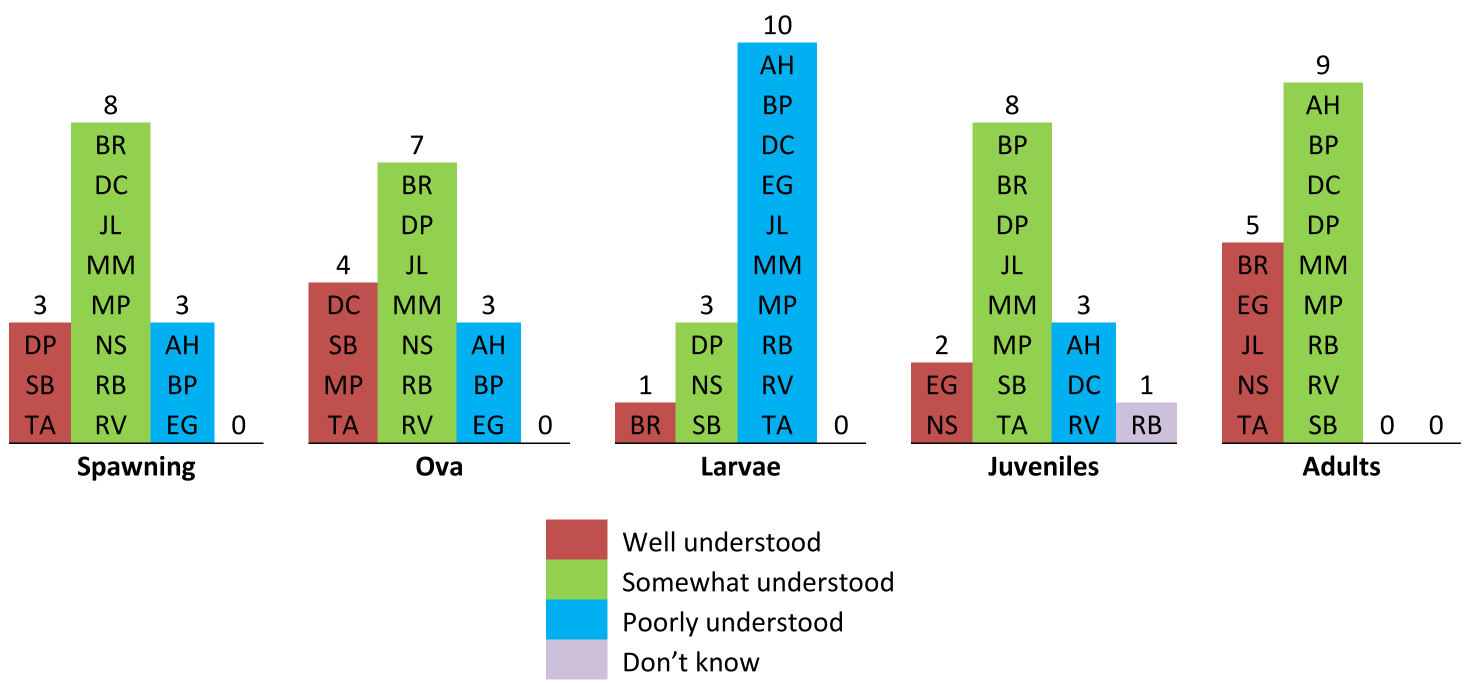
Based on the results of the TCA, it is clear that there is substantive scientific uncertainty regarding fundamental aspects of RGSM life-history with important management implications. As such it will be critical to the AM process to clarify and refine those issues and attempt to narrow uncertainty – first through detailed evaluations with independent expert support, and subsequently through the research and monitoring programs of the AM process.

An ISP will be convened to provide impartial guidance and evaluation. The panel will review the TCA, and discuss the results (and other scientific materials) with SMEs and other RGSM experts. An important first step (prior to the panel meetings) will be to summarize what is known or conjectured about RGSM, in the form of conceptual life history models. These will be prepared by the GSA team, and will be developed and presented to the panel in a neutral (non-advocacy) manner.

RGSM TECHNICAL QUESTIONNAIRE
COMPILED RESULTS

LIFE HISTORY

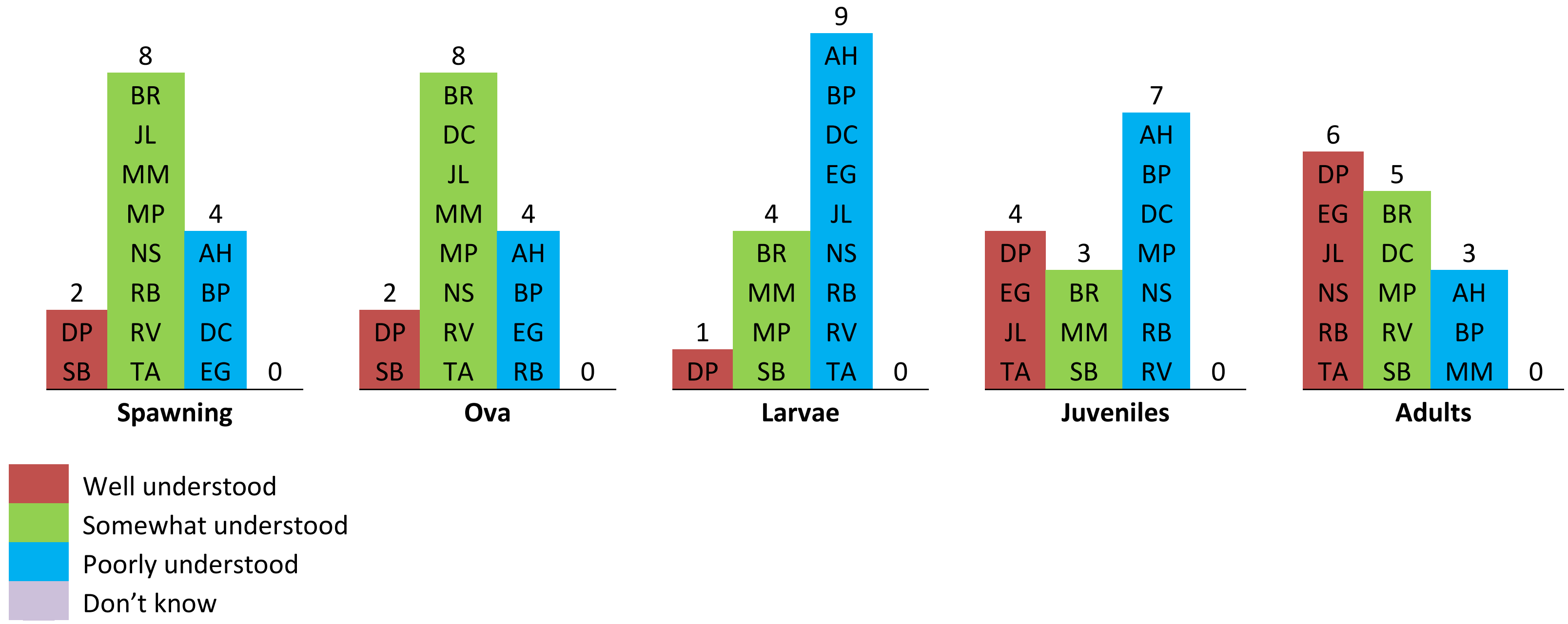
1. Of the various life history stages of RGSM, how would you characterize the current state of scientific understanding for each?



2. In terms of management options, for which life-history stage would new information be most valuable? If you had 100 units of effort towards advancing management-relevant science how would you allocate that effort?

	Spawning	Ova	Larvae	Juveniles	Adults	
AH	30	15	30	15	10	
BP	5	10	10	45	30	
BR	10	20	20	20	30	
DC	10		30	50	10	
DP	10	10	40	30	10	
EG	33	33	33			
JL			100			
MM	34			33	33	
MP	40	10	10	20	20	
NS	50	25	25			
RB	40	5	25	5	25	
RV	5	5	75	10	5	
SB				100		
TA			100			
	267	133	498	328	173	SUM
	19	9.5	36	23	12	AVG

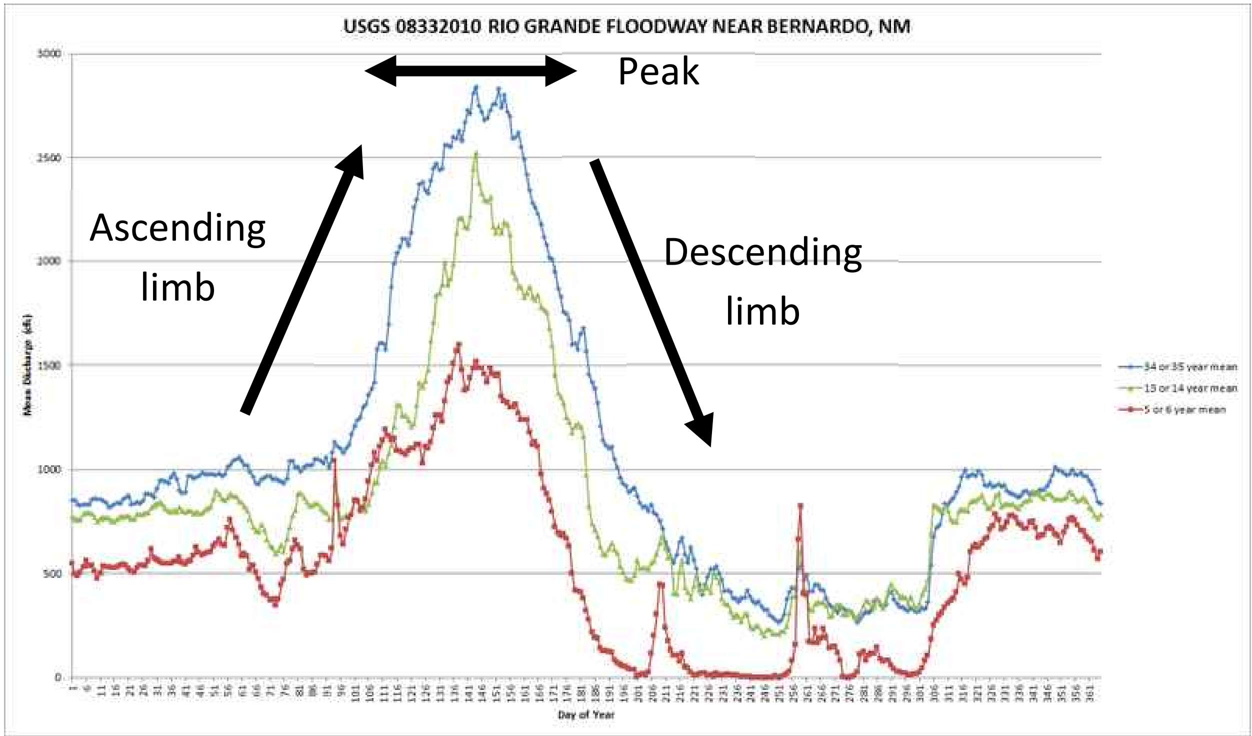
3. How would you characterize the current state of scientific understanding of the ecological/habitat requirements for each life stage?



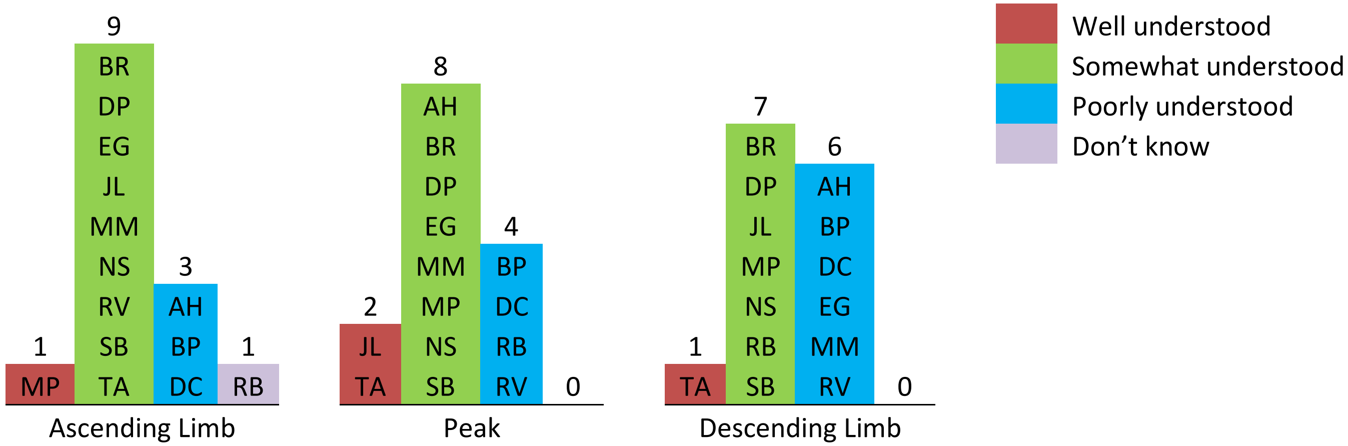
4. Are your responses to the previous life-history questions based on (it is acceptable to provide multiple responses):

	Best Professional Judgment	Field Observations	Analogy with similar species	Summary reports	Unpublished Data	Published Literature	Communication with Other Scientists	Workshops & meetings	Work w/ Naturalized Culture Unit
AH	X	X			X				X
BP	X			X		X			
BR	X		X	X		X	X		
DC	X	X	X			X			
DP	X		X	X	X	X			
EG	X	X	X	X	X				
JL	X	X	X	X	X	X			
MM	X		X			X			
MP		X		X	X	X			
NS		X				X			
RB	X	X		X		X			
RV	X	X	X	X	X	X			
SB		X		X	X	X		X	
TA	X	X	X	X	X	X			

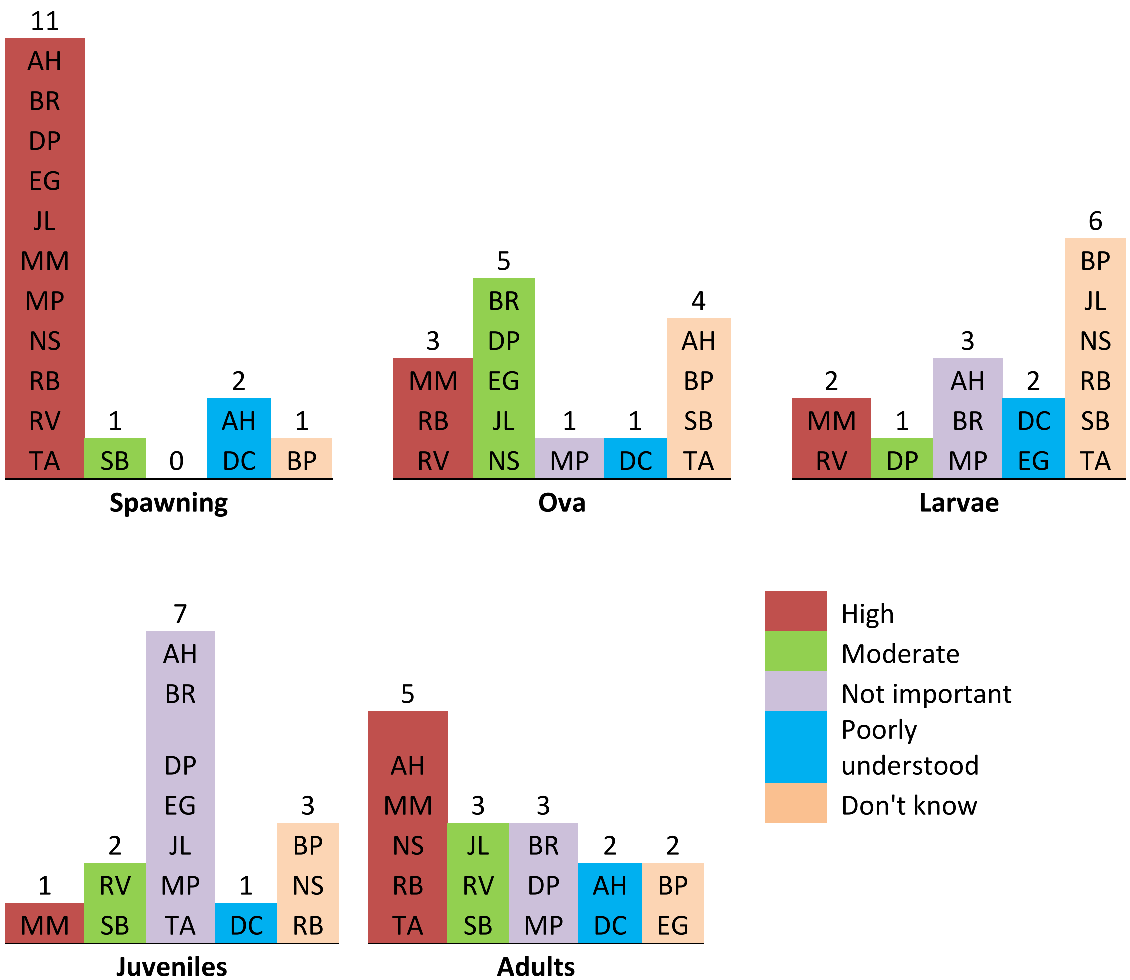
SNOWMELT HYDROGRAPH



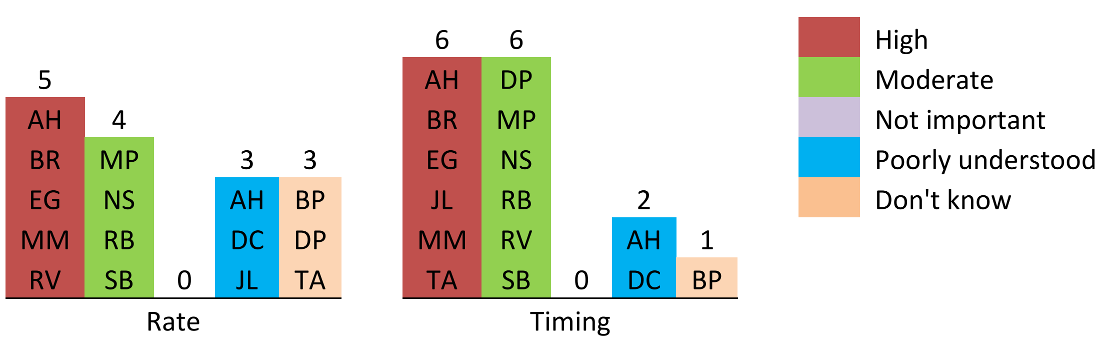
1. Are the effects of different snowmelt hydrograph stages on RGSM spawning and recruitment well understood?



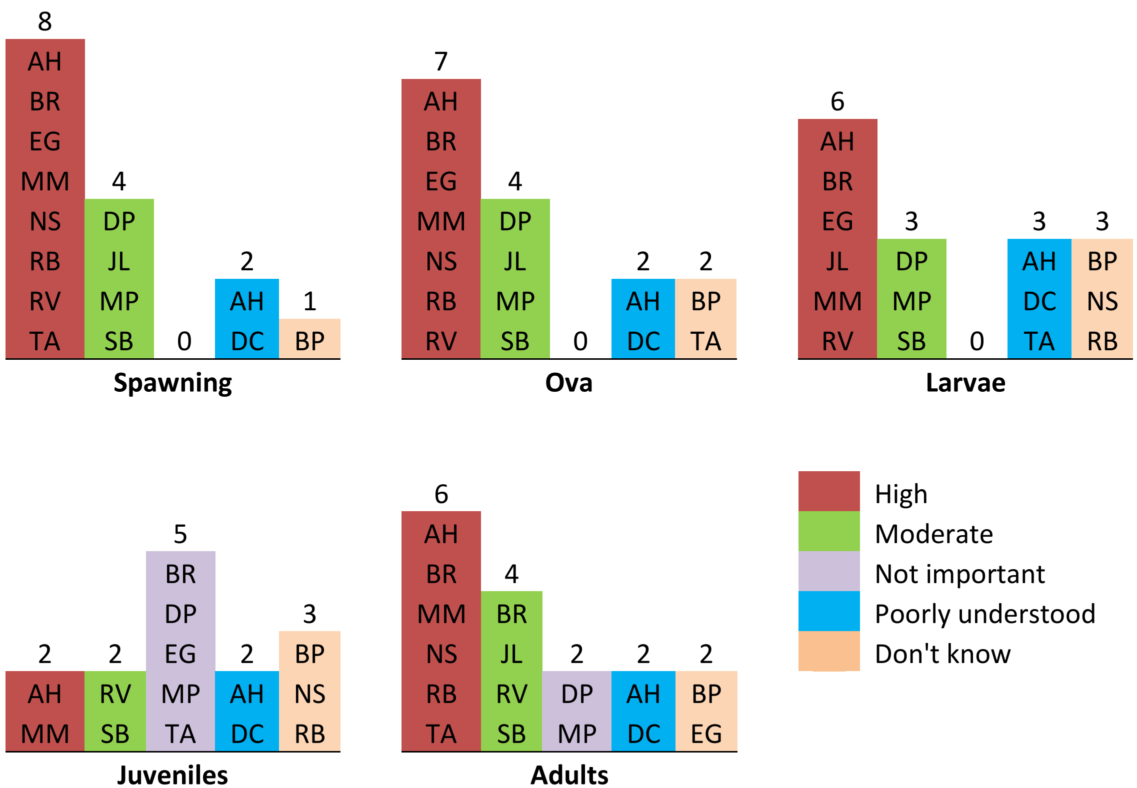
2. Rank the relative importance of the <u>ascending limb</u> of the snowmelt hydrograph on various life-history stages of the RGSM.



3. Rank the following attributes of the ascending limb in terms of importance to RGSM spawning or other relevant life-history stages.

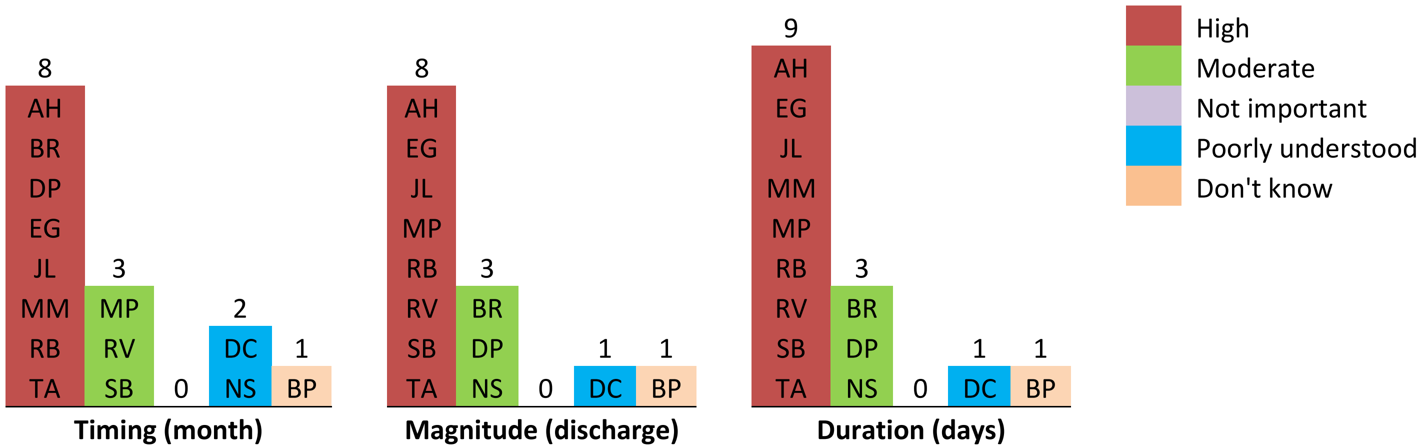


4. Rank the relative importance of the snowmelt hydrograph <u>peak</u> on different life-history stages of the RGSM.



JL: N/A

5. Rank the attributes of the hydrograph peak in terms of importance to RGSM recruitment or other relevant life-history stages.



MM: April-June
RB: May-June

MM: Depends on reach
RB: 3000

MM: 14-21
RB: 12-14

6. Place an "X" in the box(es) below each month that represent the ideal peak hydrograph timing for RGSM spawning and recruitment.

	March	April	May	June	July	Poorly understood
AH			X	X		
BP						X
BR		X	X	X		
DC						X
DP			X	X		
EG	X	X	X	X		
JL			X	X		
MM	X	X	X	X		
MP		X	X	X		
NS				X		
RB			X	X		
RV	X	X	X	X		
SB			X	X	X	
TA			X			
	3	5	11	11	1	2

7. In quantitative terms, how would you define a "desirable" recruitment event (e.g., X fish per unit area)? Please limit your response to no more than three sentences.

- AH: A relatively stable population would be desirable. If we are stocking 300,000 RGSM in the MRG, it would be desirable to see at least 300,000 RGSM represented in the next year as spawners the following spring.
- BP: Recruitment needs to be defined before this can be defined. As an example, a recruitment event may produce lots of larvae, but few of those larvae may survive to adulthood (reproductive maturity). In simplest terms from a recovery perspective a successful recruitment event would be one where the recruitment rate to adulthood exceeds the adult mortality rate.
- BR: put simply, greater than zero fish
- DC: I think a desirable recruitment event will occur when water is on the floodplain for a sufficient time for spawning and egg retention to occur <u>in the floodplain</u>.

- DP: If estimated in October, a desirable recruitment level would be 100/100m^2. This is somewhat reach dependent in that fewer than optimum in Angostura Reach (~70/100m^2) and more in San Acacia Reach (~120/100m^2).
- EG: At low population abundance increases in recruitment. At high population abundance maintenance of population. Presence of RGSM in at least 50% of samples collected. Unit area is arbitrary and effected by the amount of wetted area.
- JL: Based on the outdated FLO2D model (USACE 2010, TetraTech 2005), the estimated density [E(x)] of RGSM in fall (recruitment) is approximately equal to the acres of overbanking in May and June = 1.1504 + 0.0001 * acres OB in May-June. If overbanking occurs for 7 days, "good" would be~ 4000 ac-days, if overbanking occurs for 14 days, "good" would be ~2000 acre days; if OB was 12 d, then 1330 ac-days. R=0.92, +=00000, r^2=0.85
- MM: I don't believe sound information exists to quantify this value.
- MP: A hydrograph that increases from a baseflow of ~1000 cfs to 2500-3000 cfs (Central Gage) for a duration of 11-15 days. The event inundates sufficient floodplain for a suitable duration with floodplain water temperatures > 20°C.
- NS: Depends on the year. Some years past, just seeing wild fish was desirable.
- RB: We are still dealing with the effects of the RGSM as an r species. Adequate recruitment has not been defined. The Recovery Criteria seem a stretch, if not impossible to obtain.
- RV: If we define "recruitment" as the number of larvae produced, the desired number should be based off a survival curve and projection to survival at maturity. If we define "recruitment" as the number of individuals reaching maturity, then the desired number should be equal to or greater than the mortality of existing adults.
- SB: A desirable recruitment event would be catching more fish than have been previously caught in the past several years. More effort into the monitoring with more sites.
- TA: >5 fish/100m^2 = great, >2.5 fish/100m^2 = good, <1.0 fish/100m^2 = poor

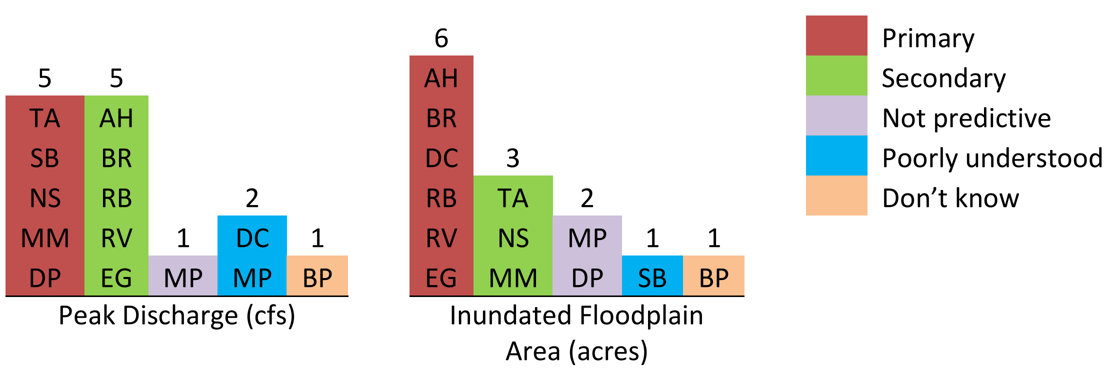
8. Place an "X" in the box(es) below each discharge that represents the <u>minimum peak</u> discharge (cfs) needed, under current river conditions, to promote a desirable recruitment event as defined above. Assume for this question that the discharge is static across all reaches.

	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	>5,000	Depends on reach	Poorly understood	Don't know
AH			X	X						X		
BP												X
BR										X	X	
DC												X
DP					X					X		
EG					X	X	X	X	X	X		
JL			X									
MM										X		
MP			X	X						X		
NS											X	
RB				X								
RV										X		
SB		X	X									
TA			X									
	0	1	5	3	2	1	1	1	1	7	2	2

9. What is the <u>minimum</u> number of days a peak discharge should be maintained to promote a desirable recruitment event, as defined above?

	1-3	4-6	7-9	10-12	>12	Poorly understood	Don't know
AH						X	
BP							X
BR						X	
DC							X
DP				X			
EG					X	X	X
JL			X				
MM					X		
MP				X			
NS						X	
RB				X			
RV				X			
SB				X			
TA			X				
	0	0	2	5	2	4	3

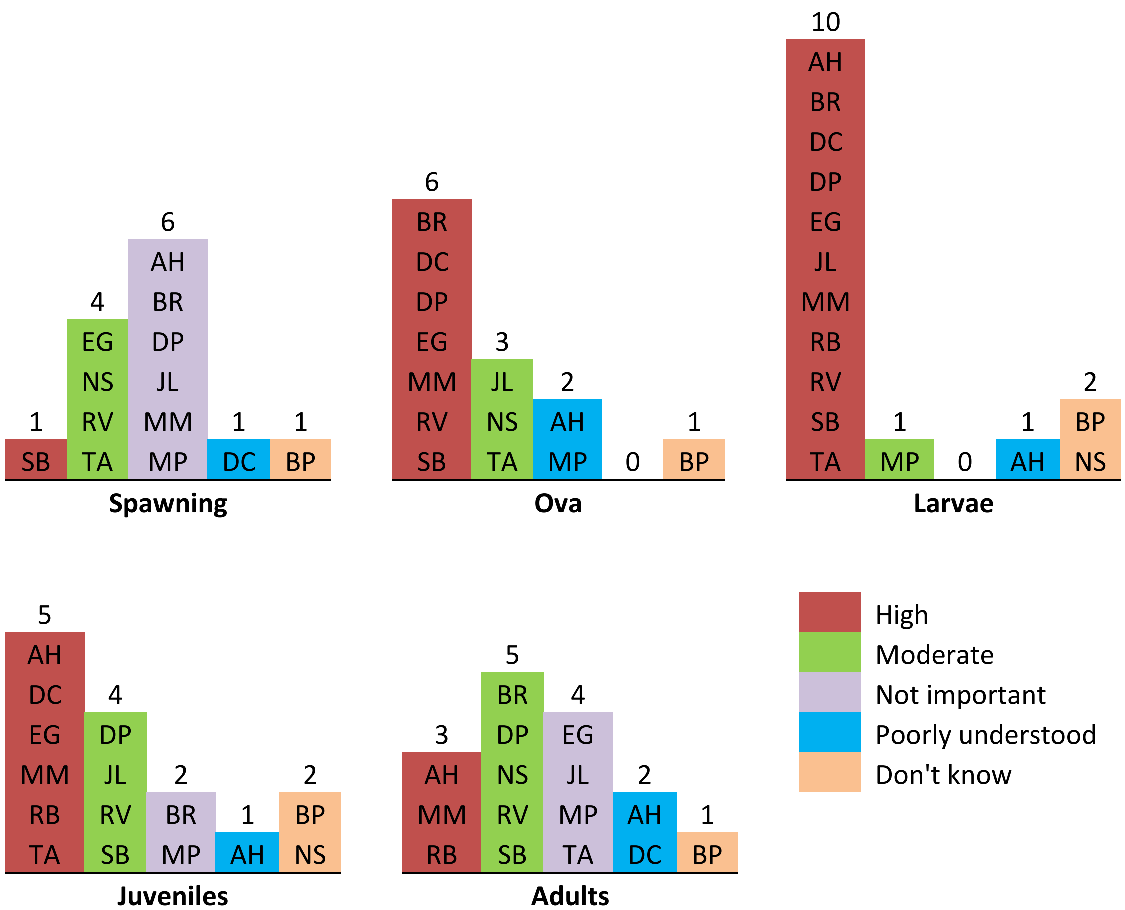
10. Which (if either) metric do you believe is a direct predictor of RGSM recruitment?



"Other" responses:

- AH: Duration of peak and duration of recession off floodplain
- BR: Duration
- EG: Duration – longer above average conditions are observed the more fish that are recruited.
- MP: Magnitude for 11 days
- RV: Duration and stability (primary); Spike flow to stimulate spawning (secondary)
- TA: Duration (primary)

11. Rank the importance of the snowmelt hydrograph <u>descending limb</u> on various life-history stages of the RGSM.



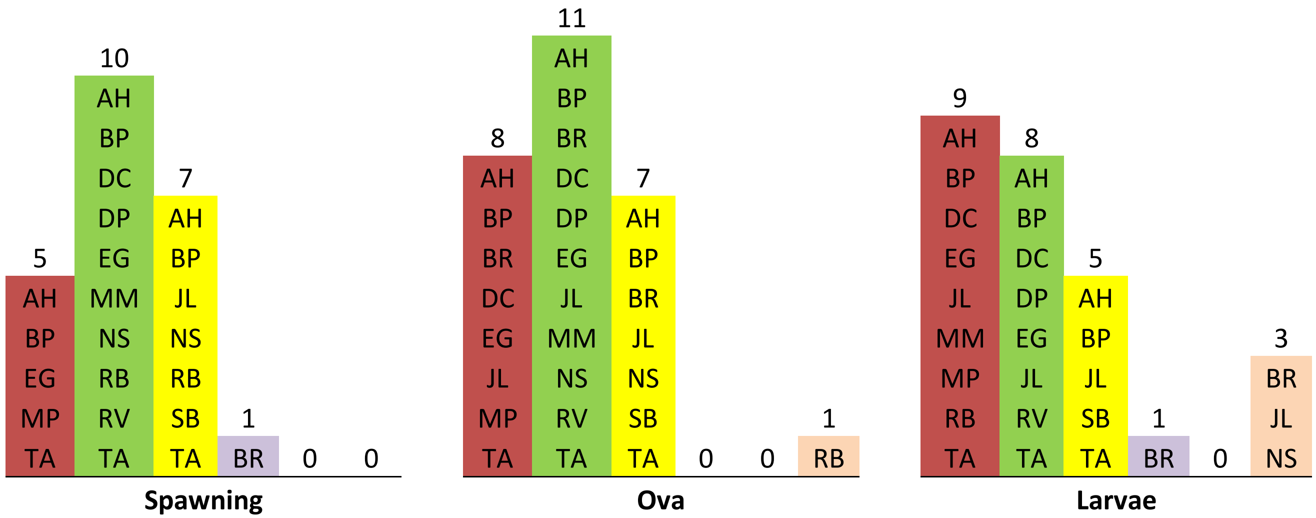
12. How important is the rate of the snowmelt hydrograph descending limb to RGSM recruitment or other relevant life-history stages?

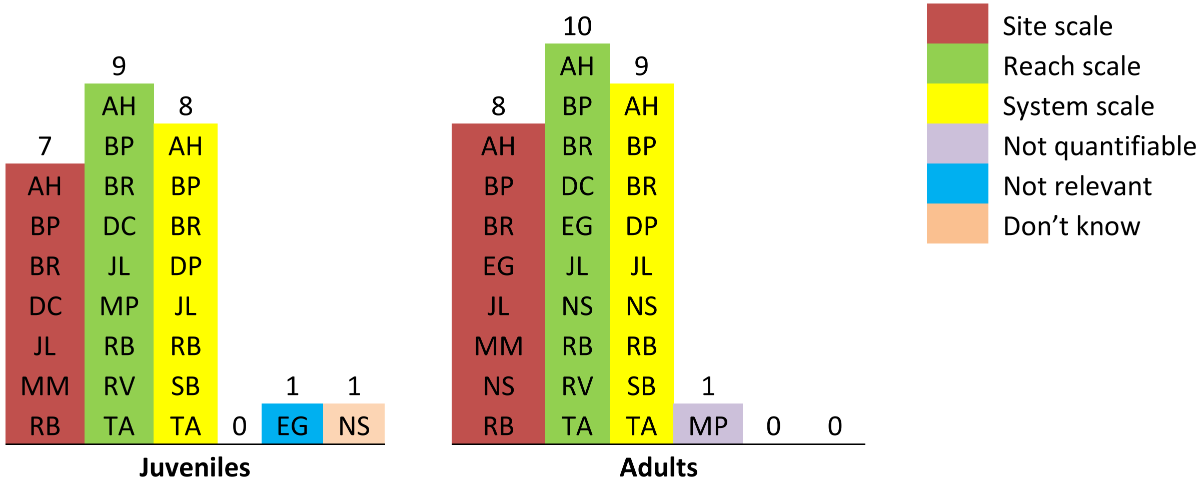
Important	AH	BR	DP	DC	EG	MM	RV	SB	TA	9
Not Important	MP	1								
Poorly Understood	AH	BP	BR	DC	JL	NS	RB	7		

13. If you had 100 units of effort to advance management-relevant science concerning hydrograph effects on the RGSM, how would you allocate that effort?

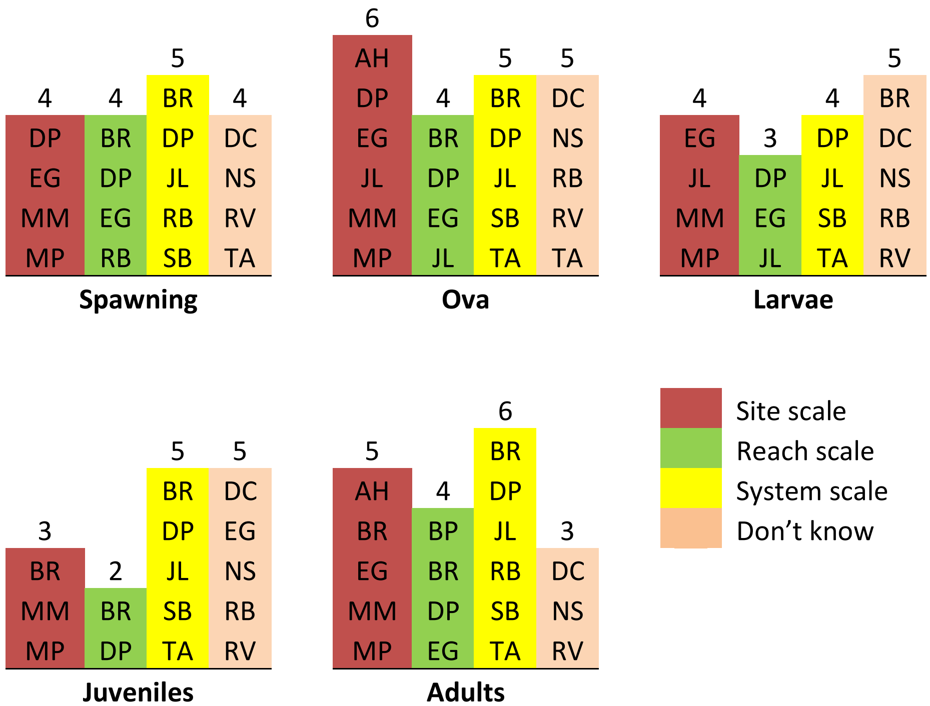
	Ascending Limb					**Peak**					**Descending Limb**				
	Spawn	**Ova**	**Larvae**	**Juveniles**	**Adults**	**Spawn**	**Ova**	**Larvae**	**Juveniles**	**Adults**	**Spawn**	**Ova**	**Larvae**	**Juveniles**	**Adults**
AH	15				15		25	10					15	20	
BP					30		20						20	30	
BR	15	15				10	10	10				15	15		10
DC								25	25				25	25	
DP	10					10						10	30	30	10
EG	10	10			5	10	10	10		5	5	5	25		5
JL		15					30	40					15		
MM	34												33		33
MP						20	40	40							
NS	25	25									25	25			
RB		10				20				10			30	20	10
RV	10						25	35	5	5			20		
SB				10	10	10		10			10	10	20	10	10
TA												40	40	20	
SUM	119	75	0	10	60	80	160	180	30	20	40	105	288	155	78
AVG	8.5	5.4	0	0.7	4.3	5.7	11	13	2.1	1.4	2.9	7.5	21	11	5.6

14. Are the relationships between the snowmelt hydrograph and various RGSM life-stages measureable/quantifiable, and if so at what scale? (*Site* = specific target area within a reach; location; *Reach* = Cochiti Reach, Angostura Reach, Isleta Reach, San Acacia Reach; *System* = all reaches).




7
AH
BP
BR
DC
JL
MM
RB
9
AH
BP
BR
DC
JL
MP
RB
RV
TA
8
AH
BP
BR
DP
JL
RB
SB
TA
0
1
EG
1
NS
Juveniles
8
AH
BP
BR
EG
JL
MM
NS
RB
10
AH
BP
BR
DC
EG
JL
NS
RB
RV
TA
9
AH
BP
BR
DP
JL
NS
RB
SB
TA
1
MP
0
0
Adults
Site scale
Reach scale
System scale
Not quantifiable
Not relevant
Don't know

15. Per your response to the previous question, place an "X" in the box(es) where <u>existing</u> MRG monitoring methodologies can be used to quantify RGSM responses to hydrograph management.

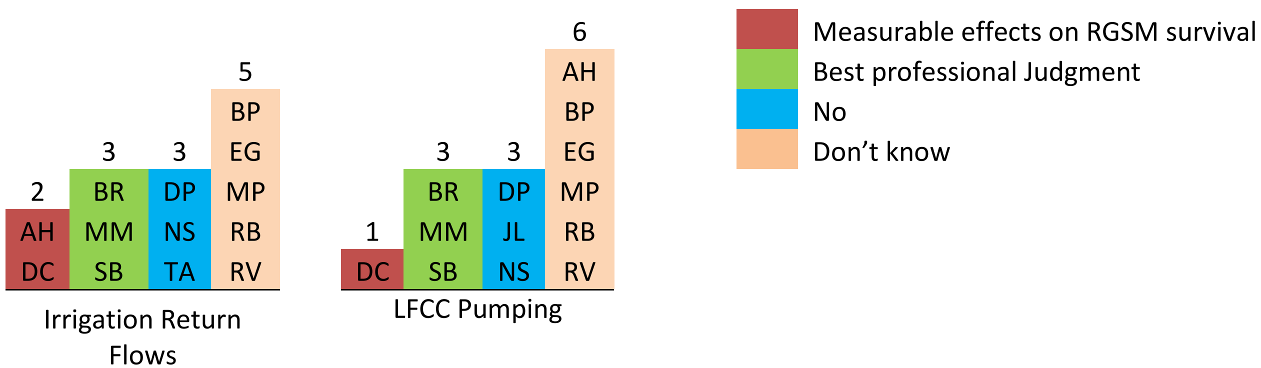


16. Are your responses to the previous questions concerning hydrograph/RGSM relationships based upon:

	Best Professional Judgment	Field Observations	Analogy with similar species	Summary reports	Unpublished Data	Published Literature	Communication with Other Scientists	Workshops & meetings
AH	X			X	X	X		
BP	X			X	X	X		
BR	X	X	X	X	X	X	X	
DC	X	X	X			X		
DP	X		X	X	X	X		
EG	X	X		X				
JL	X		X	X	X	X		
MM	X		X	X	X			
MP		X		X	X	X		
NS		X						
RB	X	X		X		X		
RV	X	X	X	X	X	X		
SB				X	X	X		X
TA	X	X	X	X	X	X		

RIVER BASEFLOW

1. When river segments experience periods of very low or no river baseflow, management actions are sometimes enacted to maintain pockets of "wetted refugia" (e.g., strategic management of drain returns, pumping from the Low-Flow Conveyance Channel, etc.). Do these actions have a beneficial effect on RGSM survival?[7]



Other responses:

- DC: My response is a professional opinion. I'm not sure how one might definitively demonstrate a beneficial effect of site-specific features because fish are mobile.
- JL: Maintain critical habitat
- RV: Survival in "refugia" relative to the greater population (Don't know) has not been measured, but is measurable
- TA: No monitoring exists/been performed

[7] The GSA team acknowledges that this question was worded poorly in the initial questionnaire, and discarded these responses for their analysis.

2. At what scale can the effects of wetted refugia management on RGSM be measured/quantified?

Site scale	AH BP BR DC EG MM MP RB RV SB TA	11
Reach scale	BP BR DP EG MM NS RB RV SB TA	10
System scale	BP NS TA	3
Can’t be quantified		0
Don’t know	JL	1

3. Do you base your assessment of wetted refugia effects on RGSM on:

	Best Professional Judgment	Field Observations	Analogy with similar species	Summary reports	Unpublished Data	Published Literature	Communication with Other Scientists	Workshops & meetings
AH	X			X	X			
BP	X							
BR	X	X	X	X			X	
DC	X	X					X	
DP	X	X	X	X	X	X		
EG	X	X		X				
JL	X	X	X	X	X	X		
MM	X		X			X		
MP				X				
NS	X							
RB	X			X				
RV	X	X	X	X	X	X		
SB					X	X		X
TA	X	X			X			

HABITAT RESTORATION

1. In the field of river restoration, the term "passive" restoration refers to using river flows to promote geomorphic changes that in turn improve habitat conditions. Given your understanding of Rio Grande hydrology and geomorphology, what river discharges would you estimate are required to enable passive restoration to de-stabilize vegetated islands and floodplains on a reach-scale?

	<3,000 cfs	3,000 - 5,000 cfs	5,000 - 7,000 cfs	>7,000 cfs	Depends on Reach	Don't know
AH						X
BP					X	
BR				X	X	
DC						X
DP					X	
EG				X	X	X
JL			X	X	X	
MM					X	
MP			X			
NS				X	X	
RB			X		X	
RV				X	X	X
SB	X					
TA						X
	1	0	3	5	9	4

2. If you checked "depends on reach" in the previous question, please use your best professional judgement to estimate the effective discharges for each reach.

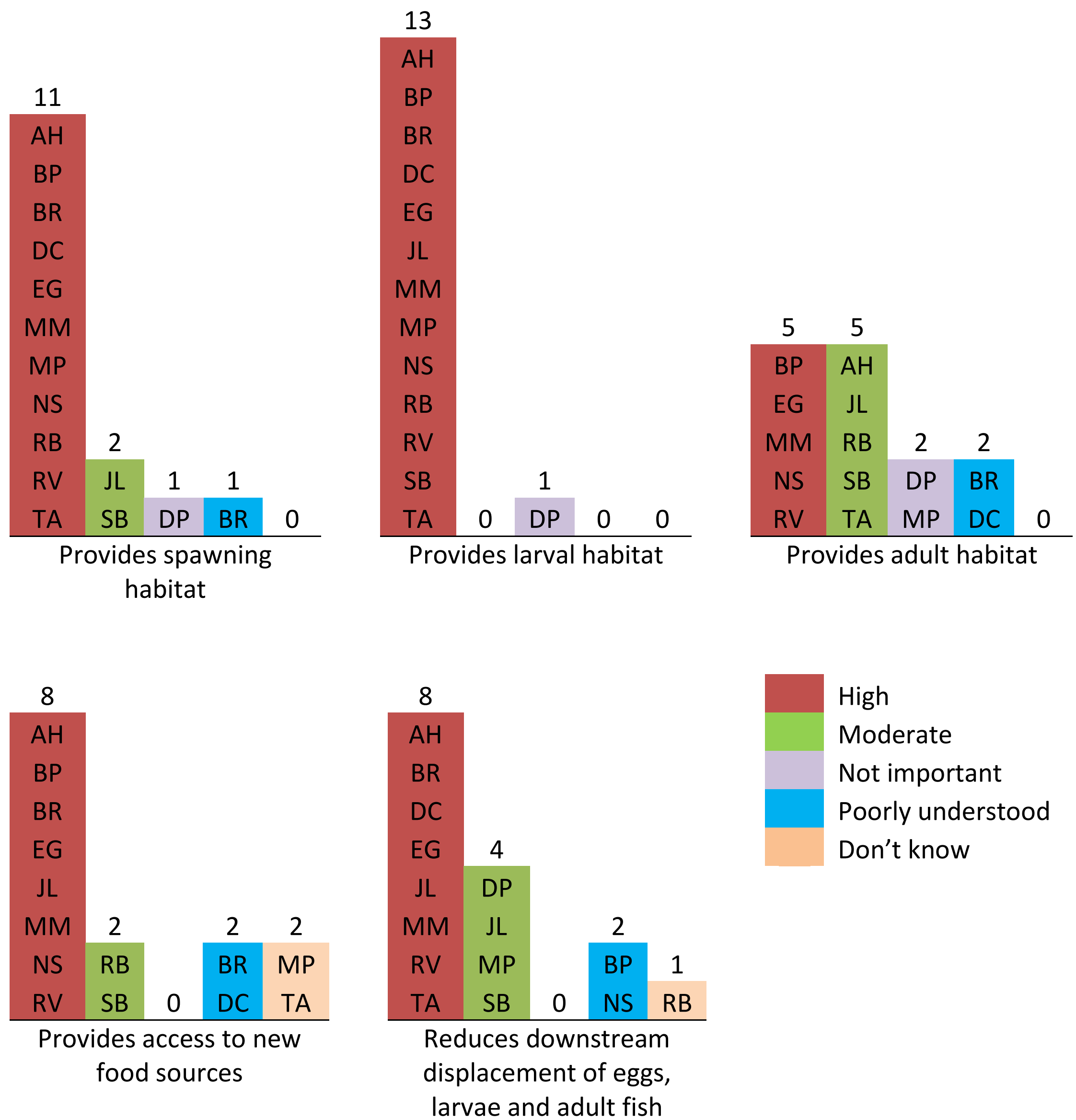
	Cochiti	Angostura	Isleta	San Acacia
JL	?	>6500	?	?
RV	>7,000	>7,000	>7,000	>7,000
DP	>7000	>7000	5,000-7,000	7,000-8,000
RB	4,000	5,000	6,000	5,000
MM	See note[8]	>7,000	>5,000	>2,000
BR	>10,000	>10,000	>10,000	>10,000
NS	>10,000			
BP	5,000-7,000	3,000-5,000	<3,000	<3,000

[8] Comment: "No RGSM is thought to exist there, or no change."

3. "Active" restoration refers to using physical (e.g., lowering islands/floodplains, planting native vegetation, etc.) methods to facilitate habitat improvements when passive approaches cannot, under normal circumstances, be relied upon to achieve a desired condition. If you had 100 units of effort to contribute to active habitat restoration, how would you allocate those resources to benefit RGSM populations?

	Increase in-channel habitat heterogeneity	Increase river-floodplain connectivity	Low-Flow Wetted Refugia	*Other*	*(Other) Maintain 80mi of perennial*	
AH	30	39	31			
BP	30	30	40			
BR	20	60	20			
DC	33	33	33			
DP		80		20		
EG		100				
JL		80			20	
MM		60	40			
MP	20	70	10			
NS	33	33	33			
RB	25	50	25			
RV	40	40	20			
SB	20	20	60			
TA		100				
	252	796	313	20	20	SUM
	18	57	22	1.4		AVG

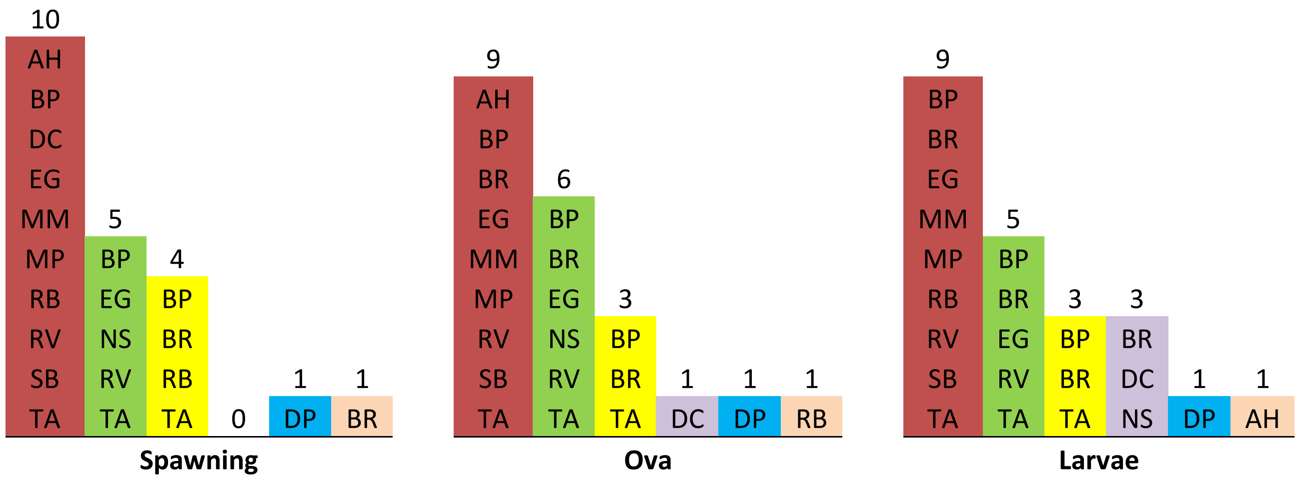
4. Rank the functional importance of lateral river-floodplain connectivity to RGSM.

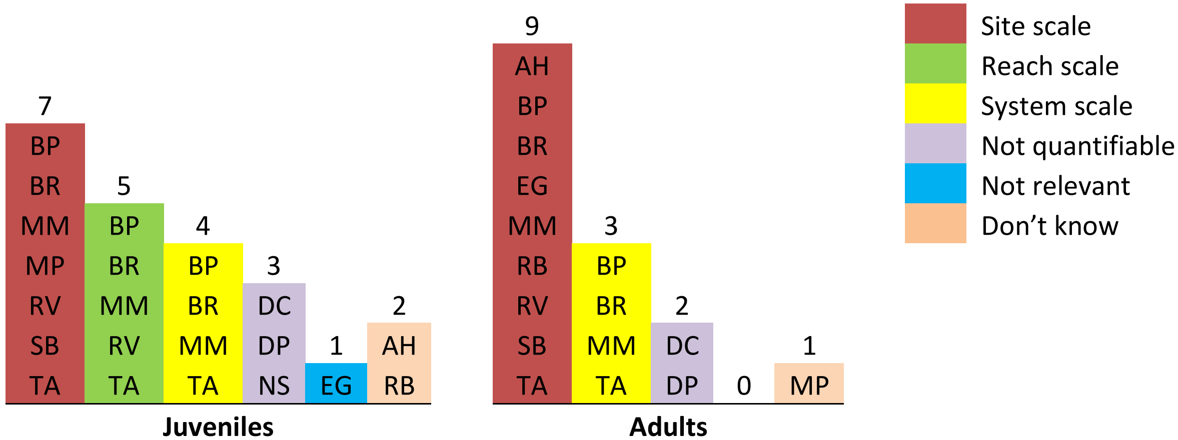


5. If you checked "high" or "moderate" for Other, please explain (2-3 sentences).

- DC: One needs to look no further than the astronomical number of (>600,000) RGSM "rescued" in the mid-2000s high water year.
- DP: Allochthonous import and large woody debris import (High)
- MM: Repair of levees to prevent breeches (High)

6. Are the relationships between active restoration techniques and various RGSM life-stages measureable/quantifiable, and if so at what scale?



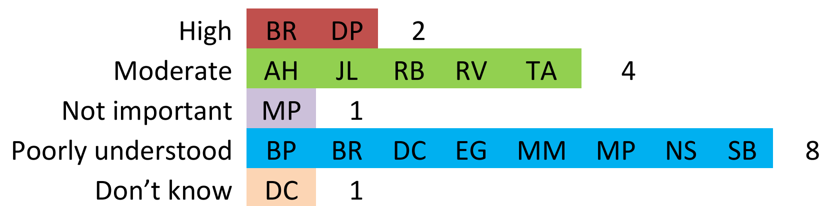

7
BP
BR
MM
MP
RV
SB
TA
5
BP
BR
MM
RV
TA
4
BP
BR
MM
TA
3
DC
DP
NS
1
EG
2
AH
RB
Juveniles
9
AH
BP
BR
EG
MM
RB
RV
SB
TA
3
BP
BR
MM
TA
2
DC
DP
0
1
MP
Adults
Site scale
Reach scale
System scale
Not quantifiable
Not relevant
Don't know

7. Are your responses to the previous questions concerning the relationship between habitat restoration and RGSM based on:

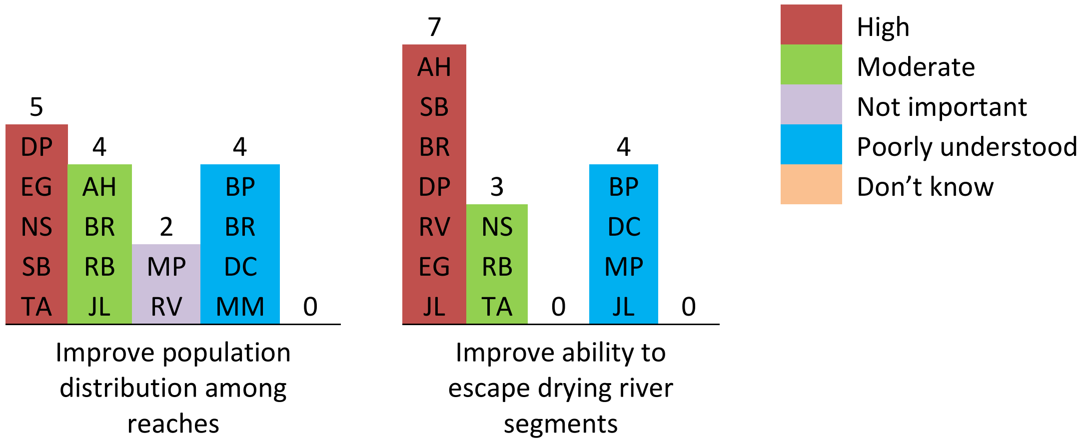
	Best Professional Judgment	Field Observations	Analogy with similar species	Summary reports	Unpublished Data	Published Literature	Communication with Other Scientists	Workshops & meetings
AH	X			X	X	X		
BP	X							
BR	X			X		X	X	
DC	X							
DP	X		X	X	X	X		
EG	X	X		X				
JL	X		X	X	X	X		
MM	X		X		X	X		
MP		X		X	X			
NS	X	X						
RB	X	X		X		X		
RV	X	X	X	X	X	X		
SB		X		X	X	X		X
TA	X	X		X	X			

LONGITUDINAL CONNECTIVITY

1. How important is adult fish movement upstream through/past irrigation diversion dams for improving RGSM population status?



2. Rank the functional benefits of improving longitudinal connectivity between river reaches.



"Other" responses:

- BR: Genetics (High), Foraging (Poorly understood)

3. Do you base your assessment of the importance of longitudinal connectivity to populations of the RGSM on:

	Best Professional Judgment	Field Observations	Analogy with similar species	Summary reports	Unpublished Data	Published Literature	Communication with Other Scientists	Workshops & meetings
AH	X			X	X	X		
BP	X							
BR	X		X	X		X	X	
DC	X							
DP	X	X	X	X	X	X		
EG	X	X		X				
JL	X		X	X		X		
MM	X	X		X		X		
MP			X	X		X		
NS	X							
RB	X							
RV	X	X	X	X	X	X		
SB		X		X	X	X		X
TA	X	X	X	X	X	X		

OTHER QUESTIONS

1. Are there existing monitoring methods or metrics used in the MRG that you believe serve as reliable predictors of RGSM population trends? Please explain your response in no more than 3-5 sentences.

- AH: No. The current monitoring methods do not provide reliable predictions of population trends. The genetics monitoring does not provide adequate information in a timely manner that could be used in management decisions or decisions regarding the hatchery/augmentation program. The population monitoring provides trends but does not provide information that could be correlated to river management decisions. Without information on how these water management decisions affect the RGSM spawning and recruitment, it is difficult to manage the species.
- BP: No efforts appear to have been made to quantify available data into some sort of predictive model related to RGSM trends. Efforts have been made to relate CPUE to some measures of river discharge, but the chosen discharge covariates are not linked to potentially important factors such as floodplain inundation. As discussed in recent workshop, a more refined set of biologically relevant covariates should be tested.
- BR:
    - The long-term monitoring works well to assess reach-wide, long-term trends while still allowing the assessment of “take” for localized projects. CPUE data serves as indicator (not predictor) of RGSM population trends.
    - Genetics monitoring.
    - Both could be improved/supplemented to provide better information for decision-makers.
- DC: Monitoring RGSM by seining is a waste of money now totaling several millions of dollars. Larger, older RGSM are underrepresented by the bias in pulling a seine in a river. Biased monitoring supports incorrect beliefs about species life span.
- DP: Current population monitoring program has repeatedly proven a reliable predictor of population trends, has been validated by peer review panels, is a commonly used method in similar systems, and a superior method has never been offered. Why is this question being repeated? Most recent peer review should have settled matter.
- EG: The magnitude and duration of spring runoff is the best predictor of the RGSM population in the upcoming October. The next would be the egg periodicity study; when few eggs are collected recruitment tends to be higher than when many eggs are collected/salvaged.
- JL: The RGSM Pop Monitoring Program provides a consistent, reliable metric of population abundance. And their occupancy model is robust. The volume (and magnitude, timing, and

duration) of total flow, spring flow, and low flow is a reasonable surrogate for managing the RGSM pop in the MRG.

- MM: Presumably yes. But I believe the current methods of monitoring RGSM are biased low due to inadequate sampling of both fish in schools (clumped distributions) and larger RGSM due to their high burst swimming rates with successful avoidance of beach seines used.
- MP:
  - The spring hydrograph duration and magnitude provides a moderate metric for modeling recruitment of juvenile RGSM illustrated by the population monitoring.
  - A low magnitude 'spike-flow' (<1000 cfs) that does not inundate floodplain is generally useful for stimulating RGSM spawning for egg salvage. The 'spike-flow' is correlated with a negative population trend.
- NS: The ratio of wild type to hatchery fish in the river.
- RB:
  - Existing monitoring methods as a start, but trend analysis is hard with that data.
  - Perhaps additional sampling sites or lengthening sampling sites or other analytical methods could help.
  - The importance or not of refugial habitats after a management action (as the river starts to try in some areas).
- RV: The existing population monitoring program generates a CPUE that is not a reliable predictor of status or trend of the RGSM. The CPUE is highly variable—as is the RGSM population. A combination of demographic parameters may be a predictor of trend, such as survival rate and recruitment to maturity. The sensitivity of these parameters can—and should—be tested to determine a better way to monitor this species.
- SB: Current monitoring and metrics currently used need to be updated. With the upcoming Rio Grande Silvery Minnow Population Monitoring Workshop Report, the monitoring and methods will hopefully be updated to serve as more reliable predictors.
- TA: The CPUE monitoring was 95% correlated with independent population estimates. The current monitoring is sufficient to detect reach-scale population trends – empirical evidence supports this.

2. Are there any <u>management-relevant</u>, <u>scientific issues or uncertainties</u> related to the RGSM not touched upon in this questionnaire that you believe should be prioritized? Limit your response to no more than three bulleted examples.

- AH:
    - The duration and magnitude of the peak for spawning. Also, how quickly can the larval fish respond to the receding water on the floodplain is a question that could be valuable to answer. If we are unable to meet a minimum duration of inundated floodplain, there may be limited survival of larval/juvenile RGSM.
    - Value of wetted refugia during periods of drying. We must try to establish the balance of egg/larvae produced during spring runoff with the impact river drying may have.
    - A top priority not mentioned above should be the hatchery program and how that effects the augmentation program, and therefore, the fish in the river. Is our program producing fish that are able to survive in the river under ambient environmental conditions or are we producing sub-par fish, then stocking them and inadvertently lowering the fitness of the wild population?
- BP: Yes
    - Key uncertainties relate to whether existing monitoring programs can detect responses or trends in adult or larvae RGSM to existing management actions such as small scale water releases to minimize channel drying conducted in 2013-2015 or site specific actions such as floodplain restoration/reconnection efforts by ACOE.
    - What is the role of non-native species in limiting RGSM recovery?
    - Are existing management actions such as hatchery augmentation or salvage operations having a measurable benefit on RGSM?
- BR: Overwinter life history
- DC: Ongoing research by a PhD student of mine is suggesting Age 0 fish are the most important in affecting population size.
    - Evaluate effect of rescuing ALL RGSM, not just the >30 mm.
    - Attempt to connect site-scale active restoration with reach-scale population dynamics.
    - Destroy preconceptions of RGSM biology that are incorrect and promote actively open-minded science that acknowledges we know damn little useful information for recovering this species.
- DP:
    - Genetic considerations
    - Role of captive propagation—which facilities succeed and which fail?
    - Most attention given to spring hydrograph, what about the other times of the year (e.g., post-runoff and pre-monsoon)?
- EG: Larval fish habitat requirements for successful recruitment to juveniles and then adults.

- JL:
    - The discretionary authorities and will of federal agencies, states (NM, CO, TX, MX) and Tribes to manage water and meet the goals for improving RGSM status while water is conveyed downstream according to laws.
    - The shape of the channel and floodplain (floodway) and the volume of flow, spring flow, and low flow should be optimized to increase RGSM habitat while meeting the legal constraints of water rights.
    - The governance structure, and the integrity of science used in decision making of water management and budgetary allocations for projects should ensure the objectivity, clarity, reproducibility and utility of information used is insulated from bias, fabrication, falsification, outside interference, and inadequate process. That is, "use and state facts and less stories."
- MM: As I state above, based on expert opinion and consideration of similar species from literature, I hypothesize that off-channel habitat provides critical post-spawn food resources for all life stages that is not available in the river channel during high flows … and I hypothesize that the lack of post-spawn food resources is the principal reason for the very high mortality in the post-spawners.
- MP:
    - Reliably enumerating the schooling adult population (numbers by age class beyond year 1) to inform the age structure and survival of RGSMs beyond the current population monitoring. This will require development and evaluating new fish sampling techniques with a double-blind study design for sampling and aging scales.
    - Evaluating and testing 'catchability' for existing and new fish sampling techniques, particularly for schooling RGSMs. This would allow calibration of current population monitoring and provide better scientific information for decision-making.
    - Integrating genetic sample collection with all field monitoring activities (across agencies), and incorporating current techniques (i.e. barcoding) to increase processing capability for a larger sample size, and more powerful statistical analyses. Use the results to inform the captive breeding & augmentation activities to protect genetic diversity.
- NS: *[No response]*

- RB:
    - Climate change impacts, modeled or actual.
    - Genetic status of the RGSM.
    - Economic impacts to the area from modifications of water management related to A) and B) *[above bullets]*
- RV:
    - Recent genetic evidence shows that the existing RGSM population in the MRG is a homogeneous group of fish of hatchery origin that is being supported and possibly sustained by augmentation—and when suitable hydrology occurs, the population may be self-sustained for a few years.
    - The apparent fact that the RGSM population is domesticated and is being sustained through hatchery augmentation should be viewed as an opportunity for more intensive research and more liberal scientific collecting permits.
    - The key to self-sustainability for the RGSM is scientific research and management intervention (through AM) that provides a better understanding of survival of larvae and recruitment to maturity under the existing flow management regime.
- SB:
    - Management- Make sure Federal, State and Tribes know the importance of the fish to the ecosystem. Think outside of the box on projects.
    - Scientific - Get more Research Projects (diet, growth, mesohabitats, artificial habitat etc.) going, think outside the box on the RGSM.
    - Uncertainties- Start coming up with ideas on what to do if the numbers of RGSM continue to decrease and tough decisions will need to be made.
- TA: Summer flow is not as critical as spring flow, but obviously fish need water. There needs to be more research to determine how best to manage drying.

Appendix E-2: Detailed Technical Discussion - Critical Scientific Uncertainties for the Rio Grande Silvery Minnow

CRITICAL SCIENTIFIC UNCERTAINTIES AND STUDY RECOMMENDATIONS FOR THE RIO GRANDE SILVERY MINNOW

Listing History, Recovery, and Population Status

The RGSM originally was described as *Algoma amara* based on specimens collected from the Rio Grande near Brownsville, Texas (Girard 1856). Subsequently, RGSM along with the plains minnow *H. placitus* was placed in synonymy with the Mississippi silvery minnow, *H. nuchalis,* by Jordan (1885) and Hubbs and Ortenburger (1929). Hubbs (1940) and Koster (1957) later recognized plains minnow as distinct from the Mississippi silvery minnow and treated RGSM as a subspecies of plains minnow as *H. placitus amarus*. Pflieger (1980) and Smith and Miller (1986) recognized RGSM as separate from other *Hybognathus* species, including plains minnow and this view, that RGSM is a unique species, was confirmed by subsequent morphological, genetic, and phylogenetic studies (Hlohowskyj et al. 1989; Cook et al. 1992; Mayden 1989; Schmidt 1994; Bestgen and Propst 1996; Moyer et al. 2009). A more complete description of the taxonomic history and synonymy of RGSM is provided by Pflieger (1980), Sublette et al. (1990) and, especially, Bestgen and Propst (1991).

Historically, RGSM was one of the most widespread and abundant species in the Rio Grande basin of New Mexico, Texas, and Mexico (Bestgen and Platania 1991). In the Rio Grande, RGSM occurred as far upstream as Espanola, New Mexico and downstream to the Gulf of Mexico. RGSM also occurred in the lower Rio Chama and the lower Jemez River, tributaries of the Rio Grande in New Mexico (Bestgen and Platania 1991; USFWS 2010); however, there is no record of RGSM from any Mexican tributary to the Rio Grande (Edwards et al. 2002, 2003). In the Pecos River, RGSM occurred from Santa Rosa, New Mexico downstream to the confluence of the Pecos River and the Rio Grande (Pflieger 1980; Bestgen and Platania 1991; USFWS 2010). RGSM occurred in the Rio Felix, a small tributary of the Pecos River in New Mexico, and was common upstream from the confluence of the Rio Felix and the Pecos River (Bestgen and Platania 1991).

There are few historic collections of RGSM from the Rio Grande (including the Rio Chama) upstream from Cochiti Lake. The earliest collection of RGSM from this reach was made in 1874, but no specimen has been collected since 1978 (Bestgen and Platania 1991; Platania 1991). Absence of RGSM from this reach is believed to be due to channel modifications that eliminated preferred habitat of RGSM (Bestgen and Platania 1991). The MRG, from Cochiti Lake downstream to Elephant Butte Lake, New Mexico, supported large numbers of RGSM between 1926 (the first collection in this reach) and 1960 (Bestgen and Platania 1991). In the LRG, downstream from Elephant Butte Lake to the Gulf of Mexico, RGSM occurred in New Mexico waters until 1938; in Big Bend National Park, Texas, until 1960; and downstream from Lake Falcon, on the Texas and Mexico border, until 1971 (Trevino-Robinson 1959; Hubbs et al. 1977; Bestgen and Platania 1991; Edwards and Contreras-Balderas 1991; Edwards et al. 2002). Loss of RGSM in the LRG was likely due to a combination of impoundments (dams that created

Elephant Butte Lake and Caballo Reservoir), severely altered discharge patterns, and reduced flows and channel modification (Bestgen and Platania 1991).

RGSM disappeared from throughout the Pecos River between the 1930s and 1960s. RGSM was collected in 1939 upstream from Sumner Lake, New Mexico, shortly after its impoundment, but has not been collected since (Bestgen and Platania 1991), possibly due to the use of fish toxicants in the newly impounded lake and the lack of recruitment from downstream reaches because of dam construction (e.g., Hatch et al. 1985). In the middle Pecos River, downstream from Sumner Lake to Avalon Lake, New Mexico, RGSM was common in historic samples (Bestgen and Platania 1991), but abruptly disappeared by the late 1960s. Cowley (1979) reported that RGSM had been replaced by plains minnow throughout the middle Pecos River and, based on a review of museum collections, found that plains minnow was present in collections made as early as 1968. Based on a 1964 collection containing two putative hybrids between RGSM and plains minnow, Bestgen and Platania (1991) suggested the initial introduction of plains minnow may have occurred prior to 1964. The 1968 collections, made near Roswell, New Mexico, included both the first documented specimens of plains minnow from the middle Pecos River and the last specimens of RGSM collected from anywhere in the Pecos River drainage (Cowley 1979; Bestgen and Platania 1991; Hoagstrom et al. 2010). Replacement of RGSM by plains minnow in the Pecos River was attributed by Hoagstrom et al. (2010) as being due to competitive displacement. In the lower Pecos River, downstream from Avalon Lake to its confluence with the Rio Grande, RGSM was uncommon in New Mexico waters and was not well sampled in Texas waters, although Bestgen and Platania (1991) argued that RGSM must have been common in the latter reach. Regardless of its historic abundance, RGSM has not been collected in the lower Pecos since 1940 (Bestgen and Platania 1991; Cheek and Taylor 2016).

RGSM currently is restricted to the MRG, a reach that is equal to about seven percent of its historic range (USFWS 2010). The MRG is fragmented by dams into four discrete reaches: the Cochiti Reach (35.9 km in length), the Angostura Reach (65 km), the Isleta Reach (85.5 km), and the San Acacia Reach (93.7 km) (Sublette et al. 1990; Bestgen and Platania 1991; USFWS 1994, 2010; Bestgen and Propst 1996; Dudley et al. 2005). RGSM is present in the three lower reaches (Angostura, Isleta, and San Acacia). Abundance of RGSM varies widely among years in these river reaches (Dudley et al. 2016), but the greatest proportion of the population (> 90%) is believed to occurs downstream from the San Acacia Dam (Ikenson 2002). Presence of RGSM has not been documented in the Cochiti Reach since 1995 (Platania and Dudley 2003; Torres et al. 2008; Braun et al. 2015) because of a lack of access for sampling (USFWS 2010). RGSM also occurs in the lower Jemez River, between the Jemez Canyon Dam and its confluence with the Rio Grande (Pueblo of Santa Ana and USFWS 2004).

Due to its reduced distribution and abundance, RGSM is federally listed under the ESA as an endangered species (USFWS 1994). RGSM also is recognized as endangered by New Mexico, Texas, and the Republic of Mexico. A recovery plan for RGSM was first approved in 1999 (USFWS 1999) and was revised in 2010 (USFWS 2010). The recovery plan has three primary goals: (1) prevent the extinction of RGSM in the MRG of New Mexico; (2) recover RGSM to the extent that it can be downlisted from endangered to threatened; and (3) recover RGSM to the extent that it can be delisted. The plan outlines a number of objectives to achieve these goals.

The first recovery goal, preventing the extinction of RGSM from the MRG downstream from Cochiti Lake, has two criteria for success based on the October standardized sampling: a population resistant to extinction as evidenced by the presence of RGSM at a minimum 15 of 20 (75%) monitoring sites, and evidence of successful reproduction as evidenced by presence of young-of-year RGSM at 75% of sampled sites, per reach. A third criterion requires the maintenance of a large, N = 50,000 to 100,000 fish, captive population of RGSM.

The second recovery goal, downlisting to threatened, requires a stable population of RGSM in the MRG and at least two additional self-sustaining populations in other areas. These populations have separate, but related, criteria for success. Criteria for existing populations in the MRG, based on the October standardized sampling, include a population of RGSM greater that five fish per 100 m^2 at all sampled sites, for at least five consecutive years throughout the MRG; and evidence of successful reproduction as evidenced by presence of young-of-year RGSM at 75% of sampled sites, per reach, downstream from Lake Cochiti for at least five consecutive years. Success for the two additional populations is defined as a quantitative demonstration e.g., population viability analysis (PVA), that the populations have a probability of extinction in the wild of less than 10% within 50 years. For all populations, there is a requirement for sufficient flows to support demographic processes (recruitment and population growth) and to provide a sufficient quantity and quality of habitat to sustain these demographic processes.

The third recovery goal, delisting RGSM, requires three self-sustaining populations of RGSM within the historic range of the species, as defined by criteria related to population size, distribution, and extinction risk. Success for all populations is defined as a quantitative demonstration, e.g., PVA, that the populations have a probability of extinction in the wild of less than 10% within 50 years. For all populations, there is a requirement for sufficient flows to support demographic processes (recruitment, survival, and population growth) and to provide a sufficient quantity and quality of habitat to sustain these demographic processes.

Middle Rio Grande Management Actions

The RGSM recovery plan (USFWS 2010) lists a number of ongoing management actions including propagation of RGSM and augmentation of existing populations, habitat restoration, water management, salvage and relocation of RGSM during dry periods, and reintroduction of RGSM into unoccupied portions of its historic range, which are briefly described below.

RGSMs are held and bred in captivity to establish captive populations as a safeguard against extinction of the species in the wild, to maintain genetic variation in captive-bred fish, augment wild populations, serve as a source of RGSM for reintroduction into unoccupied portions of the species historic range, and to provide fish for studies to improve propagation and augmentation methods. Major, or dedicated facilities, include the: (1) the Dexter National Fish Hatchery and Technology Center, which maintains a captive population of adult RGSM derived from wild collected ova to produce fish in support of augmentation and reintroduction efforts; (2) the BioPark, operated by the City of Albuquerque, which collects RGSM ova for use in propagation and augmentation programs and distributes ova to cooperating State and Federal agencies; and (3) the Los Lunas Silvery Minnow Refugium, operated and managed by the New Mexico Interstate Stream Commission, which was constructed to mimic a relatively natural channel-floodplain environment for captive RGSM, many of which have been used in studies of the biology of the species. Additionally, the New Mexico Fish and Wildlife Cooperative Research Unit, the Mora National Fish Hatchery and Technology Center, the Rock Lake State Fish Hatchery, and the Museum of Southwestern Biology have participated in various research, propagation, and grow out activities.

A framework for habitat restoration in the MRG was developed by Tetra Tech (2004). The plan identifies various restoration activities in the MRG and describes specific techniques that could be considered in future RGSM habitat restoration projects. The plan emphasizes the importance of improving egg and larval retention and addressing habitat fragmentation. Actions proposed for successful habitat restoration include: sustained flows to promote sufficient populations of wild RGSM, maintaining spring flow peaks in mid- to late-May to stimulate spawning by RGSM, establishing channel conditions that reduce downstream displacement of ova and early life-history stages, establishing a sustainable population of RGSM in the Angostura reach, establishing suitable feeding and cover habitat for juvenile and adult RGSM, and remediating river fragmentation (Tetra Tech 2004). To date, several habitat restoration projects that have been completed on the MRG, many of which involve physical modifications of the river bank and floodplain, planting of vegetation, and placement of woody structures that provide low-velocity habitat (USFWS 2010). These areas may be used for spawning by RGSM and may also sustain ova and early life-history stages (e.g., Pease et al. 2006) that occur either as a result of in situ reproduction or advective transport.

Water management within the MRG is complex and involves a number of federal, tribal, state, and municipal agencies and irrigation districts. Meeting recovery goals (USFWS 2010), for example, providing adequate spring flows to support reproduction by RGSM and survival of early life-history stages, requires interagency coordination of daily river and reservoir operations, irrigation metering and management, direct and indirect use of water from the Rio Grande as well as that impounded (stored) on tributary streams, and pumping water from the Low Flow Conveyance Channel to the river.

The MRG is subject to periods of intermittency, which usually occur between July and October. Since 2009, RGSMs have been “salvaged” by collecting them from isolated pools in drying portions of the river and relocating them to wetted areas (e.g., Archdeacon 2016). The general pattern of redistribution is from downstream to upstream areas.

Since 2009, RGSM have been reintroduced into the Big Bend reach of the LRG in Texas under a 10(j) non-essential experimental population designation (USFWS 2010). RGSM have been released at four sites within the Big Bend reach of the LRG and subsequently have been recovered at those, and other, more dispersed sites within this reach (USFWS 2010; Edwards and Garrett 2013). There is no evidence at this time that this population is self-sustaining.

Recently, the USFWS (2016) published a BiOp that outlines a four-part survival and recovery strategy (SRS) for RGSM in the MRG to help guide water management in a manner consistent with maintenance and recovery of RGSM. Briefly, the first part of the SRS identifies two Hydrobiological Objectives that: (1) call for spring flows of sufficient magnitude, duration, and timing to promote successful spawning by RGSM (i.e., a Production Strategy) and (2) sufficient flows to reduce the length and duration of river drying, which will increase RGSM survival though the summer, thereby increasing the potential number of spawning fish in the succeeding year (i.e., Survival Strategy). The second part of the SRS calls for restoring connectivity in the MRG. This can be accomplished with fish passage structures that should obviate the need to salvage RGSM during dry periods. The third part of the SRS comprises large-scale habitat restoration and enhancement in the Isleta and San Acacia reaches of the MRG to restore floodplain function so that overbanking can occur at lower flows. This should reduce the total volume of water required for successful RGSM spawning and increase the length of perennially wetted river, which should promote survival and recovery. The fourth part of the SRS calls for the creation of water-storage capacity in upstream reservoirs. Stored water then can be used to augment flows, especially during dry periods, to promote survival and recovery of RGSM. Additionally, the BiOp makes agency-specific recommendations to minimize and avoid adverse effects of water use and management in the MRG.

Critical Scientific Uncertainties

A two-day ISP meeting was held at the Tamaya Hotel and Resort on the Pueblo of Santa Ana. The ISP was composed of panel chairman Dr. Barry Noon, a conservation biologist from Colorado State University who has chaired several previous ISPs; Dr. Tom Dunne, a geomorphologist and hydrologist from the University of California, Santa Barbara, and a National Academy of Sciences member; Dr. Gary Grossman, an expert in fish ecology from the University of Georgia; and Dr. David Hankin, an expert in fishery biology and sampling design from Humboldt State University. Prior to the meeting, the ISP was provided with an extensive list of relevant publications and reports and several video presentations to introduce them to the MRG. The facilitated panel meeting comprised presentations by regional SMEs followed by question and answer sessions between the ISP and each SME presenter. Following the two-day meeting, there was a half-day closed-door executive session between the ISP and the GSA team to debrief and discuss the process for developing the ISP report.

The primary objectives for identifying the critical scientific uncertainties were to: 1) contribute to scientific knowledge, 2) ensure that monitoring, research, and experiments funded by the MRG Collaborative Program reduce management uncertainties, and 3) improve the rigor of the science informing resource management decisions and actions directed at avoiding jeopardy to the continued existence of the RGSM while still providing for current and future water users.

Identified Critical Scientific Uncertainties

The ISP identified 20 critical scientific uncertainties in five thematic areas (Population Dynamics, Reproductive Biology, Age and Growth, Physical Habitat Relations, and Sampling Methodologies). Two uncertainties, noted below, were listed in each of two thematic areas. Critical scientific uncertainties and potential studies to address them were identified by the ISP as Level 1 (most critical) or Level 2 (important, but of less immediate concern), or were unranked. Thirteen of the critical scientific uncertainties were identified as Level 1. The ISP report (Noon et al. 2017) did not specifically identify any of the uncertainties in Physical Habitat Relationships as Level 1 or Level 2; however, ISP chair Barry Noon (personal communication) reported that the panel identified two uncertainties as being Level 1. Thematic areas and Level 1 uncertainties identified by the ISP were:

Population Dynamics

1. The ISP believes that managers and researchers working with the RGSM would benefit from construction and parameterization of a matrix population-dynamics model for the species. This model would allow the identification of the age-specific fecundity and survival rates (i.e., sensitivities) that have the greatest impacts on RGSM population growth and, therefore, which aspects of the RGSM life history might be most amendable to management actions.
2. Age-specific survival rates are necessary to parameterize the recommended population dynamics model. The ISP reviewed the estimates of RGSM survival derived by Daniel Goodman (2010, 2011). The ISP observed that the survival estimates varied widely across years and reaches and concluded that age-specific survival rates were not adequately known, especially as this relates to parameterizing the recommended population dynamics model.
3. Age-specific fecundity rates are necessary to parameterize the recommended population dynamics model. The ISP reported there were no published estimates of RGSM fecundity, although fecundity estimates from a series of hatchery fish was available. The ISP concluded the fecundity and annual egg production of wild RGSM are insufficiently known to parameterize the population dynamics model. This uncertainty is similar to #8, below; they are considered in combination henceforth.
4. The ISP concluded that the relationship between the annual CPUE index and true population size has been insufficiently characterized. The CPUE index is based on fish captures made by seining, the efficiency of which varies with flow, mesohabitat, and fish size. At present, CPUE cannot be adjusted neither for variation in these factors, nor their interactions. The index, thus, is sensitive to variation in flow, habitat variability, etc., compromising its ability to track interannual trends in RGSM populations. This uncertainty is similar to #13, below; they are considered in combination, henceforth.
5. The ISP concluded that uncertainty remains regarding the relationships between RGSM demographic rates and: A) hydrologic factors; B) abiotic environmental factors; and C) biotic factors. RGSM abundance (fall CPUE index) is correlated with several environmental factors.

However, the fall CPUE-index conflates survival of different age classes and reproductive output. Further, given the limitations of CPUE described in #4 above, it is not known how hydrological, abiotic, and biotic factors affect RGSM survival and reproductive output.

Reproductive Biology

1. The ISP recommends that knowledge of the temporal variation in RGSM spawning should be improved. The efficiency of MECs, used to monitor abundance of RGSM ova in the MRG, is affected by discharge, depth, and other factors. The ISP recommends development of correction factors to allow a better understanding of the timing, location, and magnitude of RGSM reproductive activity. Also, timing of deployment of MECs limits their use in detecting potential monsoonal spawning events and the ISP recommends expanding the seasonal sampling frame to assess the presence and significance of monsoonal spawning events. This uncertainty is similar to #12, below; they are considered in combination, henceforth.
2. Although RGSM are known to spawn on the ascending hydrograph, there is uncertainty as to the precise environmental cue(s) that trigger spawning. This uncertainty is similar to #10, below; they are considered in combination henceforth.
3. Size-specific fecundities of naturally spawning RGSM and number of (fractional) spawning events are unknown (see also uncertainty #3, above). (Note, the priority of this uncertainty was reported as Level 2 in Noon et al. [2017].)

Physical Habitat Relations

1. The ISP concludes there is uncertainty in the spatial extent and hydraulic quality of habitats used by RGSM for key life-stages (spawning, larval rearing, juvenile, and adult). Habitats used by some like history stages (juveniles, adults) are well known, but those used for spawning and larval stages are less well known. Also, the spatial extent and distribution of such habitats has not been determined.
2. The precise proximate trigger for spawning (e.g., flow velocity, temperature, rate of increase in flow velocity, or some combination) is not known (see also uncertainty #7, above).

Sampling Methodologies

1. The ISP concludes there is uncertainty in the age structure of the RGSM population and the typical longevity of individuals.
2. There is uncertainty in the vertical and horizontal distribution of RGSM ova, within the MRG water column, as a function of flow and location. This uncertainty is similar to #6, above; they are considered in combination, henceforth.
3. The CPUE index as currently calculated is sensitive to variation in catchability due to a number of factors (discharge, depth, etc.), which limit the ability of the index to track changes in RGSM population abundance (see also uncertainty #4, above) and would benefit from studies that

better describe, and allow for correction of, sampling limitations. (Note, the priority of this uncertainty was reported as Level 2 in Noon et al. [2017].)

The Level 1 critical scientific uncertainties for RGSM are interconnected. In some cases, information pertaining to one uncertainty is related to, or is necessary to inform research on, other critical uncertainties. Information on RGSM age structure (uncertainty #11) is required to estimate age-specific survival (uncertainty #2; left-hand side of Figure 23). Estimates of age-specific survival and age-specific fecundity, as informed by age structure, are necessary to determine life-history sensitivities (uncertainty #1), and all of these measures are required to develop and assess models relating demographic rates and environmental conditions (uncertainty #5). The relationship between demographic rates and the environment is related to, and informs studies of, the spatial and temporal distribution of ova (uncertainty #12) and RGSM habitat quality (uncertainty #9). CPUE is necessary, as a dependent variable, to assess models of demographic rates and environmental conditions (uncertainty #5) and the quantity and quality of RGSM habitat. Finally, cues for spawning (uncertainties #7 and #10) are needed to understand the timing and periodicity of RGSM spawning (uncertainty #6), and both are needed to fully understand the spatial and temporal distribution of ova. Presentation of these interrelationships is not intended to indicate the relative importance of various uncertainties but may be useful in determining the order in which the uncertainties are addressed.

Connectivity Among Critical Scientific Uncertainties

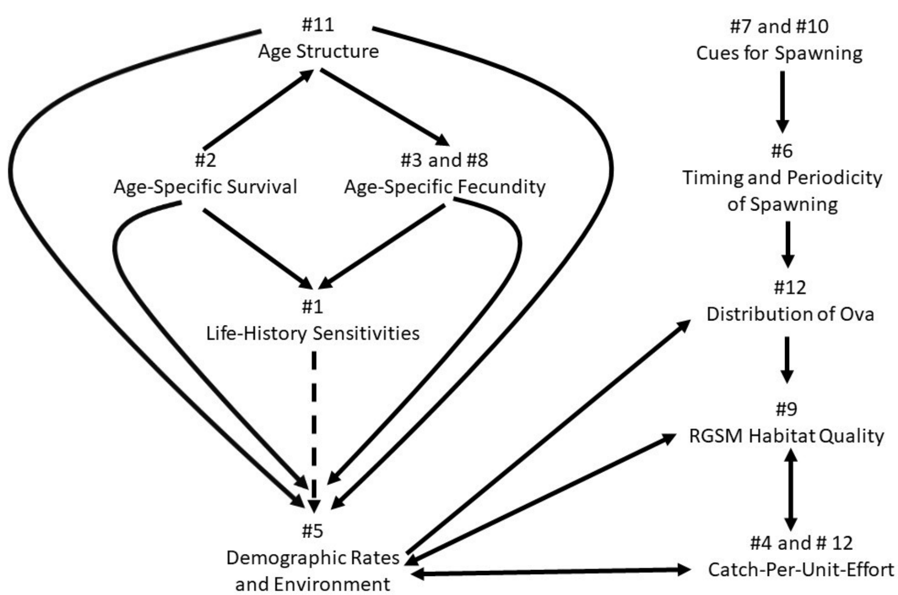


Figure 23. Interrelationships of Level 1 scientific uncertainties identified by the Independent Science Panel.

Other Critical Scientific Uncertainties

The following seven scientific uncertainties were identified by the ISP as important, but of less immediate concern (Level 2), or were unranked (see Executive Summary [Noon et al. 2017] for the original wording):

Population Dynamics

- There is uncertainty in whether density-dependent factors limit RGSM population growth (Level 2). Also, if such factors exist, there is uncertainty regarding the magnitude of their impacts. There is uncertainty in the effect of hatchery augmentation on RGSM population dynamics and achievement of recovery objectives.
- There is uncertainty in the magnitude of the contribution to RGSM population dynamics of fish collected and transported during salvage operations, conducted during periods of river channel drying.

Reproductive Biology of Rio Grande Silvery Minnow

- There is uncertainty in the optimum reproductive habitat for RGSM.

Age and Growth

- There in uncertainty in the typical longevity of RGSM (Level 2). See also, uncertainty #11, above.

Physical Habitat Relations of Rio Grande Silvery Minnow

- There is uncertainty in the role and relative contribution to fish production (age-0 recruitment and survival of all age classes) of channel and floodplain habitats.
- Potential for fish production (recruitment and survival of age-0 fish) in each reach of the MRG should be better understood.

CRITICAL SCIENTIFIC UNCERTAINTY #1: CRITICAL LIFE-HISTORY SENSITIVITIES

Study Question: What are the critical life-history sensitivities of RGSM and which age-specific survival and fecundity rates most affect the rate of population change?

Scientific Relevance

KEY LIFE-HISTORY SENSITIVITIES SCIENTIFIC RELEVANCE
Estimates of age (or size)-specific survival and fecundity rates, i.e., population vital rates, can be used to parameterize a simple matrix model (Leslie 1945; Caswell 2001) that can be used to estimate the future size of a population, the relative abundance of different age (or size) classes, and the rate of population growth. Linking matrix models with environmental variables allows not only prediction of population responses, but an understanding of the mechanisms responsible for those changes. Matrix models also can be used to assess life-histories, which measure which age-specific survival and fecundity rates have the greatest impact on population growth.

The Leslie matrix model (Leslie 1945) and various extensions thereof (see Caswell 2001) typically comprise a projection matrix that contains estimates of age- (or size-) specific survival and fecundity rates and a population vector that contains the number of individuals in each age (size) class. Multiplying the projection matrix and population vector allows prediction of future states of the population. Noon et al. (2017) constructed a simple, deterministic matrix model for RGSM:

$$\begin{pmatrix} p_0 m_1 & p_0 m & p_0 m \\ p_1 & 0 & 0 \\ 0 & p & p \end{pmatrix},$$

where the top row is a vector of age-specific fecundities (m_1 for age 1 RGSM, m for ages 2 and 3) and p represents age-specific survival rates (p_0 is survival from egg to age 1, p_1 is survival from age 1 to age 2, and p is survival of older age classes).

Using age-specific estimates of p and m derived by Noon et al. (2017) yields the projection matrix:

$$\begin{pmatrix} 0.0016 * 658 & 0.0016 * 1480 & 0.0016 * 1480 \\ 0.05 & 0 & 0 \\ 0 & 0.55 & 0.55 \end{pmatrix}.$$

The first eigenvalue of this matrix is a measure of the population growth rate (λ). Manipulation of the projection matrix provides estimate of age-specific sensitivities and elasticities for each survival and fecundity rate (Caswell 2001; Noon et al. 2017). Sensitivities show how much the population growth rate is influenced by changes in a parameter. Elasticities show how much the population growth rate changes for a proportional change in a parameter. Elasticities are more often used in conservation biology because sensitivities are affected by the magnitude of a parameter (Benton and Grant 1999; Mills et al. 1999; Mills 2013). For example, given the relative magnitude of age-specific fecundities above, compared to survival rates, one would expect fecundity to have a greater sensitivity. This would not necessarily be the case for elasticities. **The value of these analyses is that they can direct management attention towards the age(s) and parameter(s) (i.e., fecundity or survival) that will have the greatest impact on population growth rate.**

The model presented by Noon et al. (2017) is of limited use, as they note. First, it is possible to extend the model so that survival rates of different early life-history stages (ova, protolarvae, mesolarvae, metalarvae, and early juvenile stages [e.g., Synder 2013]) are incorporated. Also, the model developed by Noon et al. (2017) is deterministic and assumes constant survival and fecundity rates, which they note are likely to vary though time, among reaches, and as a result of sampling variation. Noon et al. (2017) recommend that, ultimately a stochastic model is developed, which incorporates variation in age-specific survival and fecundity rates across sites, habitats, and years. The general model proposed by Noon et al. (2017) can be further extended by inclusion of environmental co-variates (e.g., Wilde and Durham 2008a), which can provide a more precise (i.e., mechanistic) understanding of the relationship between covariates and population responses.

Construction and analysis of a projection matrices is the most efficient means of estimating and exploring sensitivities and elasticities of critical life-history vital rates for RGSM.

Management Application

KEY LIFE-HISTORY SENSITIVITIES MANAGEMENT APPLICATION
Sensitivity and elasticity analyses provide important management insight into which aspects (age-specific survival rates, age-specific fecundities) of RGSM life-history have the greatest effect on rates of population change, thereby allowing improvements in design and implementation of future management and research efforts, by directing those actions and studies to the life-history stages where they would have the greatest affect. For example, a given habitat manipulation could affect several life-history stages; however, the manipulation might have little effect on RGSM populations if other, more influential stages, are not affected by the manipulation. Coupling projection matrices with (1) estimates of the natural variation in each vital rate and (2) relevant hydrologic and other environmental covariates can provide probabilistic estimates of the direction and magnitude of population responses and an understanding of the potential impact of management actions on long-term population viability.

Sensitivity and elasticity analyses will help identify those vital rates (e.g., age-specific survival and fecundity rates) that have the greatest effect(s) on population growth rate and, therefore, that might be most effectively influenced by management actions. Based on correlations between RGSM population size in October samples and hydrologic characteristics in the preceding spring, current management of RGSM is largely directed toward providing habitat and spring flows to facilitate RGSM spawning. Elasticity analysis can confirm these practices or suggest other aspects of RGSM life history that might have a greater effect on population growth. Further, depending on how the projection matrix is constructed, whether age-0 considered in its entirety or is treated as a series of life-history stages (ova, protolarvae, mesolarvae, metalarvae, and early juvenile stages), insight can be gained into which specific early life-history stage(s) are most critical. This could facilitate population recovery and aid in the optimization of water and other resources directed toward management of RGSM. Inclusion of environmental covariates that have the greatest impact on those vital rates (e.g., age-specific survival and fecundity rates) that are most responsible for population changes, whether due to management or as a result of natural variation in environmental conditions such as spring runoff. These analyses will help guide future management or research efforts towards those most likely to have the greatest impact.

Recovery Application

KEY LIFE-HISTORY SENSITIVITIES RECOVERY APPLICATION
Recovery goals for RGSM provide explicit abundance (CPUE) and reproductive success criteria for prevention of extinction and eventual downlisting. These criteria are not commonly met, particularly in dry years. Understanding which life-history sensitivities are most important to the rate of population growth and are most amenable to management will facilitate the achievement of RGSM recovery goals.

Recovery goals for the RGSM require self-sustaining populations that meet specific abundance, reproductive, and permanency criteria. Meeting these criteria will require manipulation of river flows and habitat restoration. The nature, timing, and magnitude of management activities will differentially affect different RGSM life history stages and, hence, recovery of the species. Sensitivity and elasticity analyses, by identifying the most influential population vital rates, provide guidance as to which management activities will have the greatest effect.

Study Plan Considerations

Initial estimates of life-history sensitivities should focus on estimating the elasticity value of each age-specific survival and fecundity rate. Initial parameterization of the projection matrix can be based on existing data (for example, see Noon et al. 2017), although there are some limitations to those data, and there are length-based means of estimating missing parameters (e.g., Velez-Espino et al. 2006). Once a projection matrix is constructed, elasticities of age-specific survival and age-specific fecundity rates can be calculated using eigenanlysis as described by Caswell (2001). To the extent possible, age-specific survival and fecundity rates should include estimates of spatial (among mesohabitat types and reaches) and temporal (across years) variability. The projection matrix presented by Noon et al. (2017) is deterministic and was constructed for heuristic purposes and they recommended eventually including measures of parameter uncertainty. Hilborn and Mangel (1997) distinguish between two types of uncertainty: observation uncertainty and process uncertainty. Observation uncertainty is, essentially, measurement error. There are many potential sources of measurement error, for example, different members of a field crew might vary in their measures of RGSM length, or different sampling crews or gears may have different abilities to capture RGSM, which could affect estimates of survival. Process uncertainty describes temporal and spatial variation in the underlying process being studied. For example, survival of age-0 RGSM will likely vary from year to year. At a minimum, estimates of process uncertainty for each age-specific survival and fecundity rate should be incorporated into analyses of the projection matrix. Incorporating process uncertainly (i.e., stochasticity) within matrix models requires simulation solutions. Conducting these stochastic life-stage simulations will give more precise estimates of population growth rates and the vital rates most responsible for changes therein.

The projection matrix, and insights derived from it, can be greatly improved as age-specific survival and fecundity estimates (see critical uncertainties #2 and #3, below, respectively) and estimates of their variances are acquired.

Priority Ranking

Addressing critical scientific uncertainty #1 is considered a Level 1 Priority (Table 11) and was among the most important management-relevant scientific uncertainties identified for the RGSM by the ISP.

CRITICAL SCIENTIFIC UNCERTAINTY #2: AGE-SPECIFIC SURVIVAL RATES

Study Question: What are the survival rates, and estimates of their natural (process) variability, of different age classes of RGSM?

Scientific Relevance

AGE-SPECIFIC SURVIVAL RATES

SCIENTIFIC RELEVANCE

RGSM abundance can vary by over two orders of abundance within a year and varies substantially among reaches within the MRG. To understand variation in the abundance and distribution of RGSM, it is essential to have estimates of the underlying demographic parameters that give rise to the observed population abundances. This requires estimates of age-specific survival rates and estimates of their variability.

Estimates of age-specific survival rates of RGSM have been poorly studied but are integral to construction of (Leslie matrix) projection matrices and, therefore, to estimating sensitivities and elasticities of population vital rates (Noon et al 2017). In short-lived fishes such as RGSM, survival rates are usually quite small in the first year of life, especially the first summer (e.g., Wilde and Durham 2008b), but then can be much greater in succeeding year classes (Quist and Guy 2001; Rahel and Thel 2004; Wilde and Durham 2008a). Lengths of RGSM captured during population monitoring are recorded (e.g., Dudley 2016) and can be used to estimate survival of fish within the first year (age-0) and annually for adult fish. Preliminary estimates of survival were presented and discussed by Goodman (2011). Those estimates suggest that survival is variable across years and reaches. This variability argues strongly against the use of deterministic projection matrices; therefore, estimates of age-specific survival rates and their variances will be necessary to parameterize stochastic matrix models (Tuljapurkar and Caswell 1997; Caswell 2001), in which age-specific survival rates vary among years and river reaches.

Management Application

AGE-SPECIFIC SURVIVAL RATES

MANAGEMENT APPLICATION

Sensitivity and elasticity analyses of age-specific survival rates can provide management insight into which age(s) of silvery minnow have the greatest on population growth rates and how temporal and spatial variation in survival affect population growth rates. This will contribute toward improvements in design and implementation of future management and research efforts.

Sensitivity and elasticity analyses of age-specific survival rates can show which age class(es) or early life-history stages have the greatest effect on population growth rate. Effectiveness of management actions then could be maximized by considering actions that promote survival of those specific those ages or early life-history stages. Based on correlations between RGSM population size in October samples and hydrologic characteristics in the preceding spring, current management of RGSM is largely directed toward providing habitat and spring flows to facilitate RGSM spawning and survival of early life history stages. These actions are based on correlation rather than on any specific mechanistic model, which could be developed though analysis of sensitivities and elasticities. An understanding of the effects of spatial and temporal variation in age-specific survival rates can allow appropriate allocation of adjustment of management actions across years and among river reaches.

Recovery Application

AGE-SPECIFIC SURVIVAL RATES

RECOVERY APPLICATION

Recovery goals for RGSM provide explicit abundance (CPUE) and reproductive success criteria for prevention of extinction and eventual downlisting. These goals also explicitly recognize the importance of RGSM populations within difference reaches of the MRG. Understanding temporal and spatial variation in age-specific survival rates will help direct attention and action toward ages or early life-history stages that are most important to the rate of population growth and which would be most amenable to management, which will facilitate the achievement of RGSM recovery goals.

Recovery goals for the RGSM require self-sustaining populations that meet specific abundance, reproductive, and permanency criteria. Meeting these criteria will require manipulation of river flows and habitat restoration. The nature, timing, and magnitude of management activities will differentially affect different RGSM life history stages and, hence, recovery of the species. Sensitivity and elasticity analyses, by identifying the most influential population vital rates, provide guidance as to which management activities will have the greatest effect and how these activities may be most profitably varied among reaches or over time.

Study Plan Considerations

Age-specific survival rates are likely to vary temporally and spatially (among mesohabitats and reaches) in response to variation in environmental conditions. The ISP recommends making age-specific survival rates estimates in two basic ways. First, CPUE can be partitioned by age class (age 0, age 1, age 2) using, for example, October CPUE indices, from successive years. Comparing CPUE for a given cohort (i.e., RGSM spawned in a given year) with CPUE of that cohort in the following year allows the use of ratio estimators to provide an estimate of annual survival rate:

$$Survival = \frac{CPUE(t+1)}{CPUE(t)}.$$

Separating CPUE by mesohabitat, river reach, and year, allows estimates of survival and its spatial and temporal variance to be obtained. The ISP notes these estimates depend on constant catchability. However, these estimates also assume there is no movement of RGSM between reaches and mesohabitats. This latter assumption is problematic for mesohabitat types and will complicate estimates of mesohabitat-specific survival rates.

Lengths of RGSM captured during CPUE sampling are recorded. These lengths are then used to assign ages to captured RGSM assuming standard growth rates (e.g., Dudley et al. 2016). The ISP recommends instead that these assignments be made using the R *mxdist* library (or a comparable package), which uses maximum likelihood methods to estimate mean lengths, and their variances, from length frequency information (MacDonald and Pitcher 1979; MacDonald 2015). Thus, rather than using a fixed relationship between length and age estimates, the length-age relationship (and variances) can be updated at any desired time step (e.g., monthly, annually). With some expansion, this effort could be expanded to incorporate one of the two studies recommended by the ISP for resolving uncertainties in RGSM age structure (Critical Scientific Uncertainty #11). The ISP recommended that small samples of RGSMs be aged each year (in October and spring) to provide estimates of mean length and variance in length at age. (Note, these fish contribute to studies estimating age-specific fecundity and ovarian histology of RGSM.) Annual estimates of the age-length relationship allow for time-dependent assignments to age-class and provide insights into how length varies over time. These estimates could be used as input for the R mxdist library (MacDonald 2015) to resolve overlapping length-frequency distributions into component age distributions. This package requires the user to specify the number of age classes present. Three age groups should be assumed (ages 0, 1, and 2 in October; ages 1, 2, and 3 in spring) and the validity of this assumption can be assessed by altering the number of age classes and assessing model fit. If aged samples cannot be collected, then current "best guesses" of means and variances of lengths at ages 0, 1, 2, and 3 (e.g., Horwitz et al. 2011) should be used, based on historic age samples.

The ISP did not specifically recommend studies of age-specific survival among months within a year, but they did acknowledge the work of Goodman (2010, 2011). The potential utility of this approach could be evaluated with existing data.

Survival also can be estimated using regression-based estimators (e.g., Skalski et al. 2005; Goodman 2011) that follow the abundance of a cohort over time, typically in annual steps. These methods could be used for adult RGSM based on the October CPUE index, or for age-0 fish, using seine catches made over a period of weeks or months. In fisheries, the regression of ln(catch) over time, for a cohort, is referred to as a catch curve and commonly is used to estimate mortality and by manipulation, survival (Ricker 1975). Catch curves can be used to estimate annual survival using data incremented over annual periods or it can be used to estimate survival over shorted time periods, which is commonly done to estimate survival of age-0 fish (Dahlberg 1979; Quist and Guy 2001; Wilde and Durham 2008b). Smith et al. (2012) recently reviewed, and made methodological recommendations for, analyses of catch curves.

Given the large variation in length at age in age-0 fish, the most precise field estimates of survival might be derived from catch curve analyses, as above, based on numbers of fish with ages estimated from otoliths (e.g., Wilde and Durham 2008b). Given the low daily survival rates of early life-history stages, removal of fish from the wild would have no discernable population effects. Alternatively, recently dead age-0 fish could be obtained from isolated pools during periods of summer drought in tandem with ongoing salvage activities. Validation of otolith age estimates (Taubert and Coble 1977; Durham and Wilde 2008a) could be conducted with fish obtained from hatcheries or other research facilities such as Dexter National Fish Hatchery, Albuquerque BioPark, and the Los Lunas Refugium.

Precise field-based estimates of survival, particularly for early life-history stages, may be difficult to make in the field. Pepin (1991) found that temperature accounted for a large proportion of the variation in ova survival rates and that temperature and size were the primary factors that influenced survival of age-0 fish. RGSM reared in hatcheries and other research facilities (Dexter National Fish Hatchery, Albuquerque BioPark, and Los Lunas) could possibly be used to measure survival rates and conduct controlled experiments that examine environmental effects on survival.

Priority Ranking

Addressing critical scientific uncertainty #2 is considered a Level 1 Priority (Table 11) and was among the most important management-relevant scientific uncertainties identified for the RGSM.

CRITICAL SCIENTIFIC UNCERTAINTIES #3 (AND #8): AGE- (SIZE-) SPECIFIC FECUNDITIES

Study Question: Age- (size-) specific fecundities of wild RGSM are poorly known: what is the fecundity of RGSM and how does it vary with age or size?

Scientific Relevance

AGE-SPECIFIC FECUNDITIES

SCIENTIFIC RELEVANCE

Silvery minnow abundance can vary by over two orders of abundance within a year and varies substantially among reaches within the MRG. To understand variation in the reproductive output and success of silvery minnow, it is essential to have estimates of age-specific fecundities and their variability.

Fecundity in fish is strongly related to mass (Bagenal 1978; Wootton 1973). Because fish mass increases with length and, generally, age, fecundity also is related to length and age (Babiker and Ibrahim 1979; Zlvkov and Petrova 1993; Óskarsson et al. 2002; Lauer et al. 2005); however, the strongest and most direct relationship generally is with mass.

At present, very little information is available on fecundity of RGSM, other than for a small series of fish spawned at Dexter National Fish Hatchery (Colleen Caldwell, New Mexico State University, personal communication to Barry Noon). Noon et al. (2017) estimated age- (size-) specific fecundity based on results from the hatchery fish. Because fecundity is sensitive to dietary history (Bagenal 1969; Bromage et al. 1992), the fecundity estimates used by Noon et al. (2017) may not be directly applicable to wild fish, a limitation they noted. Also, the estimates used by Noon et al. (2017) were obtained from fish that had received hormonal injections, which may have resulted in an increase in observed fecundities.

Management Application

AGE-SPECIFIC FECUNDITIES

MANAGEMENT APPLICATION

Sensitivity and elasticity analyses of age-specific fecundity rates can provide management insight into which age(s) of silvery minnow have the greatest contribution on population growth rates and how temporal and spatial variation in fecundity affect population growth rates. This will contribute toward improvements in design and implementation of future management and research efforts.

Sensitivity and elasticity analyses of age-specific fecundity rates can show which age class(es) make the greatest contribution to reproductive output and, hence, population growth rate. This understanding can lead to improvements in the effectiveness of management actions.

Recovery Application

AGE-SPECIFIC FECUNDITIES

RECOVERY APPLICATION

Recovery goals for silvery minnow provide explicit criteria for abundance (CPUE) and reproductive success to prevent extinction and to allow eventual downlisting. These goals also explicitly recognize the importance of silvery minnow populations within different reaches of the MRG. Understanding temporal and spatial variation in age-specific fecundity rates will help direct attention and action toward age-classes that are most important to the rate of population growth and which would be most amenable to management, which will facilitate the achievement of silvery minnow recovery goals.

Recovery goals for the RGSM require self-sustaining populations that meet specific abundance, reproductive, and permanency criteria (USFWS 2010). Meeting these criteria will require manipulation of river flows and habitat restoration. The nature, timing, and magnitude of management activities will differentially affect different age classes of RGSM, which differ in size and, consequently, fecundity rates. These differences, in turn, affect reproductive output and affect recovery of the species. Sensitivity and elasticity analyses, by identifying the most influential population vital rates, provide guidance as to which management activities will have the greatest effect and how these activities may be most profitably varied among reaches or over time.

Study Plan Considerations

Fecundity of RGSM in wild populations can be expected to vary among and within age classes, due to spatial and temporal variation fish size, physiological state, and other factors. To develop fecundity-size (age) relationships for wild RGSM, the ISP recommends collection of a sample of gravid females from the wild, just before initiation of peak flows in the spring. These RGSMs should span the range of sizes (i.e., age classes present in the population). Collected fish would be euthanized and aged by counts of annular rings on otoliths. Enumeration of the numbers of oocytes in different stages of development can be done by macroscopic examination, by differentiating “immature” and “mature” oocytes. However, given the possibility that RGSM may spawn multiple batches of ova and may spawn over a protracted period, counts of oocytes may not yield useful estimates of fecundity (Heins and Rabito 1986; Heins and Baker 1987; Rinchard and Kestemont 1996). Therefore, oocyte counts should be supplemented with measurements of mature oocyte diameters, which when presented as histograms, would provide information on the variation in developmental stages among “mature” oocytes that would provide some insight into whether RGSM spawn multiple batches of ova, over a period of days. Variation in stages of maturity among oocytes also could be studied microscopically using histological preparations of ovarian tissue. Different preservatives generally are used for samples intended for histological analysis (Patiño and Takashima 1995), a small but important consideration. Of the two methods, histology will yield more detailed and definitive information on variation in oocyte developmental stages. It is uncertain whether RGSM is a multiple spawning species and, if so, whether later spawns are biologically important. Histological analysis of RGSM ovaries collected in spring samples will provide some insight into this question (Fernandez-Delgado and Herrera 1994; Ali and Kadir 1996; Lowerre-Barbieri et al. 1996; Rinchard and Kestemont 1996). However, to definitively determine whether fractional spawning occurs, and how substantial it is, will require collection of samples throughout the putative spawning season. It seems likely that RGSM do produce a large, synchronous spawn (Durham and Wilde 2008b) in early spring and sampling this season alone should provide information useful in developing fecundity-size (age) relationships.

As a possible alternative to the above study, as a means of estimating fecundity, the ISP suggests capturing wild RGSM from the MRG, moving them to a breeding facility, and inducing spawning either through the use of hormones or by manipulation of environmental spawning cues. After spawning, RGSM could be released back into the wild. Counts of spawned ova and lengths of females used could then be used to estimate size-fecundity relationships, which then could be used to estimate age-specific fecundity. There are caveats to this approach. First, if fish are released, age cannot be directly assessed. Second, hormones used to induce spawning may result in the final maturation of a greater proportion of oocytes (= greater number of ova spawned) than might be expected if spawning was not hormonally induced. This would result in an over estimate of fecundity. The potential magnitude of this effect could be assessed with hatchery fish. Here, two samples of female RGSM, one injected and other not, would be used for a histological comparison of the number and stages of oocytes. Third, simply removing RGSM from the wild, as per the study outline above, results in a small decrement in population; however, capture, transport, and re-introduction post-spawn RGSM into the wild may decrease the number of fish lost, but because of the multiple stresses these fish will have experienced, this protocol risks possible introduction of disease into the wild population.

As a possible alternative to capturing RGSM and transporting them to a breeding facility for induction of spawning, Wilde and Urbanczyk (unpublished data) have had some success with capture and in situ induction, using hormones, of spawning in flow-through chambers kept within the river. Study species included plains minnow and all fish used the in-situ spawning studies were successfully released alive. This approach would allow estimation of size-fecundity relationships, without removing fish from the wild, but with not allow any direct assessment of age.

Here, as for age-specific survival, it is clear that the ISP recommends multiple estimates, not necessarily derived from multiple methods, so that estimates of spatial and temporal variation in age-specific fecundity, and their variances, are obtained.

Priority Ranking

Addressing critical scientific uncertainty #3 (including #8) is considered a Level 1 Priority (Table 11) and was among the most important management-relevant scientific uncertainties identified for the RGSM.

CRITICAL SCIENTIFIC UNCERTAINTY #4: LIMITATIONS OF THE CPUE INDEX

Study Question: What is the relationship between the annual CPUE index and true RGSM population size?

The ISP identified two primary limitations to the current CPUE index: (1) the relationship between RGSM CPUE and true population size is unknown because of variation in catchabilities related to fish size, current velocity, mesohabitat, etc. (Critical Uncertainties #1 and #12, above) and (2) whether it is appropriate to aggregate CPUE across mesohabitats (Critical Uncertainty #12, above).

Scientific Relevance

LIMITATIONS OF THE CPUE INDEX

SCIENTIFIC RELEVANCE

The CPUE index currently used to monitor silvery minnow abundance and assess population responses is a count-based index of population size based on seine catches. Silvery minnow catchability is likely to vary among size (i.e., age) classes and as a function of river flows and mesohabitat types. Consequently, the relationship between the CPUE index and the true abundance of silvery minnow is unknown and variable over time and across mesohabitats, which limits the usefulness of the CPUE index as a reliable measure of status and trends in the silvery minnow population. Reliability of the CPUE index can be improved by studies that better characterized the index and which possibly allow for adjustment for variation in catchability.

CPUE indices are based on the fundamental assumption that catches (*C*) and fish abundance or biomass (*B*) are related according to the formula:

$$C = q \cdot f \cdot B,$$

where *f* is a measure of fishing effort and *q* is a catchability coefficient. The CPUE index is arrived at by rearrangement:

$$CPUE = \frac{C}{f} = q \cdot B.$$

Enumerating catches of RGSM and estimating effort (i.e., number of seine hauls, distance or area seined) is straightforward. Catchability, or gear efficiency (e.g., Hilborn and Walters 1992), which ranges from 0 (fish are not captured) to 1 (fish are captured in direct proportion to their true abundance) is difficult to measure and, in practice, often is unknown. Catchability is affected by biological and gear-related factors, which can be interrelated. Biological factors affecting catchability include fish size and shape, swimming speed, and behavior towards the sampling gear all of which might also be affected by other factors such as season, time of day, and environmental characteristics. Gear-related factors include gear size, mesh sizes, color, positioning, and extent of area or time sampled.

Catchability of fish by seining, as used in the RGSM population monitoring program (e.g., Dudley et al. 2016), is affected by fish swimming speed, seine size (height and width), mesh size, water depth and velocity, substrate type, and presence of obstacles, among other habitat factors. Seine efficiency, hence catchability, generally decreases with seine size and water depth because of increased hydrologic drag. Although seining usually is conducted in an upstream to downstream direction in flowing waters (Matthews and Hill 1979, 1980), water velocity still influences catchability as current pushes the seine downstream. Seine efficiency also is affected by fish size because the swimming speed of a fish is directly related to its body size (Beamish 1978; Bayley and Herendeen 2000). Swimming speed and endurance of RGSM are positively related to total length (TL) and are affected by water temperature in fish ranging from 53- to 75-mm TL (Bestgen et al. 2010). Dudley et al. (2012) estimated RGSM detection probabilities from an occupancy model to be 0.44 for age 0 fish, 0.29 for age-1 fish, and 0.07 for age 2. Although these estimates largely reflect differences in relative abundance of these age classes, they are qualitatively consistent with swimming abilities estimated by Bestgen et al. (2010).

Estimates of RGSM abundance made during summer months combine results for fine- and small-mesh seines (Dudley et al. 2016), which are used to sample larval and larger RGSM, respectively. In addition to differences in mesh size, the seines differ in height and width. An expert panel assembled in 2015 to evaluate CPUE as a means of monitoring RGSM, recommended against combining samples from these gears into a single CPUE index because of potential differences in size selectivity and, hence, catchability among the two gears (Hubert et al. 2016).

Dudley et al. (2012) presented a general comparison of RGSM population estimates derived from the October CPUE-index, which is based on samples collected by seining, and those based on a series of depletion samples, made with electrofishing, over a four-year period. The two population estimates indicated comparable temporal trends in RGSM, which suggests the October CPUE may be acceptable as a general index of abundance (Dudley et al. 2012; Hubert et al. 2016). Dudley et al. presented simulation results that suggest the two estimates had an approximate correlation of 0.64, but the years studied included two with high population estimates and two with much lower (approximately an order of magnitude) estimates, so the exact nature of the relationship between these estimates cannot be assessed. Population estimates based on depletion samples were consistently 2x greater than those based on the October CPUE-index. Therefore, it cannot be ascertained which, if either, represents a faithful measure of true RGSM abundance.

Dudley et al. (2012) reported differences in capture probabilities for RGSM collected in depletion samples in five mesohabitat types. Capture probabilities ranged from 0.69 to 0.84, which represents a potential 20% difference in capture probabilities among mesohabitats. Whether, or how, capture probabilities vary among unenclosed mesohabitat patches (i.e., such as are sampled for the CPUE index) is not known. The analyses presented by Dudley et al. (2012) also were sensitive to differences among locations, but they provided no analysis of those potential effects.

Thus, there is evidence that RGSM catchability varies in relation to mesohabitat and fish size. No information is available that allows a direct assessment of the effects of flow on catchability of RGSM, but it seems likely that flow would affect catchability to two ways. First, seining is affected by water depth and velocity. Second, the magnitude of flow can alter the relative abundance of different habitat types, which does affect capture probabilities (i.e., Dudley et al. 2012).

In summary, RGSM catchability varies by mesohabitat. Failure to summarize, or stratify, CPUE by mesohabitat represents a loss of information, inflates of estimates of sample variability, and yields an estimate of abundance that is variable over time and across mesohabitats.

Management Application

LIMITATIONS OF THE CPUE INDEX MANAGEMENT APPLICATION

The framework for habitat restoration in the MRG (Tetra Tech 2004), the RGSM recovery plan (USFWS 2010), and the recent BiOp for USBR and its BiOp Partners' water management activities in the MRG (USFWS 2016) recommend management and restoration activities, the success of which are tied to changes in RGSM abundance as measured by the fall (October) MRG basin-wide CPUE results. How the CPUE index is calculated affects its accuracy and variability and, therefore, its ability to accurately measure changes in RGSM abundance due to management and restoration. Correcting the CPUE index for catchability would enhance its accuracy and usefulness.

RGSM management and restoration activities primarily are directed toward providing spawning habitat and spring flows that are of sufficient magnitude and duration to allow successful RGSM spawning and survival through the summer (USFWS 2010, 2016). These actions alter the absolute and relative abundance of different mesohabitats. RGSM population responses and catchability, in response to changes in mesohabitat availability, are conflated, obscuring the true population response.

Recovery Application

LIMITATIONS OF THE CPUE INDEX RECOVERY APPLICATION

Recovery goals for RGSM are related to measures of population size as one of the criteria for downlisting. Thus, it is important to have measures (i.e., CPUE) of population size and response to management actions that accurately reflect the true abundance of RGSM and which have a small sampling variance.

The recovery goals for the RGSM are presented in USFWS (2010). The first recovery goal, prevention of extinction, requires maintenance of RGSM population resistant to extinction as evidenced by the presence of RGSM at a minimum 75% of monitoring sites, per reach, in the MRG. The second recovery goal, downlisting to threatened requires a population of RGSM greater that 5 fish per 100 m^2 at all sampled sites, for at least five consecutive years throughout the MRG, plus two additional populations that have a low probability of extinction based on PVAs. The third recovery goal, delisting, requires three RGSM populations that are self-sustaining as defined by a number of criteria including population size. Achieving these recovery goals, and measuring progress toward them, requires and an accurate and precise measure of population response.

Study Plan Considerations

There is a growing interest within the sciences for the adoption of practices, termed reproducible research, that require, among other considerations, that data sets and computer code used in studies be made available to other researchers so that results can be verified and alternative analyses conducted (Peng 2009; Sandve et al. 2013). This matter was not addressed by the ISP, but ***reproducible research practices are strongly suggested here as an integral part of all studies recommended by the ISP*** for two reasons. First, many of the reports cited herein, as well as those cited and reviewed by the ISP, do not present sufficient descriptions of study methods or summary statistics to allow the reader to fully evaluate the data and arguments presented. Second, in trying to implement studies suggested by the ISP, basic study design considerations, such as estimating sample sizes and conducting proscriptive power analyses, are made difficult, if not impossible, because necessary measures of sample variability are not reported.

The ISP recommended two studies to assess the relationship between the CPUE index and true RGSM abundance. These studies could be conducted in the field as an extension of ongoing surveys. First, CPUE estimates obtained by seining should be collected in conjunction with estimates obtained by depletion sampling such as those presented by Dudley et al. (2012). The ISP suggests that abundance estimates obtained from depletion sampling are likely to be more accurate than those obtained from seining if the depletion sampling is thorough. This does seem likely given that RGSM population estimates based on depletion sampling were consistently twice as high as those derived from seining (Dudley et al. 2012). RGSM abundance estimates from depletion sampling can then be used to “correct” or “calibrate” the seine-based CPUE index using a ratio estimator (Cochran 1977; Thompson 2002). The ISP suggested this study should be conducted over at least two years. The study by Dudley et al. (2012) compared estimates collected during 2008-2011, which was sufficient to suggest that the (seine-based) CPUE index was indicative of general population trends; however, results of that study are applicable to the range of habitat and flow conditions that occurred during the four years of that study. Dudley et al. (2012) presented standard errors for their estimates of capture probabilities in different mesohabitats but did not present any information on interannual or flow-related variation in capture probabilities. At a minimum, their standard errors could be used in a prospective power analysis (Peterman 1990; Maxell 1999) to estimate the necessary number of replicates and, possibly, years of study needed.

The ISP also recommended a study that would compare catches of RGSM in the fine-mesh seines used to sample adult RGSM and the finer-mesh seines used to sample age-0 RGSM, with catches from a very fine-mesh seine that, presumably would non-selectively capture RGSM of all sizes. Catches from this latter seine then could be used calibrate RGSM catches from the seines used for adult and age-0 RGSM using ratio estimators. Comparing catches in two seines types varying in size selectivity would allow assessment of the degree to which smaller age-0 RGSM are missed in mid-summer surveys and could support current aggregation of RGSM catches from the "adult" and "age-0" seines into a single index of CPUE, the appropriateness of which was questioned by Hubert et al. (2016). The size of the study can be determined with prospective power analysis, based on the precision desired, using catch rates and estimates of their variability from existing data. Note, a relatively modest expansion of this effort could also address one of the studies recommended by the ISP to address uncertainties in RGSM age structure (Critical Scientific Uncertainly #11.) In addition to the above, the ISP recommends collecting RGSM from inundated floodplain habitats using fyke nets and seines in areas in which both gears can be effectively deployed (see Gonzales et al. 2014). Seine catches could be adjusted for size selectivity using fyke net catches, under the assumption that RGSM catches in fyke nets, which are a passive gear (they are set in place and fish enter into the net under their own effort) will more closely represent the true distribution of RGSM lengths and ages than will catches from seines, which are an active gear, catches of which will be influenced by seine operation and variation in avoidance (i.e., swimming speed differences attributable to differences in lengths and ages of RGSM). A fitted selection curve can then be used to adjust length data for gear-selection bias before these data are used to resolve length-frequency distributions into component age distributions using the R *mxdist* library or comparable statistical methods.

The ISP recommended presenting CPUE estimates for specific mesohabitats rather than combining results across mesohabitats. Further, the ISP recommends using the current CPUE metric be replaced with a mesohabitat-specific metric calculated for a single mesohabitat, characterized by high abundance of RGSM, that has substantial availability in all primary sampling reaches, they state, "The time-series of this metric should provide a more reliable indicator of trends in October abundance of RGSMs because it assumes only that catchability within this mesohabitat type are constant across years at the time of October sampling. As flows during October are probably low and have relatively little variation across years (relative to other months), we believe that this assumption is a reasonable one." We acknowledge the potential shortcomings of the use of a single mesohabitat to monitor catches, but such an approach would eliminate among-mesohabitat variance from the metric proposed by the ISP and be used to supplement, rather than replace, the CPUE index. The potential merits of this recommendation can be studied with existing data. First, mesohabitats with the greatest catch rates in which seine results and depletion sampling are most correlated can be examined as candidate mesohabitats. Then simulation studies can be conducted to determine which measure, the currently constructed CPUE or the mesohabitat-specific CPUE, provides the most accurate and precise estimates of trends in RGSM abundance.

Priority Ranking

Addressing critical scientific uncertainty #4 (and #13 from Noon et. al 2017) is considered a Level 1 Priority (Table 11) and was among the most important *management-relevant* scientific uncertainties identified for the RGSM.

CRITICAL SCIENTIFIC UNCERTAINTIES #5: DEMOGRAPHIC RATES AND ENVIRONMENTAL FACTORS

Study Question: How do key RGSM vital rates (i.e., age-specific survival and fecundity rates) vary as a function of hydrologic factors, abiotic environmental factors, and biotic factors?

Scientific Relevance

DEMOGRAPHIC RATES AND ENVIRONMENTAL FACTORS

SCIENTIFIC RELEVANCE

The relationship between RGSM CPUE, among other population characteristics, and a substantial number of environmental variables, particularly those related to aspects of the MRG hydrograph, has been studied. However, these studies have been correlative in nature and, while useful in suggesting relationships amenable to management action, do not provide an understanding of the specific mechanism(s) by which these relationships affect RGSM populations.

As described in sections above, the ISP recommended studies to address critical scientific uncertainties #1 (sensitivities of key population vital rates, i.e., age-specific survival and fecundity rates), #2 (inadequate information on age-specific survival rates), and #3 and #8 (age- and size-specific fecundity rates). These efforts will allow the parameterization of a stochastic matrix population model for RGSM that will be important in guiding research and management actions. Combining that model with environmental covariates, and their interactions, such as those identified by Dudley et al. (2016), as well as those included among the hydrological variables in the survival and recovery strategy for RGSM (USFWS 2016), will provide an understanding of how the RGSM population responds to temporal and spatial variation in environmental conditions and to management actions. Is a change in RGSM population due to survival of one or more key life history stages? Or is it due to a change in population age-structure and, in turn, age-specific fecundity? Current modeling of RGSM population dynamics is based on the CPUE index. As discussed previously, CPUE conflates age-specific survival and reproductive output. Thus, the cause of a population change cannot be precisely identified.

There are a number of ways in which the relationship between vital rates and environmental variables can be modeled and incorporated within the population model (Caswell 2001; Newman et al. 2014). The ISP suggested that vital rates be modeled as function of environmental covariates using regression, as described by Newman et al. (2104). For example, age-specific survival (or life-history stage), which ranges from 0 to 1, could be modeled for each age class as a function of habitat, hydrologic, and other environmental variables using logistic regression (see Noon et al. 2017). Fecundity rates could be modeled directly, or indirectly using mass or length as the dependent variable, for each age class as a function of environmental variables using a wide variety of linear and nonlinear regression models depending on the assumed underlying variance structure. Regression-derived estimates of vital rates, and their variances, could then be substituted into the stochastic matrix population model. These models, then, could be used to predict and assess the responses of RGSM vital rates, and populations, to temporal and spatial variation in environmental conditions and to management actions.

It is worth noting that this approach, that of developing a mechanistic population model and using it to assess population responses to environmental conditions, also was recommended by the External Expert Panelists convened in the 2015 Rio Grande Silvery Minnow Population Monitoring Workshop (Hubert et al. 2016).

Management Application

DEMOGRAPHIC RATES AND ENVIRONMENTAL FACTORS

MANAGEMENT APPLICATION

To manage RGSM and most effectively allocate water and other resources, it is necessary to move beyond correlational analyses of RGSM abundance, reproductive success, etc., to understanding how exactly specific actions affect abundance, survival, and reproductive success.

Current RGSM management and habitat restoration activities, including the Hydrobiological Objectives with potential water management strategies for RGSM production and survival (USFWS 2016), are based on correlation. These correlational studies relate temporal and spatial variation in RGSM abundance (i.e., fall CPUE) with variation in environmental conditions and are valuable in identifying possible causes for variation in RGSM populations, but they do not, nor can they be used to, imply causal relationships. Further, it is unclear exactly how, for example, the magnitude of the snowmelt hydrograph affects RGSM abundance: is it through spawning habitat, survival of early life-history stages, or food availability? Therefore, management actions may be imprecise, and their effectiveness can be compromised. Modeling population vital rates (age-specific survival and fecundity) as a function of environmental variables will provide a greater understanding of how RGSM populations response to management and environmental change: is the response due to increased reproductive success, or to an increase in survival of key life-history stages? This understanding can lead to increased effectiveness of management actions.

Recovery Application

DEMOGRAPHIC RATES AND ENVIRONMENTAL FACTORS RECOVERY APPLICATION
Recovery goals for silvery minnow provide explicit abundance (CPUE) and reproductive success criteria for prevention of extinction and eventual downlisting. These goals also explicitly recognize the importance of silvery minnow populations within difference reaches of the MRG and establishing additional populations elsewhere. Understanding how silvery minnow abundance and population vital rates respond to temporal and spatial variation in environmental conditions will facilitate recovery in the MRG and will also provide useful insight into conditions required for re-establishment of silvery minnow in other portions of its historic range.

Recovery goals for the RGSM require self-sustaining populations that meet specific abundance, reproductive, and permanency criteria within the MRG and, ultimately, establishment of viable populations in other portions of the species historic range. Meeting these criteria will require manipulation of river flows and habitat restoration. At present, several studies show associations between RGSM abundance and environmental variables such as various elements of the MRG hydrograph. However, the mechanisms for RGSM population responses are not known. Modeling responses of population vital rates as a function of environmental variables will provide a greater understanding of how RGSM abundance, survival, and reproductive success are responds to temporal and spatial variation in environmental conditions. This will facilitate recovery by directing management activities toward creating or resolving specific conditions and it will allow better use of resources directed to management and research.

Study Plan Considerations

The ISP recommends that population vital rates (age-specific survival and fecundity rates) as well as CPUE data should be modeled as a function of broad-scale hydrologic variables, mesohabitat type, and abiotic factors that may vary across mesohabitat types (e.g., salinity, turbidity, water depth, local flow rates, etc.). These models should explicitly explore the inclusion of mesohabitat-type and reach as covariates. If age-specific survival and fecundity rates are available to fully parameterize a stochastic population matrix model, initial modeling exercises could be conducted with existing data.

Once age-specific survival and fecundity rates have been modeled as a function of scale hydrologic variables, mesohabitat type, and abiotic factors, the ISP suggests that field studies could be used to validate and refine the models. These studies would take advantage of natural temporal and spatial variation in candidate response variables, including age-specific survival and fecundity, reproductive output, and abundance to further evaluate the effects of environmental covariates (predictor variables). These studies, primarily based on inferences drawn from regression type models, are appropriately viewed as correlational studies. The size (time frame, number of samples, etc.) of the study can be determined with prospective power analysis, based on the precision desired, using estimates of CPUE and population vital rates, as well as estimates of their variability, from existing data.

Once mechanistic relationships between environmental factors and abundance and population vital rates are understood, the ISP suggests that hypothesis-based experimental studies could be conducted under controlled conditions at the Los Lunas or Albuquerque BioPark hatchery facilities. These studies would, of necessity, be limited to those factors that can be simulated or manipulated, but the results would help elucidate exact causal mechanisms and would have greater predicative power than those obtained from observational studies.

Priority Ranking

Addressing critical scientific uncertainty #5 is considered a Level 1 Priority (Table 11) and was among the most important management-relevant scientific uncertainties identified for the RGSM.

Table 11. Study framework attributes for critical scientific uncertainties for the Rio Grande Silvery Minnow.

Uncertainty Statement/Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Recommended Priority
What are the key life-history sensitivities of RGSM and which age-specific survival and fecundity rates most affect the rate of population change?	• Sensitivity and elasticity analyses identify aspects of RGSM life history that have the greatest effect on rates of population change • Coupled with relevant hydrologic and environmental covariates these analyses can facilitate understanding of management actions	• From existing data, and data to be conducted in other studies, construct stochastic life-history matrices (age-specific survival and fecundity rates, and their variances) • Calculate sensitivities and elasticities	• Elasticity and sensitivity of age-specific survival and fecundity rates • Responses of sensitivities, elasticities, and population growth rate to change in hydrological and environmental covariates	• Multi-year • All MGR reaches	• Incorporate reproducible research practices • Initial parameterization, without variances, may be possible from existing data, but new data especially for fecundity are necessary • Stochastic matrix models require simulation for solution and assessment	Level 1
What are the survival rates, and estimates of their natural (process) variability, of different age classes of RGSM?	• Need to know age structure to estimate reproductive output • Survival estimates are needed to understand population responses to management • Mechanistically relate population responses to hydrologic and other environmental variables to survival of specific age classes	Field studies and existing data: • From field counts, calculate the ratio(s) of successive age classes as a measure of survival • Collect, measure, and age small number of RGSM to verify length-age relationships • Assess intra-annual (among months) mortality of RGSM • Use regression (catch curve) measures of survival within and among years Experimental studies: • Determine RGSM growth and survival rates in relation to temperature	Field studies and existing data: • Numbers and lengths of fish captured in field sampling • Length and age of fish collected for length-age verification • Collect, measure, and age small number of RGSM Experimental studies: • Length, age, growth rate, and survival	• Multi-year • All MGR reaches	• Incorporate reproducible research practices • Use R Project library mxdist, or similar method, to assess size-frequency information to be used in survival estimates • Need to verify length as indirect measure of age • Assess information separately for each mesohabitat type • Estimates of process uncertainty are necessary	Level 1
Age-specific fecundities of wild RGSM are poorly known: what is the fecundity of RGSM and how does it vary with age or size?	• Need to know fecundity and timing of reproduction to understand population responses to management • Mechanistically relate population responses to hydrologic and other environmental variables to fecundity of specific age classes	Field studies and existing data: • Collect gravid females to estimate fecundity rates • Collect, measure, and age small number of RGSM for histological analysis of ovaries Experimental studies: • Move wild-caught fish to an experimental facility to induce spawning for fecundity estimates • In situ spawning for fecundity estimates	Field studies: • Lengths and ages of collected fish • Counts of ova, measurements of ova sizes • Histological analyses of ovaries Experimental studies: • Lengths and ages of collected fish • Counts of released ova	• Multi-year • All MGR reaches	• Incorporate reproducible research practices • Initial parameterization, without variances, may be possible from existing data, but new data are necessary • Estimates of process uncertainty are necessary • Design should include measures to assess presence of fractional spawning • Samples, ideally, will spawn the length of the spawning season to determine presence and importance of fractional spawning	Level 1

Table 11. Study framework attributes for critical scientific uncertainties for the Rio Grande Silvery Minnow.

Uncertainty Statement/Study Question	Management Relevance	Study Type	Measurement Attributes	Temporal and/or Spatial Scale	Study Design Considerations	Recommended Priority
What is the relationship between the annual CPUE index and true RGSM population size?	• CPUE index is not a reliable measure of true RGSM abundance • Accuracy of CPUE index likely varies over time and across mesohabitats	Field studies: • Compare current CPUE index with catch estimates from depletion sampling to calibrate index • Compare RGSM catches made with seines used in the standard sampling program with catches made by a very fine-mesh seine • Compare fyke net catches with seine catches in floodplains to assess gear-size selectivity Analyses of existing data: • Calculate CPUE (and variances) separately for each mesohabitat type	Field studies: • Number of fish captured, including mean and variance of catches • Length of fish captured, including mean and variance of sizes of fish Analyses of existing data: • Mesohabitat specific indices of CPUE (plus variances) and an overall index weighted and stratified by mesohabitat type	• Multi-year • All MGR reaches	• Incorporate reproducible research practices • Use R Project library mxdist, or similar method, to assess size-frequency information • Assess information separately for each mesohabitat type	Level 1
How do key RGSM vital rates vary as a function of hydrologic factors, abiotic environmental factors, and biotic factors?	• Model RGSM (matrix model) populations as a function of key hydrologic and other variables to predict and assess population responses to management actions	Field studies: • Number and lengths of RGSM captured in standard sampling compared with model predictions based on hydrology and other environmental variables Experimental studies: • Reproduction, survival, population growth of RGSM in response to experimental manipulation of environmental variables in research facility settings	Field studies: • Number and length of RGSM captured in field sampling • Measurements of hydrologic and environmental variables believed to affect RGSM populations Experimental studies: • Number and length of RGSM and population growth rates • Measurements of manipulated environmental parameters	• Multi-year • All MGR reaches	• Incorporate reproducible research practices • Field samples are necessary to test and refine models • Once stochastic matrix models are parameterized, initial exploration of effects of environmental variables may be conducted using existing data in retrospective analyses	Level 1

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