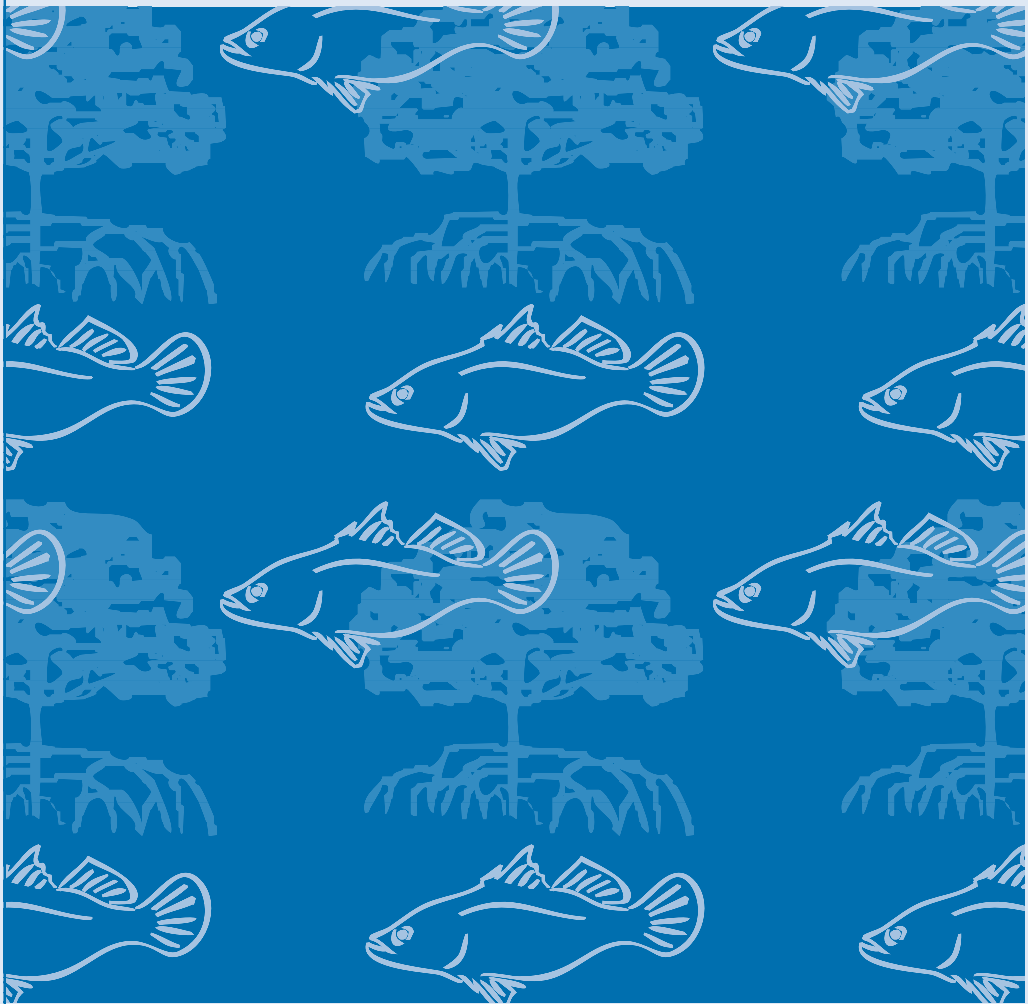
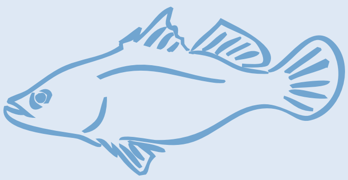
Queensland **the Smart State**

Fish Habitat Guideline FHG 006

Fisheries Guidelines for Fish-Friendly Structures





Kurt Derbyshire

July 2006

Queensland Government
Department of **Primary Industries and Fisheries**

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FHG 001:

Cotterell, E.J. (1998) *Fish Passage in Streams: Fisheries Guidelines for Design of Stream Crossings,* Department of Primary Industries, Queensland, Fish Habitat Guideline FHG 001, 37 pp.

FHG 002:

Hopkins, E., White, M. and Clarke, A. (1998) *Restoration of Fish Habitats: Fisheries Guidelines for Marine Areas,* Department of Primary Industries, Queensland, Fish Habitat Guideline FHG 002, 44 pp.

FHG 003:

Bavins, M., Couchman, D. and Beumer, J. (2000) *Fisheries Guidelines for Fish Habitat Buffer Zones,* Department of Primary Industries, Queensland, Fish Habitat Guideline FHG 003, 39 pp.

FHG 004:

Clarke, A. and Johns, L. (2002) *Mangrove Nurseries: Construction, Propagation and Planting: Fisheries Guidelines,* Department of Primary Industries, Queensland, Fish Habitat Guideline FHG 004, 32 pp.

FHG 005:

Challen, S. and Long, P. (2004) *Fisheries Guidelines for Managing Ponded Pastures,* Department of Primary Industries, Queensland, Fish Habitat Guideline FHG 005, pp 27.

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The Department of Primary Industries and Fisheries (DPI&F) seeks to maximise the economic potential of Queensland's primary industries on a sustainable basis.

This publication provides guidelines for the planning, design, construction and operation of aquatic infrastructure so that it is 'fish-friendly'.

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About this guideline

In May 2004, the Department of Primary Industries and Fisheries hosted the *Urban Mangrove Management Workshop*, sponsored by The Port of Brisbane Corporation, the Brisbane Airport Corporation Ltd, and the Brisbane City Council. The purpose of the Workshop was to discuss best practice mangrove management in urban waterways to sustain fisheries productivity. An outcome from the Workshop was a commitment from DPI&F to: *Develop fish habitat guidelines to promote stakeholder use of fish-friendly, soft engineering solutions for structures placed in estuaries and embayments*. This document meets that commitment.

The purpose of this document is to encourage consideration of, and provide guidance for, the planning, design, construction and operation of aquatic infrastructure so that it is 'fish-friendly'. Proponents intending to develop aquatic infrastructure should use these guidelines to help ensure that impacts on fish and fish habitats are minimised, and that opportunities for the enhancement of structures as fish habitat are maximised. The document also provides guidance in making existing structures fish-friendly. The guidelines are *not* intended to encourage proliferation of additional aquatic infrastructure beyond a level required to serve primary infrastructure needs. This document will be of use to planners, designers, engineers, ecologists, consultants, developers, local governments, educators, students, researchers, community groups and managers.

Aquatic infrastructure commonly found in Queensland waters, and fish-friendly issues associated with such structures, are discussed in these guidelines. Structures such as artificial reefs, fishways and stream crossings that are the subject of other DPI&F publications are not included (see Chapter 2).

These guidelines do not provide complete design requirements nor do they replace regulatory standards for aquatic infrastructure, but they will complement such standards and highlight the fish habitat management implications of infrastructure design. All relevant Standards and/or Codes should be consulted and applied where necessary. This is not a statutory or regulatory document. Approvals for aquatic infrastructure may be required from local, State and Australian Government agencies.

Using this guideline to select fish-friendly options

Readers should consider the principles and the full range of design features included in the guidelines — rather than only consulting individual sections — to ensure that the benefits of fish-friendly features are maximised.

The guidelines include:

- An introductory discussion of fish-friendly structures.
- A set of principles that provide a guiding fish-friendly philosophy.
- A series of design features, including:
    - design considerations that can be applied generally;
    - designs for specific types of infrastructure; and
    - artificial habitat modules designed to enhance infrastructure as fish habitat.
- A fish-friendly structures checklist (Appendix 1).

It is important that the document be considered in its entirety so that design decisions are informed by guiding principles and general design concepts as well as specific design measures. Perusal of individual sections in isolation is not recommended. Nonetheless, information particular to specific infrastructure types is presented, including for the most common structures in Queensland waters:

- Jetties and pontoons (Chapter 4.2.2)
- Boat ramps (Chapter 4.2.3)
- Revetments (Chapter 4.2.4).

The concept of fish-friendly structures is an emerging field, with new research and information progressively becoming available. These guidelines will be periodically updated to reflect research advances and stakeholder feedback. In addition, the guidelines will link with DPI&F's *Urban Fish Habitat Management Research Program*, which includes a research stream focused on artificial structures as fish habitats (Department of Primary Industries and Fisheries, 2005). The web version of the guidelines on the DPI&F website (www.dpi.qld.gov.au) is the most current version.

Readers are encouraged to provide feedback on these guidelines to help inform future editions. Please address any comments or enquiries to:

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1. Introduction

1.1 Background

In Australia, most of the population lives near the coast and most developments occur in coastal catchments (Glasby and Connell, 1999). Recent population growth in Queensland is higher than in any other state in Australia, and is concentrated in urban coastal centres (Department of Local Government Planning Sport and Recreation, 2005a). In particular, south east Queensland (including the coastal strip from the Sunshine Coast to the Gold Coast) is the fastest-growing metropolitan region in Australia, with more than one quarter of Australia's population growth to the year 2026 expected to occur there, resulting in a regional population of 3.7 million people (Department of Local Government Planning Sport and Recreation, 2005b).

Aquatic infrastructure is an important part of the outdoor lifestyle in Queensland. Ports, marinas, jetties, boat ramps, breakwaters, seawalls and the like contribute significantly to enjoyment of Queensland's aquatic environments and to the State's economy. At the same time, construction and operation of these structures can have impacts on natural ecosystems and on the benefits that these tidal and subtidal ecosystems provide to the community. While already widespread along Queensland's shorelines, the extent of aquatic infrastructure is likely to increase with growing coastal population pressures.

Government intends to respond to the challenge of growth and change in Queensland by managing development in a sustainable way to protect and enhance quality of life (Department of Local Government Planning Sport and Recreation, 2005b). Given the predicted increase in the urbanisation of coastal areas, coastal infrastructure should be designed for minimal impacts on fish and fish habitats and opportunities for beneficial habitat uses of structures be capitalised on.

1.2 What is a fish-friendly structure?

Fish-friendly structures are those that:

- Cause minimal disturbance to the existing environment
- Incorporate design features that provide an enhanced habitat in which fish can live.

Throughout this document, the term 'fish' is used in its broadest sense, as defined in Section 5 of the *Fisheries Act 1994* and includes finfish, crustaceans, molluscs, echinoderms, worms, etc.

Fish-friendly structures should emulate the values that natural habitats provide for fish, and should cause minimal disturbance to these habitats. Natural fish habitats, including *Melaleuca*, saltmarsh, mud banks, sand bars, mangroves, seagrass, algae, rocks and snags provide values such as shelter, food and surfaces for organisms to settle on (Figure 1). Natural habitats and their values should be maintained wherever possible.

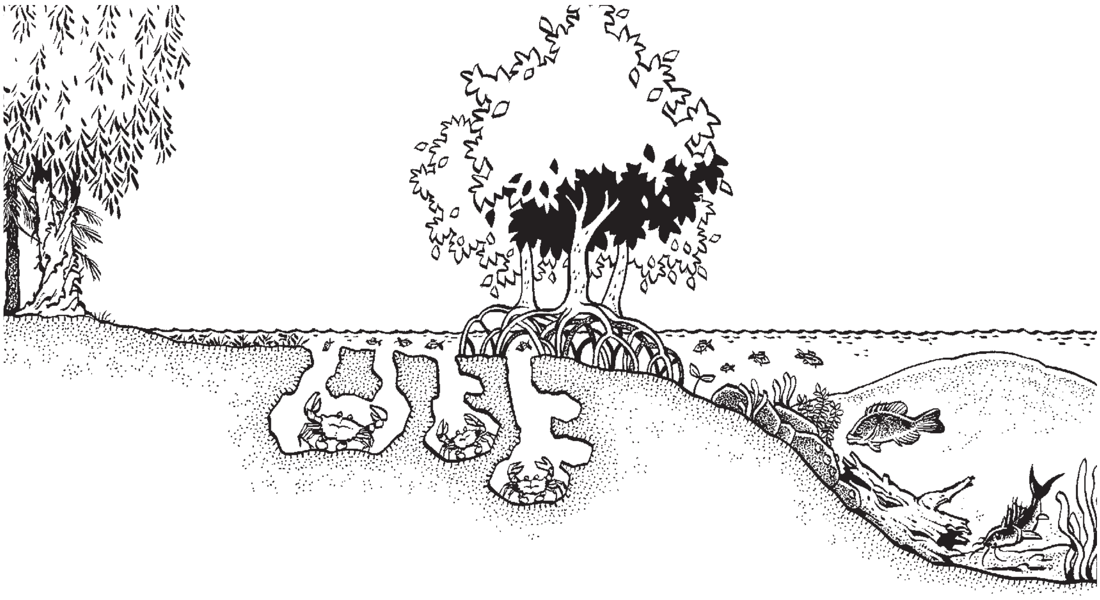

Figure 1. Natural fish habitats.

Usually, the primary purpose of aquatic infrastructure is not to provide fish habitat, but it may, nonetheless, do so simply by providing new substrates for fish to exploit. By incorporating additional fish-friendly features, the structure may provide further opportunities for fish to live, feed and grow. Hence, a jetty that is primarily for berthing vessels may also function as an enhanced fish habitat if appropriate design features are incorporated. Fish-friendly structures may also provide additional access for fishing.

A schematic representation of the major fish-friendly structures concepts developed throughout these guidelines is shown in Figure 2.

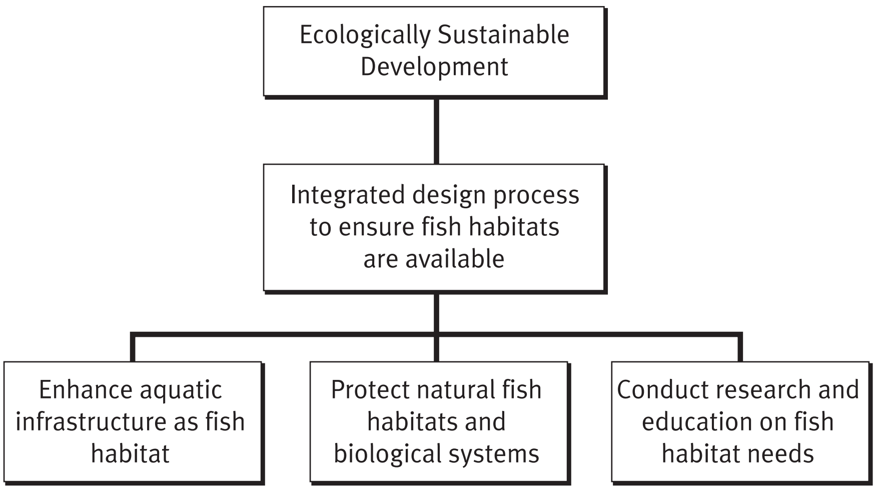

Figure 2. Fish-friendly structures overview.

1.3 Benefits of fish-friendly structures

Incorporation of fish-friendly elements into the design of structures can help to provide a balance between urban development and maintenance, or enhancement, of the productive capacity of fish habitats for Queensland's fisheries. Fish-friendly structures can minimise development impacts by providing additional habitats for fish, while causing minimal disturbance to natural fish habitats. The effect of such structures may range from simply concentrating existing fish numbers, through to increasing fisheries productivity by providing opportunities for additional survival, growth and reproduction of fish. The additional habitats provided by fish-friendly structures may help to partially mitigate the loss of natural habitats due to the impacts of development, although such structures should not be used to justify disturbance of natural habitats. Suitable aquatic infrastructure may also provide the only adequate local site for land-based fishing, an important consideration in ensuring equitable access to fisheries resources.

1.3.1 Why are fish attracted to artificial structures?

The additional fish habitats provided by artificial structures attract fish for many reasons, including protection from predators, feeding opportunities, shelter from currents, and extra settlement habitat for recruitment. Both the presence of artificial structures and the organisms growing on those structures influence associated fish assemblages. The physical characteristics (material, complexity, size, etc) of the structure also influence fish assemblages. The location of artificial structures is important in encouraging biological exchange between habitats. Exposure of structures to currents carrying larvae and other biological material may be significant. Fish communities found near infrastructure may differ considerably depending on the nature of the structure and its location.

Artificial structures increase habitat diversity by providing ‘hard’ surfaces in largely ‘soft’ natural habitats (United States Army Corps of Engineers, 1989). These hard artificial surfaces develop diverse, productive biological communities (United States Army Corps of Engineers, 1993) and form part of the complex of habitats available locally to fish. Structures such as jetties and seawalls are common in many developed estuaries and bays, and provide potential additional fish habitat over a relatively large spatial scale (Clynick, 2002). Even within a single species, a range of habitats spread through many localities may be important for fish to complete their life-cycles, and suitable artificial structures may contribute to this habitat mosaic.

Case study: mangrove jack (Russell et al., 2003)

Artificial structures provide habitat for the iconic mangrove jack (*Lutjanus argentimaculatus*) in Queensland. This highly prized recreational sport and food fish is also caught in the commercial reef line fishery. Mangrove jack have a complex life history, with distinct habitat requirements at different ages. Adults are found in offshore waters, including the Great Barrier Reef, and probably spawn in deep water. Young fish live in rivers and inshore coastal areas, including tidal and freshwater swamps. Rocks and snags are the preferred mangrove jack habitats in the estuarine and lower freshwater reaches of Queensland wet tropics streams, and very few fish are in open water. Many of these streams have banks armoured with rock revetment to prevent erosion (Figure 3). Juvenile mangrove jack use the crevices between the rocks of these revetments as refuge habitat (Figure 4). While the primary purpose of the infrastructure is to protect stream banks from erosion, these structures also provide fish-friendly benefits as habitat for juvenile mangrove jack.

Figure 3. Rock revetment, Russell River. Photo John Russell DPI&F

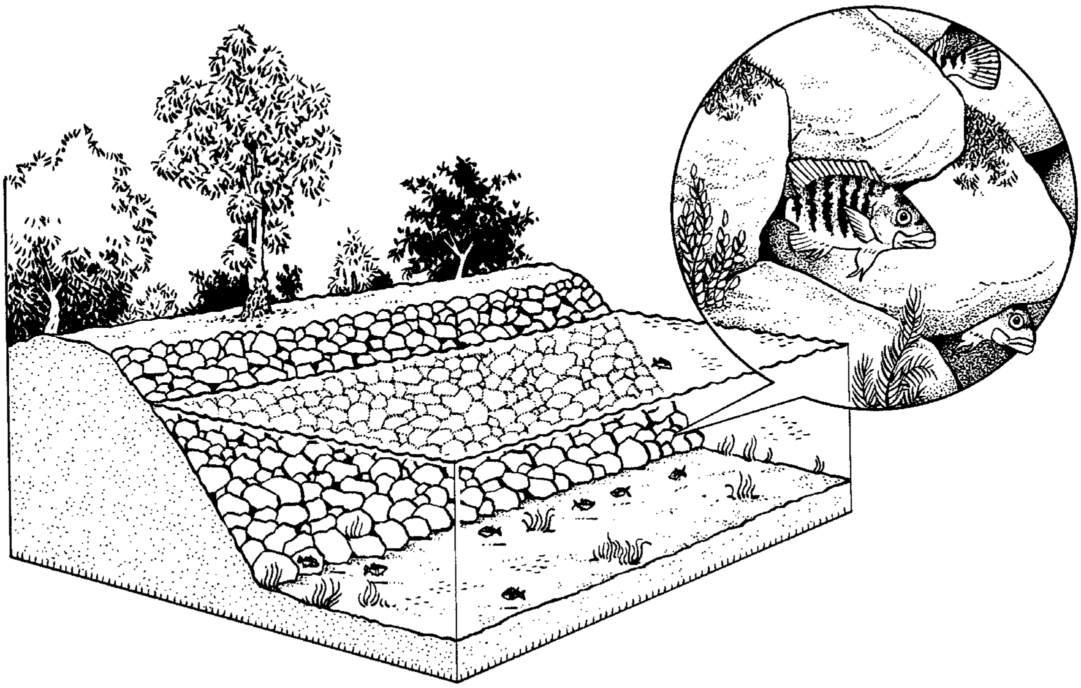

Figure 4. Revetment habitat for juvenile mangrove jack.

In some locations, a smooth surface treatment above water level may be required to discourage usage of habitat by pest species such as rats.

1.4 Impacts of aquatic infrastructure

There is a spectrum of thought on the merits of artificial structures in aquatic environments. Some assume that addition of artificial habitats will automatically be better for fish. At the other end of the continuum, some fear that any change from the natural state is inevitably bad. Arguments about whether more is necessarily better, or whether change is necessarily bad, may be more moral than scientific, and tend to be case-specific (Glasby and Connell, 1999). These guidelines recognise that aquatic infrastructure is an important part of the built environment and that all reasonable efforts should be made to reduce their impacts and increase benefits.

It is clear, though, that artificial structures can potentially have detrimental impacts on natural systems, including:

- Loss, fragmentation and damage of natural habitats.
- Disruption of natural water flows (Burns, 2001).
- Increased predation pressure, especially on younger fish by larger predators (United States Army Corps of Engineers, 1993).
- Changes in natural assemblages of organisms (Connell and Glasby, 1999).
- Interference with connectivity between natural habitats, whereby artificial structures 'capture' fish bound for natural habitats (Pears and Williams, 2005).
- Opportunities for colonisation by invasive species, causing 'biological pollution' (Elliot, 2003).

Measures described in these guidelines will help to alleviate the types of impacts listed above, although some issues may be more difficult to address than others. The risk of biological pollution, in particular, requires further research and monitoring effort. There is concern that aquatic infrastructure may provide artificial 'stepping stones' for biota, including pest species, to invade environments that would otherwise not support these (Glasby and Connell, 1999).

Regardless of potential risks, it is likely that the extent of aquatic infrastructure in Queensland will grow with increased coastal development. It is prudent and timely, therefore, to recognise risk and to maximise the potential benefits of aquatic infrastructure through the use of fish-friendly designs.

1.5 Research review: Artificial structures as fish habitats

There is a body of research into the usefulness of artificial structures as fish habitat, particularly comparisons of artificial structures with natural habitats. The results of the various studies are sometimes contradictory, and include structures not considered in this document. This section provides a brief discussion of the research and should not be considered a comprehensive review.

A number of studies have concluded that finfish abundance is higher in areas modified with complex artificial structure than in areas without such structures. Catch rates of finfish were higher at habitat-enhanced piers than at unmodified piers in Piedmont Carolina (USA) reservoirs (Barwick et al., 2004). Hernandez et al. (2001) found that rock jetties on the Louisiana (USA) coast may act as a refuge area for larval and juvenile finfish in the absence of other structurally complex habitat. Cappo (1995) found that a pier in the Gulf of St Vincent, South Australia, provided important habitat for morwong and that rough, hard substrates (including limestone blocks) under the pier were specifically used as sleeping, sheltering and feeding sites by fish. Rilov and Benayahu (1998) found that larger and more complex pylons on oil jetties in the Red Sea supported more abundant and diverse finfish assemblages. Hair et al. (1994) found that artificial structures installed under a wide range of conditions may benefit a greater number of species, and proposed that additional settlement habitat would be of most benefit where larvae are plentiful and habitat is limited or has been lost.

Management implication: Fish-friendly structures can provide additional habitats for fish. This may be of most benefit where there is a plentiful supply of fish larvae and limited nearby good-quality natural fish habitat.

Artificial structures in marinas in Sydney Harbour support similar finfish assemblages to nearby rocky reefs (Clynick, 2005). Finfish assemblages were strongly correlated with the amount of epibiota on marina pilings, although few differences in assemblages were observed between structures made of different materials. In addition, differences between locations were greater than differences between structures within a location. Clynick (2005) also found that numbers and species of finfish around both natural and artificial structures decreased with distance from the estuary mouth. This may indicate that finfish assemblages are less influenced by the type of structure present than by exposure to ocean currents. The relationship between natural recruitment sources and artificial structures requires more research, and raises the question of whether aquatic infrastructure can feasibly be located to maximise recruitment potential given its primary infrastructure purpose.

Management implication: Infrastructure must be located to serve its primary purpose. Can structures also be located to increase their benefits as fish habitat?

There is ongoing research into comparisons of epibiota on adjacent natural and artificial habitats in Sydney Harbour, Australia. Connell (2001) found that pilings and pontoons create new habitats for epibiota compared to adjacent rocky reefs. Connell and Glasby (1999) found that aquatic infrastructure may increase the abundance and diversity of subtidal epibiota in shallow estuarine areas. Chapman and Bulleri (2003) found that seawalls and rocky shores supported a similar suite of species, although the spatial distribution and relative abundance of many species varied between habitats. Moreira (2005) found that limpet reproductive output was greater on rocky shores than on seawalls, as seawalls support mostly juvenile limpets. Bulleri (2005) found that the intertidal invertebrate assemblages that developed in cleared areas made on seawalls and on rocky shores were different. Bulleri concluded that intrinsic differences (e.g. topography, weathering, shape and extent of surfaces) between artificial and natural habitats could lead to establishment of distinct algal and invertebrate assemblages. These studies suggest that, while artificial structures may provide new habitat for epibiota, they may not act as exact surrogates for natural habitats and should not be regarded as a substitute for natural habitats (Chapman and Bulleri, 2003).

Management implication: Artificial structures should not be regarded as substitutes for natural fish habitats and should not be used to justify disturbance of natural habitats.

Epibiotic assemblages may also differ between structures that are fixed and those that float (Glasby, 2001; Holloway and Connell, 2002). Organisms on floating structures such as pontoons are exposed to a relatively uniform light regime, whereas light exposure on fixed structures varies with the tide. Pontoons are constantly immersed in water and are not exposed to tidal range in the manner of fixed structures such as jetties and pylons. Fixed structures are exposed to a greater variety of larvae through a range of depths as the tide changes, while pontoons are exposed only to larvae in surface waters (Holloway and Connell, 2002). People (2006) found that mussel beds growing on artificial structures provide a secondary substrate for other biota, and that these more diverse assemblages varied according to the type of structure and its location. Based on observed differences in epibiota on seawalls under wharves compared to those not under wharves, Blockley (2005) asserts that managers should consider the combined impacts of different structures on organisms.

Management implication: The combined impacts of different types of co-located structures on fish need to be considered.

Boardwalks have been found to be associated with localised disturbances to macrofauna in mangrove forests (Kelaher et al., 1998a). Skilleter and Warren (2000) found that even small-scale changes in physical structure can cause significant changes to macrobenthic communities. They suggest that management should focus on minimising modification of the physical structure and integrity of the ecosystem, rather than just concentrating on prevention of loss of patches of habitat. This approach may help to maintain the physical heterogeneity of the habitat and reduce any impacts on the abundance and diversity of fauna.

Management implication: Changes caused by artificial structures to the physical structure and integrity of natural systems should be minimised.

1.6 The importance of fisheries and fish habitats

Queensland's fish habitats belong to an extensive and diverse aquatic ecosystem that is an important part of the State's culture, lifestyle and economy. Queensland's fresh and marine waters support commercial, recreational and traditional fisheries that harvest over 31 500 t of fish each year (Williams, 2002).

Commercial fisheries make a significant contribution to the national and State economy. Almost 20% of Australia's commercial fishing fleet is based in Queensland, and the economy of many coastal towns is highly reliant on this fleet, as is the seafood-consuming public.

Recreational fishing is an important part of the lifestyle of many Queenslanders and also contributes to the State's economy. Around 735 000 recreational fishers take home almost 8500 t of fish annually in Queensland.

Traditional fishing activities are widely practiced by indigenous peoples throughout the State, particularly in northern coastal communities. Fisheries resources are of critical importance to indigenous communities, not only as food but also for purposes of culture, spirituality, trade, health and education (Sheppard, 2004).

To maintain and enhance sustainable fisheries production in Queensland, fish need access to a range of fish habitats for spawning, migration, feeding, growth and shelter. Maintenance of, and accessibility to, a broad range of habitat types, attributes and functions are therefore critical to fisheries productivity.

1.7 The role of DPI&F

The mission of DPI&F is to maximise the economic potential of Queensland's primary industries on a sustainable basis, including the sustainable management and economic development of Queensland's fisheries. Fisheries in Queensland are managed by DPI&F through the provisions of the *Fisheries Act 1994* (the Act). The main purpose of the Act is to provide for the use, conservation and enhancement of the community's fisheries resources and fish habitats in a way that seeks to apply and balance the principles of Ecologically Sustainable Development (ESD).

DPI&F undertakes a variety of activities to achieve the objectives of the Act, including management of fish habitats. The Act provides for, amongst other things:

- Protection of all marine plants (mangroves, seagrass, saltmarsh, etc), which may not be disturbed without approval. This protection recognises the dependence on marine plants of many fisheries species that support the commercial, recreational and indigenous fishing sectors.
- The declaration and management of declared fish habitat areas (FHAs). FHAs protect fish habitats of all types (vegetation, sand bars, mud banks, rock beds, etc.) that are critical to sustaining the State's fisheries. Development in FHAs is severely restricted, being largely limited to maintenance of existing structures and to further development of community facilities such as public boat ramps and jetties. A network of 71 FHAs protects some 800 000 ha of coastal and estuarine fish habitats in Queensland, while allowing day-to-day community uses such as lawful fishing and boating activities.
- The restoration of disturbed fish habitats.

Beyond its legislative responsibilities, DPI&F undertakes and encourages research and education activities, and provides advice to planning and assessment processes as part of its undertaking to sustainably manage and develop Queensland's fisheries. Fish-friendly research is supported by DPI&F through its Urban Fish Habitat Management Research Program (UFHMRP). The UFHMRP: (a) provides direction for applied research that will contribute to sustainable management of Queensland's urban fish habitats; (b) prioritises urban fish habitat research issues and identifies potential research projects (including fish-friendly research); and (c) provides a mechanism to link smaller projects to a larger research framework, and to encourage awareness and information exchange across projects.

DPI&F currently offers a Marine Fish Habitat Scholarship Program for Honours research, which is linked to the UFHMRP. Incorporation of fish-friendly designs into developments is one of the fish habitat targets of the Department's *Fisheries and Aquaculture Research and Development Priorities for 2005–2009*.

DPI&F has developed a series of operational policies and guidelines (such as this document) for management of fish habitats in Queensland. More information on the department's fish habitat management activities is available on the DPI&F website (http://www.dpi.qld.gov.au).

The use of fish-friendly structures as outlined in these guidelines will contribute to finding a balance between the development needs of the community and sustainable fisheries productivity, and will meet the Queensland Government's Smart State vision of using innovation to increase productive capacity (Department of the Premier and Cabinet 2005).

2. Scope

These guidelines contain fish-friendly measures for the planning, construction and operation of aquatic infrastructure such as jetties, piers, docks, breakwaters, boat ramps, revetments, pontoons, seawalls, boat harbours, groynes, boardwalks, fishing platforms, moorings, etc. 'Soft engineering' alternatives to aquatic infrastructure including beach nourishment and use of dredge spoil are also presented.

Fish-friendly issues such as artificial habitat enhancement, maintenance of fish migration and water circulation, reduction of direct impacts on natural habitats, and provision of fishing access are discussed. Related issues, such as mitigation for habitat loss, provision of adequate buffers and restoration of disturbed habitats, are considered, but readers should refer to Dixon and Beumer (2002), Bavins et al. (2000) and Hopkins et al. (1998) respectively for further information.

The following structures and issues are *not* discussed in this guideline:

- *Artificial reefs.* Artificial reefs that do not have a primary infrastructure purpose are not considered in these guidelines[1]. Such structures are usually intended to attract fish and enhance fishery catch in their own right. Jebreen (2001) discusses artificial reefs in the Queensland context.
- *Constructed or modified waterways.* These structures, including drainage waterways, may be fitted with pools, riffles and other features to provide fish habitat and encourage fish movement. See Cotterell (1998) for information on fish passage in streams, and Hopkins et al. (1998) for information on restoration of fish habitats.
- *Erosion and sediment control* measures may include fish-friendly management practices during construction and operation of infrastructure. For more information on erosion and sediment control best practice, refer to the *Soil Erosion and Sediment Control Engineering Guidelines for Queensland Construction Sites* (International Erosion Control Association Australia, http://www.ieaust.org.au).
- *Fishways.* These structures are designed to facilitate fish movement over waterway barriers (dams, weirs, etc). For more information, refer to Peterken (2001).
- *Floodgates.* Floodgates can reduce fish access to important habitats. These structures will be the subject of a forthcoming DPI&F guideline.
- *Screening systems.* These structures can prevent fish from moving to inappropriate places (e.g. power station turbine intakes), but are not discussed here.
- *Stream crossings.* A range of measures can be taken to facilitate fish passage through stream crossings (culverts, causeways, etc). For more information, refer to Cotterell (1998).

[1] These guidelines include discussion of artificial reef structures that have a primary infrastructure purpose, or where artificial reef 'modules' are used to enhance infrastructure as fish habitat.

3. Principles

The following set of 11 principles provides a guiding philosophy for fish-friendly structures. These principles should be used to inform all aspects of infrastructure planning, design and operation to create fish-friendly structures, and are reflected in the design features that follow later in the guidelines.

Principle 1 (Overarching Principle): *Implement ESD.*

Development of aquatic infrastructure should be in accordance with the principles of ESD. This requires consideration not only of structure design, but also protection and enhancement of natural fish habitats and biological processes (a holistic approach). An ESD approach to aquatic infrastructure development will help to achieve the proper use, conservation and enhancement of fish habitats and fisheries resources.

Principle 2: *Avoid sensitive/critical fish habitats.*

Structures should be located away from important undisturbed fish habitats wherever possible. Proposals should avoid replacing naturally productive fish habitats with artificial ones if possible, as the impacts of artificial structures on natural systems may outweigh any potential benefits. Site selection for aquatic infrastructure should therefore be considered a critical part of the development planning process. Development that does not require a coastal or aquatic location should not be located there. DPI&F policy does not support disturbance of marine plants and/or FHAs where they are not fully justified and where reasonable alternatives with lesser impact exist (Couchman and Beumer, 2002; Zeller and Beumer, 1996).

Principle 3: *Artificial structures should not be considered as surrogates for natural habitats.*

Artificial and natural habitats may have distinctly different biological assemblages, and should be regarded as different parts of a mosaic of habitats available to fish. The presence of an artificial structure should not be used as justification to remove natural habitats, nor should incorporation of fish-friendly features be used as justification for damaging natural fish habitats where such damage would not otherwise be allowed. Fish-friendly structures may, however, be considered as possible mitigation for loss of natural fish habitats. This would only apply where the proposed loss of habitat is justifiable, unavoidable and acceptable under relevant legislation and policy. DPI&F policy for mitigation of fish habitat loss is outlined in Dixon and Beumer (2002).

Principle 4: *Take an integrated approach to designing aquatic infrastructure.*

Fish-friendly consideration should be integral to project design, not additions made late in the planning and assessment process. Integrated designs would consider both protection of existing fish habitat values and enhancement of infrastructure as fish habitat. Integration of fish-friendly features into project design is likely to result in more successful outcomes for fish, fishers and developers. A fish-friendly project design may proceed through the development approval process more readily as less agency assessment effort is required and the possibility of further agency requirements is reduced.

Principle 5: *Minimise disturbance of fish habitats.*

In situations where damage to fish habitats cannot be avoided, design measures should be implemented to minimise impacts. Structures should cause the smallest amount of disturbance possible to natural habitats and biological processes. Minimal disturbance of natural habitats may also decrease future maintenance requirements (e.g. for mangrove trimming around infrastructure). Consideration should be given to whether infrastructure may need to be demolished in the future and how that would be done in a way that minimises fish habitat disturbance.

Principle 6: *Schedule works to avoid critical biological events.*

Construction works should be scheduled to avoid critical biological events such as flowering and fruiting of marine plants, and fish migration peaks. In general, the best time to schedule works is during autumn/winter; however, this may vary depending on the location of the works and the key species present. Proponents should seek advice from regional DPI&F officers regarding timing of critical biological events when planning construction schedules.

Principle 7: *Recognise the risks and benefits that artificial structures may bring.*

Artificial structures can have both beneficial and adverse effects on fish and fish habitats. The design of artificial structures should seek to maximise potential benefits to fisheries resources, while any adverse impacts should be avoided or minimised where possible.

Principle 8: *Improve the fish habitat values of existing structures.*

Consider enhancing existing structures with fish-friendly features. Notwithstanding Principle 4, opportunities to incorporate fish-friendly features into existing structures (e.g. during upgrade or maintenance works) should be taken if appropriate. Advantages of modifying existing structures include reduced cost compared with building new structures, and the potential for habitat enhancement over relatively large areas (e.g. in an area with a large marina or many marinas).

Principle 9: *Enhance fishing access.*

Many fishers do not have access to resources such as vessels for fishing. Access to land-based fishing sites provides additional opportunities for Queensland's many recreational fishers. Structures that incorporate fishing-friendly features, e.g. fishing platforms, will improve community access to fisheries resources. At the same time, structures should not obstruct or restrict fishing activities (e.g. through inappropriate location on fishing or bait collecting grounds).

Principle 10: *Conduct research and monitoring into the effects of fish-friendly structures.*

Research into the performance of fish-friendly structures — and into the effects generally of aquatic infrastructure — should be encouraged. Baseline inventories of existing fisheries resources will help to inform fish-friendly structure design. Monitoring of fisheries resources associated with aquatic structures may provide useful information to help guide future fish habitat management decisions. DPI&F has developed the Urban Fish Habitat Management Research Program (http://www.dpi.qld.gov.au), which identifies potential research projects including the use of artificial structures as fish habitats. Socio-economic evaluation of fish-friendly structures can reveal how society may benefit from particular projects (Milon, 1991).

Principle 11: *Educate and engage with the community.*

Opportunities should be taken to foster public awareness of fish-friendly structures and improve understanding of the links between fish and fish habitats. For example, development projects could have education programs (signs, brochures etc) that promote the purpose and benefits of any fish-friendly structures incorporated into the development. Community groups can also be involved in planning for fish-friendly structures, particularly structures intended for public use. Public consultation is best initiated early in the planning process (Gourlay et al., 2004).

4. Design features

Three levels of fish-friendly design are presented:

- general design features (broad design methodology);
- specific infrastructure designs (design features for particular types of infrastructure); and
- designs for artificial fish habitat modules.

Readers should consider information from all three design levels along with the preceding set of principles to inform design decision-making. The design features presented here seek to minimise disturbance of natural habitats and biological processes, while enhancing structures as habitats for fish.

4.1 General design features

This section outlines a broad design approach to yield fish-friendly outcomes for developments that require aquatic infrastructure. These considerations may be applied generally to a variety of structures.

Habitat quality. Good quality habitat will encourage more productive biological communities on a structure. Materials used should be as compatible with the natural environment as possible. Materials that encourage settlement and growth of epibiota may provide additional food and natural refuge for fish:

- **Natural materials** such as wood (untreated with chemicals) and rocks may generally provide more ‘natural’ habitat than artificial materials such as concrete, steel, vinyl and plastic (Department of Fisheries and Oceans, 2002).
- **Rocks** are especially durable and stable in marine environments and different rock sizes can provide a variety of interstitial spaces to accommodate different fish species and life-cycle stages (Lukens and Selberg, 2004).
- **Wood** may be less robust and long-lasting than desired in many situations. Where natural wood is not appropriate, recycled plastic composite ‘timber’ may be an option.
- **Concrete** can provide a relatively good substrate for growth of epibiota, particularly if sloping and textured. It is durable and stable in the marine environment.
- **Fibreglass** appears to support less rapid development of epibiota than concrete (Lukens and Selberg, 2004). This may be due to the relatively smooth surface of fibreglass.
- **Electrodeposition** is the process of accreting calcium and magnesium salts on a cathode by direct electric current (Lukens and Selberg, 2004). Artificial structures can be formed using a modular wire mesh cathode, with power usually supplied by wind or solar energy. This technique is largely experimental and requires further research (Lukens and Selberg, 2004).
- **Geotextile** fabric can support rapid growth of diverse marine epibiota. Jackson et al. (2005) found that non-woven geotextile fabric supported more epibiota than woven fabric or nearby rock structures in Arabian Gulf waters.

Case study: Terrafix® geotextile

In 1999–2000, the Gold Coast City Council (GCCC) constructed an artificial reef at Narrowneck to stabilise sand-nourished beaches in the vicinity and to provide a surf break. The 450 m by 200 m structure is composed of 400 large (20 m long, up to 400 t) geotextile sand bags placed perpendicular to the beach in depths up to 10 m. The geotextile used for the sand bags is Terrafix®, a non-woven, synthetic staple-fibre needle-punched composite fabric. Jackson et al. (2004) found that the Terrafix® sand bags provided a 'better than expected' substrate for a diverse range of biota.

Monitoring revealed that algae began colonising the bags within eight days of deployment and 'complete' algal coverage occurred within three weeks. Algae and other 'soft' biota such as sponges, ascidians, soft corals and anemones are the dominant sessile organisms established on the reef, but 'hard' fauna, including barnacles and abalone, also occur. A range of mobile animals, including rock lobsters, prawns, octopus, echinoderms and many species of finfish, have been recorded on and around the structure. Zonation of algae is apparent, with larger forms growing on sand bags in deeper waters.

The open-pore surface of Terrafix® appears to capture pieces of drifting algae (Jackson et al., 2004) and to allow a layer of sand to deposit within the fabric (Greg Stuart, GCCC, pers. comm.), thereby providing a suitable substrate for plant growth. The attached marine vegetation equally provides protection for the sand bags, including from UV light, which may prolong the life of the structure. The biological communities on Narrowneck Reef appear to enhance local biodiversity and productivity, and may contribute to regional productivity (Edwards, 2003). Although intended primarily to provide coastal protection, the sand bags of the reef have provided fish habitat and attracted recreational fishing activity.

The following materials are *not* recommended:

- **Polystyrene** as it can break down over time and be hazardous to fish through ingestion.
- **Tyres** and tyre rubber due to concerns about the impacts of petrochemical and heavy metal leachate on the environment.
- **Wood treated with chemicals** (e.g. creosote, copper napthenate, etc) as these materials may leach harmful substances into the water.
- **Uncured cement** as its high pH levels (due to lime content) may be toxic to invertebrates for up to 12 months (Lukens and Selberg, 2004).

Habitat complexity. The physical complexity of structures should be maximised wherever possible to increase habitat availability. More physically complex structures offer further opportunities for exploitation (shelter, refuge, etc) by biota (United States Army Corps of Engineers, 1989). This is because heterogeneous structures provide more interstitial spaces and greater surface area than homogeneous structures, resulting in more surfaces for epibiota to attach to and a labyrinth of spaces for fish.

Examples of simple measures to increase habitat complexity include:

- Sloping sides on structures will increase surface area.
- Irregular submerged surfaces (rough, textured, etc) provide more habitats than homogenous structures such as solid vertical steel and concrete sheets.
- Sinuous, or meandering, structures are preferable to straight lines, which provide less surface area and fewer habitats.

Habitat diversity. A variety of habitat enhancements on and around a given structure may support more diverse biological communities. Different types of enhancements may support different species and life-cycle stages.

Water depth. Structures built in deep waters may support a more diverse flora and fauna, as vertical biological zonation is more likely than in shallow waters (United States Army Corps of Engineers, 1989). Structures built through a range of depths (e.g. from the shore out to sea) may support different fish communities at different depths and distance from the shore.

Habitat requirements of local species. Artificial habitat enhancements should be tailored to suit local species and communities. Fish-friendly structures will benefit from a design process that includes an assessment of local species and their habitat preferences. This may be particularly pertinent for iconic, targeted species. For example, an area with rock lobsters, crab or similar cryptic crustaceans may benefit from habitat enhancements that include 'caves' for these species to inhabit. The natural territorial requirements of animals may need to be considered so that target species can make best use of fish-friendly enhancements (e.g. to avoid crowding effects). Existing biological knowledge should be used to inform structure design and additional research may be required to address knowledge gaps. Periods of larval recruitment are particularly important as far as placement of structures.

Reducing risks from pest species. Williamson et al. (2002) suggest a number of management options to prevent and/or hinder the spread of introduced pests. These include pest monitoring programs in high risk areas (e.g. ports), isolation of international shipping from domestic vessels and restoration of disturbed natural habitats. In addition, it may be possible to design artificial structures to be less attractive to potential pests, while still providing habitat for desirable local species. This is likely to require knowledge of or research into potential invasive species and their habitat requirements, along with the habitat requirements of local species.

Water flow and fish movement. Existing water flows and tidal regimes should be maintained to the greatest extent possible to help maintain natural biological processes. Fish migration barriers may be formed by continuous structures below mean low water. Alteration of current flow has the potential to damage fish habitats such as seagrass meadows and yabby beds, and to affect transport of eggs, larvae and mangrove propagules. It is also possible that longer residence times of biological material in a given area due to reduced water circulation may increase the risk of pest species invasion. Floating structures or structures with gaps will facilitate better water flow and fish passage than solid structures.

Construction practices. Best practice construction methods should be employed to minimise both on-site and off-site impacts, including minimisation of turbidity and sediment movement. Blasting during construction should be avoided where possible as this can cause fish kills. Air bubble screens, or curtains, can be used to reduce sound wave energy when blasting cannot be avoided (United States Army Corps of Engineers, 1991). Where possible, natural habitats that have been disturbed through development activities should be restored (re-profile substrate, replant vegetation, etc). For more information on restoration of fish habitats, see Hopkins et al. (1998). Disturbance of acid sulphate soils (ASS) should be avoided wherever possible to prevent impacts on fish and fish habitats. Acid runoff can also cause costly infrastructure damage through 'digestion' of concrete.

Maintenance. Construction materials should be resilient and suited to the environment to minimise maintenance requirements. In general, structures should be left un-cleaned where possible to promote biotic growth and to support aquatic ecosystem health (Kapitzke et al., 2002). In some cases a regular maintenance program may be required to ensure that structures continue to function as fish habitat (e.g. to prevent smothering of fish-friendly features by silt) and to reduce drag forces from waves and currents. An appropriate maintenance program, including structure monitoring, should be developed, costed and properly communicated between the designer, developer and any subsequent owner (Gourlay et al., 2004).

Structure strength and durability. Any fish-friendly components of aquatic infrastructure should be designed to survive prevailing physical conditions, such as wind loads and wave motion, to prevent parts breaking free or compromising overall structural integrity (Kapitzke et al., 2002). Materials used should also be resistant to degradation due to the chemical forces of the aquatic environment.

Development footprint. The development footprint of aquatic infrastructure should be kept as small as possible to minimise disturbance of natural habitats:

- Shared facilities (e.g. public facilities) and common access points reduce disturbance of natural habitats.
- Buildings (e.g. sheds) should not be placed over water. Buildings tend to necessitate aquatic structures with a larger development footprint.
- Clearly defined work and storage areas will help avoid unnecessary disturbance of natural habitats (Council of Europe, 1999).

Shading. Complete or excessive shading of natural habitats by artificial structures should be minimised, as it may discourage fish from using the area, and prevent plant growth. Sufficient light may be provided by using grids, grills, grates, slats or mesh decking to create a 'skylight' in situations where major structures would cause continual shading. Artificial lighting (e.g. on jetties, fishing platforms, etc) may attract certain fish. See also Section 4.2.2 for more information on reducing shading impacts.

Buffer zones. Buffer zones can be used to reduce construction and operational impacts of aquatic infrastructure on nearby fish habitats. DPI&F recommends a generic minimum buffer width of 100 m between developments and tidal lands, and of 50 m between developments and freshwater areas (Bavins et al., 2000). Aquatic structures are, however, necessarily located in the water and appropriate separation distances from important adjacent fish habitats are best determined on a site-specific basis. GBRMPA recommends the following buffer distances between structures and 'sensitive environments' (Great Barrier Reef Marine Park Authority, 2004):

- tourist pontoon, observatory, navigation aid (<50 m);
- heli-pontoon, jetty, landing facility (50 to 499 m); and
- marina, groyne (>500 m).

4.2 Specific infrastructure designs

This section includes design features for specific types of infrastructure, and for issues particular to such structures. The general design features in the preceding section should also be considered for each type of structure discussed here.

4.2.1 Small boat harbours and marinas

Marinas are generally designed to moor recreational vessels in a sheltered location with land-based access provided to vessels and facilities. Marinas are found along much of Queensland's urbanised coastline and waterways and contribute significantly to recreational fishing and boating activities. Site selection is the key to minimising potential impacts of marinas on fish and fish habitats (United States Army Corps of Engineers, 1993):

- Marina sites that utilise natural attributes and require minimal disturbance to natural habitats should be selected. For example, capital and maintenance dredging can be minimised by selecting naturally deep sites with low sediment transport potential.
- Flushing of marina waters is the prime consideration in maintaining water quality. The following design features will improve environmental quality of boat basins through enhanced water flow:
    - Sites in open water or at the mouth of waterways have higher flushing rates than those further upstream.
    - The shape of the basin should 'fit' (i.e. maintain) natural flow patterns. Marina basins can generally be designed to maximise tidal exchange without affecting navigation (Gourlay et al., 2004).
    - Avoid square or dead-ends to provide adequate water circulation for biological processes.
    - The basin should be shallower than the access channel.
    - The entrance should be wide and deep with gradually decreasing depth to the inner harbour to promote flushing and avoid isolated deep holes with stagnant water.
    - Structures should include flow-though designs (open piles, floating breakwaters, culverts, etc). Employing floating rather than fixed breakwaters enhances fish migration, water circulation and littoral transport of larvae, mangrove propagules and other biological material (Figure 5).

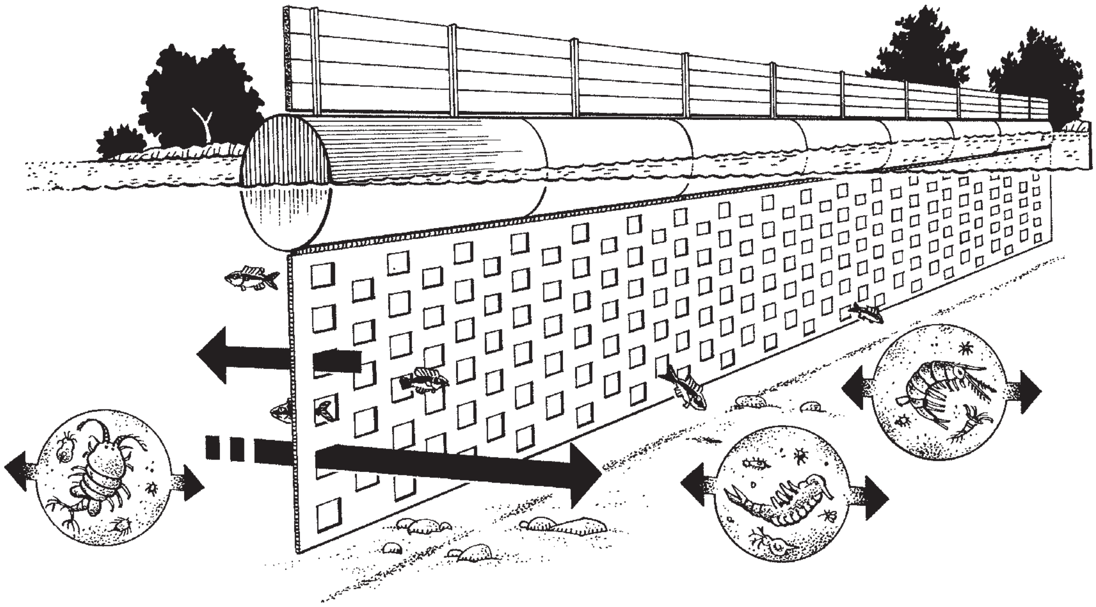

Figure 5. Floating breakwater.

- Harbours with a range of depths will support more diverse biota. For example, shallow vegetated habitats in a harbour can be used by small fish and can absorb nutrients to maintain water quality, while larger fish may inhabit deeper waters within the harbour.
- Maximise vegetated landscaping. In some cases, it may be possible to revegetate stabilising walls with suitable plants to provide additional strength and enhance fish habitat.
- Use sloping riprap walls with underlying geotextile fabric for stabilisation of land margins. These maximise habitat niche creation, are cost-effective and reduce wave reflectance problems (Bugler, 1994).

4.2.2 Jetties and pontoons

These structures, particularly pontoons, are very common in Queensland waters and are often located in marinas. Some terms for these structures are used interchangeably, including docks, jetties, piers, wharves, etc. These structures are usually fixed in place by pylons driven into the substrate.

The following fish-friendly measures are recommended for jetties and pontoons:

- Incorporate artificial fish habitat modules into jetties and similar infrastructure wherever appropriate. A discussion of artificial habitat modules is included under *4.3 Designs for artificial fish habitat modules.*
    - Artificial fish habitat structures should be sized to fit under piers, and between pylons and other support structures. By remaining 'hidden' under existing structures, fish habitat enhancements are less likely to cause aesthetic and boating safety issues.
    - Consider safety issues where swimming and diving are allowed near infrastructure. Avoid using structures in which swimmers and divers are likely to become tangled. It may be necessary to prevent public access to habitat enhancement structures under jetties (e.g. by fencing off the enhanced areas) where swimming and diving are allowed.

- Use T- or L-shaped docks to separate different activities (e.g. boat traffic, foot traffic, swimming and sitting/viewing areas) and reduce congestion. This may allow the same usage to be achieved within a smaller footprint, resulting in less disturbance of natural habitat, increased dock stability and lower costs (Burns, 2001). A modular design allows dock components to be maintained, added or removed over time as needs dictate.
- In contrast to traditional pylon-supported jetties, crib docks are supported by square log structures built in alternate cross-layers of slats (like a log cabin) that are filled with rocks. Such structures may provide additional habitat for biota, but require a relatively large area of substrate to be smothered (Burns, 2001). Crib docks should be as small as possible to minimise substrate disturbance, and should have an open-faced design without solid planking to allow water movement and fish access. Beuchamp et al. (1994) found that rock crib piers enhanced the density and diversity of fishes in Lake Tahoe, USA. They proposed that the vertical relief and interstitial spaces of rock crib piers provided more cover for fish and a greater attachment area for epibiota than nearby pylon-supported piers.
- Cantilever and suspension docks may be appropriate in some locations. These are suspended from the shore with no in-water supporting components. Suspended docks cause no disturbance to water or aquatic substrates; however, they do disturb the shoreline and shade aquatic habitats (Burns, 2001), and do not provide additional structural fish habitat. Similarly, portable structures such as rolling docks provide little habitat value, but also cause little permanent disturbance of natural habitats. These are wheeled into place to provide temporary access for small craft, particularly in lake environments.
- The minimum water depth under pontoons should be approximately 1 m at low water to prevent contact with, and disturbance of, the substrate (Burns, 2001).
- *Docks in seagrass habitats.* In some circumstances, it may not be possible to avoid placing structures in sensitive habitats, including those with aquatic vegetation[2]. Docks that cause less shading will have less impact on seagrasses. Height of the structure above the substrate is the most important single factor controlling shading (Burdick and Short, 1998). These authors found that for US seagrass meadows, the ideal dock design to minimise shading was a tall (minimum 3 m above substrate), narrow (1 m wide) pier on a north-south (within 10°) orientation. Wider jetties must be taller to prevent increased shading. Shading can also be minimised by ensuring adequate deck plank spacing or using grate decking. Physical removal of seagrass can be reduced by limiting the number of jetty pylons.

  Shafer and Lundin (1999) recommend a minimum pylon spacing of about 5 m while appropriate installation methods (e.g. barge-mounted pile driver rather than jet pumps) will also reduce seagrass disturbance. Pontoons cause greater impacts on seagrass beds than fixed jetties due to their constant shading effect and should only be installed beyond the depth limit of local seagrasses (Burdick and Short, 1998).

[2] Note that DPI&F policy does not support disturbance of marine plants where reasonable alternatives with lesser impact exist.

The SUNDock™ has been developed specifically to reduce shading and physical disturbance of submerged aquatic vegetation. To access vessels, users ride a battery-powered vehicle along an aluminium monorail set on a narrow platform. The narrow design, set on inverted v-shaped pylons, reduces the structure's footprint and there is little decking. The manufacturer (see Appendix 2) claims a 90% reduction in shading compared to traditional dock designs.

4.2.3 Boat ramps

Boat ramps play in important role in providing access to fishing grounds for Queensland's many recreational fishers and boat users. Installation of boat ramps usually requires some disturbance of shoreline habitats. Public boat ramps serve the majority of the community but individual property owners may also have boat launching access and facilities. The following fish-friendly measures were mainly sourced from United States Army Corps of Engineers (1993):

- Well-planned public facilities in suitable locations can reduce the extent of any shoreline habitat disturbance compared with the alternative of many ramps serving the same area and same purpose.
- Well-marked routes to a boat ramp can protect important fish habitats and their dependent fish by keeping vessels away from sensitive areas.
- Boat ramp access channel depths that provide a minimum clearance of about 1 m between the propeller of a vessel and the channel bottom at low water should be sufficient to prevent increased turbidity.
- To minimise potential bank erosion, boat ramps should not be placed on erosive bends of waterways.
- Ancillary facilities, such as car parks, staging areas and toilets, should be located on non-tidal land to minimise fish habitat removal.
- Consider alternatives to ramps that may require less habitat removal:
    - Various boat lift designs can be used to lift a boat into and out of the water. Lifts are usually used in sites with near-shore deep water where there is an existing pontoon, jetty or seawall.
    - A marine railway can also be used as an alternative to a boat ramp. This requires lifting the boat onto a rail and lowering the boat down the rail into the water. The rail structure disturbs less habitat than a traditional boat ramp, and boats can be launched in areas with a shallow slope at low tides.

4.2.4 Stabilisation structures

Revetments, seawalls and groynes are designed to protect the structural integrity of beaches, foreshores, banks and other margins at the land-water interface. Erosion of these areas, while often a natural process, can cause loss of valuable land and increased sedimentation and turbidity. Stabilisation structures usually replace natural habitats, and may have impacts on adjacent shorelines and fish habitats through physical processes such as scouring. In many circumstances, 'softer' alternatives to hard structures are considered a more appropriate method of stabilising shorelines (e.g. see *Living shorelines* and *Beach replenishment* in this section). Stabilisation structures should only be considered where erosion is present or likely to occur without protective measures.

The following fish-friendly measures are recommended for stabilisation structures:

- Recommended materials (United States Army Corps of Engineers, 1995) include:
    - Rubble toe or riprap revetment will provide more habitats for biota than homogeneous structures such as smooth concrete.
    - Large armour stone is more stable with greater diversity of habitat structure (interstitial spaces) than smaller stone.
    - Variable rock sizes within a structure create greater habitat diversity through larger and more varied spaces (Lennon, 2003).
    - Toe protection on submerged structures provides more diverse, 'reef-like' habitat.
    - Shoreline vegetation should be retained where possible and planted where appropriate. Vegetation provides fish with additional habitat, shade to maintain suitable water temperatures and a flow of organic material (leaves, fruits, insects, etc).
- Seawalls with created habitat crevices may provide 'homes' for cryptic species and retain water during low tides (Chapman, 2003). Suitable microhabitats that may increase opportunities for biota on seawalls include: holes left unfilled during maintenance; indented grouting between blocks; ledges (which also provide habitat on the under-surface); and constructed cavities (holes, hollows, caves, etc). Artificial habitat modules may also be deployed at the base of seawalls to provide additional fish habitat (Lennon, 2003).
- Use of a gentle slope (e.g. 1:1) will dissipate more wave energy, cause less scour damage and provide more fish habitat than steeper slopes (United States Army Corps of Engineers, 1995; Chapman, 2003).
- Vertical structures not only provide less fish habitat than sloping structures, but may also accelerate foreshore erosion and create unsuitable habitat for epibiota through increased turbulence and scour. If vertical walls are necessary, these should contain weep holes covered with a geotextile fabric to prevent water build-up behind the structure (Bugler, 1994).
- Consider a meandering design for shoreline revetment. Increased shoreline sinuosity provides increased surface area, and therefore available fish habitat, compared to straight structures. If a meandering structure is impractical, installation of rock spurs adjacent to the revetment will provide additional fish habitat (Lennon, 2003). Spurs should be designed to avoid scouring and disruption of natural sediment movement; in general, relatively small spurs placed at irregular intervals are likely to be most compatible with the main revetment structure (Lennon, 2003).
- *Living shorelines* are a 'soft engineering' revetment method that can provide foreshore erosion control and also create additional fish habitat in suitable areas. To create a living shoreline, revetments are constructed seaward of an eroding bank in shallow water, and appropriate fill is placed behind the revetment. The fill is then planted with suitable vegetation such as salt marsh grasses. The result over time is a created aquatic habitat intended to attract endemic fauna, provide erosion protection and act as a filtering

buffer strip for upland runoff. Once established, living shorelines are largely maintenance-free and self-sustaining (Stark, 2004). Note that such structures are only supported where erosion is present.

Case study: Charles Holm Park

In Queensland, the Gold Coast City Council has trialled methods of arresting foreshore erosion at Charles Holm Park on the Coomera River. Erosion is exacerbated by wave energy from frequent vessel traffic. Previous use of rock rip-rap placed on the eroding foreshore prevented mangrove colonisation. As an alternative, sand bags and concrete A-Jacks were installed seaward of the shoreline (Figure 6). Fill was not placed behind the structure; rather, sediment accumulated naturally behind it. Mangrove propagules subsequently recruited to the accumulated sediment and it is intended that the mangrove colonisation and growth will eventually help to stabilise the bank and to improve visual amenity by concealing the artificial structure (R. Eden, Gold Coast City Council, pers. comm.). Difficulties were encountered with fish being stranded in water pooled behind the structure. 'Fish pipes' were installed through the A-Jacks, but would need to be modified (installed lower, made longer and more pipes) to allow substantial passage of fish (Gabriel et al., 2004). The sand bags are a 'softer' option than the A-Jacks, but are more vulnerable to vandalism (R. Eden, Gold Coast City Council, pers. comm.).

Figure 6. A-Jacks revetment at Charles Holm Park.

Case study: Sherwood Park

The Brisbane City Council installed rock gabions under a boardwalk and seaward of the bank at Sherwood Park on the Brisbane River to provide erosion protection (Figure 7). Sediment has accumulated naturally behind the gabions and mangroves have colonised and grown in the sheltered conditions on the deposited sediment. Biological activity, including the presence of fiddler crabs, is evident (Figure 8). In the long term, a healthy mangrove community may provide additional bank stabilisation along with natural fish habitat. The gabions also provide additional hard structure habitat for fish under the boardwalk.

Figure 7. Sherwood Park gabions.

Figure 8. Fiddler crab, Sherwood Park.

- *Beach replenishment* (also known as beach nourishment or beach fill) is generally favoured as a 'soft engineering' alternative to more traditional hard structures for shoreline stabilisation, particularly on oceanic shores. It is often carried out not only to provide coastal protection, but also to enhance visual and recreational amenity (Gourlay et al., 2004). Beach replenishment is considered a relatively simple, cost-effective measure that avoids the risk of damage to adjacent shorelines that can result from use of hard structures such as rock revetments (Piorewicz, 2002). Sediment for replenishment is often sourced from a seaward dredge site, but may also come from land-based sources. While generally considered a 'soft' alternative, potential impacts of beach replenishment on fish and fish habitats still require careful consideration. Gourlay et al., (2004) suggest that assessment of the impacts of beach replenishment on biota should incorporate environmental data collection, monitoring (including re-establishment of organisms) and reporting. Impacts of beach replenishment and possible solutions are listed in Table 1.

Table 1. Beach nourishment impacts and solutions.

Impact	Acceptable solution
Filling of tidal fish habitats to provide larger foreshores.	Ensure that replenishment is limited to that required to provide coastal protection, not to claim new land for development purposes.
Impacts on biota at the site where the material is sourced.	A sufficient depth of original material should be left at the source site to allow for recolonisation by local biota (Gourlay et al., 2004).
Smothering of existing habitats and epibiota through initial spoil disposal, and through subsequent seaward and/or longshore movement of deposited material.	Predictions of the movement of deposited material, and assessment of the likely impact of sediment movement and changes in sediment composition on fish and fish habitats, should be made prior to works commencing.
Disturbance of fish and fish habitats caused by regular replenishment of deposited material.	Compare the likely impact on fisheries resources of regular sand replenishment with the likely impacts of alternative options such as hard revetment.
Disruption of fishing activities.	Designs should consider enhancing beach uses such as fishing, while minimising any disturbance of fishing activities in the vicinity.

4.2.5 Dredge spoil

It is DPI&F policy that dredge spoil be disposed of on non-tidal land, or if a suitable land-based site is not available, at a designated dredge spoil disposal site at sea (Hopkins and White, 1998). Disposal of dredge spoil on productive shallow-water habitats is the least preferable option due to possible impacts on fisheries resources and fisheries productivity.

While the DPI&F policy position seeks to maintain existing natural fish habitats, dredge spoil has been used to create a range of aquatic habitats, particularly in the US. These created habitats include salt marshes, mangrove wetlands, freshwater wetlands, seagrass meadows and oyster beds (United States Army Corps of Engineers, 1987). Despite the 'naturalness' of dredged material habitats, there is debate about their usefulness and habitat values. Streever (2000) suggests that salt marshes created from dredged material probably do not perform all of the ecological functions of natural marshes; for example, created marshes may support lower densities of polychaete worms and crustaceans than natural marshes.

Use of dredge spoil to create habitat usually involves replacing one habitat with another, even though the replacement habitat may be relatively 'natural'. Selecting a given development alternative may be a highly judgmental process and public opinion, along with biological and engineering expertise, is likely to be important in determining the best option for habitat creation using dredge spoil (United States Army Corps of Engineers, 1987). From a fisheries perspective, the most important consideration should be to ensure that the impacts of created habitats on existing fish habitats and fisheries resources do not outweigh any benefits.

Case study: Noosa River

Intertidal banks near the mouth of the Noosa River estuary were dredged to provide sediment to nourish nearby eroded foreshore. The sand banks at the dredge site provide habitat for benthic invertebrates, which are food for locally targeted fish such as whiting, flathead and bream. As mitigation for loss of the fish foraging habitat at the dredge site, DPI&F required that the dredge spoil be used to construct 'replacement' intertidal sand bars at the eroded foreshore site. A further requirement was that the created sand banks be monitored to determine whether the 'habitat exchange' provided any benefits for fisheries resources. Preliminary results indicate that the created sand banks are used by fish (Miller et al. 2002). Skilleter et al. (in press) found, however, that dredging led to the sediment composition and the benthic community at the extraction site becoming more similar to other parts of the estuary, raising concerns about an overall reduction in the diversity of habitats and biota in the system.

Case study: Cabbage Tree Creek — Boondall foreshore

Placement of dredge spoil from the maintenance dredge program at Cabbage Tree Creek, Brisbane, in front of the Boondall foreshore has seen the development of intertidal mangrove communities. The spoil was placed in a U-shaped bank facing seawards to allow tidal access and colonisation by mangroves. Over twelve years, the stability of the three banks has seen a loss of 'unvegetated' intertidal habitats that have been replaced by a permanent mangrove community.

4.2.6 Boardwalks

Boardwalks can provide community access and educational opportunities in areas of sensitive habitat. They should be established with a minimum of disturbance to these habitats and associated natural biological processes. Boardwalks generally cause less disturbance than traditional footpath construction. Design recommendations include:

- Spaced decking allows leaf litter and other debris to fall to the substrate rather than being trapped on the boardwalk. This helps to allow light penetration and maintain biological productivity, and may reduce maintenance requirements.
- Design and construction should minimise changes to the physical heterogeneity of the local environment:
  - align boardwalk to minimise habitat disturbance during construction.
  - use construction methods that minimise substrate disturbance, e.g. by commencing construction from the bank and using the initial boardwalk section as a work platform for subsequent sections, etc; and
  - ensure that substrate profiles are returned to natural levels following installation so that natural water flows are maintained.

4.2.7 Mooring buoys

Mooring buoys can reduce impacts on sensitive habitats from dragging boat anchors and/or repeated anchoring. Mooring buoys consist of a permanent fixture on or in the substrate, a floating buoy on the surface (sometimes with a floating 'pick-up' line attached), and a line connecting the two. Diver installation may be required for some systems. Mooring buoys are convenient for users and their presence can reinforce the concept of avoiding contact with fragile habitats.

This section describes how mooring buoys can best be employed to reduce impacts on fish habitats. Most of the information in this section is summarised from the *Mooring buoy planning guide*, published online by the Project AWARE Foundation and PADI International Inc (http://www.projectaware.org/americas/english/pdfs/moorbuoy.pdf).

- Buoys are best employed in designated mooring areas within existing high-use areas to reduce impacts, rather than in rarely visited areas where their presence may in itself increase damage to sensitive habitats by attracting more users.
- Public moorings in designated mooring areas, managed by a responsible authority, are preferable to private moorings.
- Regular inspection and maintenance programs will help to ensure that buoys remain in good repair and continue to protect sensitive habitats.
- An 'elastic rode' mooring line may reduce habitat damage caused by dragging lines. The elastic properties of the polyurethane blend line maintain a more steady pull than on conventional lines, thereby reducing dragging of the line across the substrate. Hazelett Marine produce a commercially available elastic rode mooring line (see Appendix 2).
- There are limitations on the size of vessel that a particular mooring buoy design can hold. A system of colour-coded public mooring buoys is employed in the Great Barrier Reef Marine Park to direct users to moorings suitable for particular vessel sizes (http://www.gbrmpa.gov.au).
- Mooring buoys require different anchoring solutions depending on the substrate present. Mooring buoys may not be suitable in environments that have steep slopes, a thin layer of loose substrate over hard rock, great tidal ranges, and particularly strong currents (which impede installation). A variety of designs have been developed for particular substrates, including:
    - *Traditional block systems*. These usually employ a heavy chain attached to a concrete block placed on the substrate. These simple systems are only suited to shallow mud, sand or gravel bottoms, and are not recommended for more sensitive areas. While relatively inexpensive, block moorings may be less fish-friendly than other options as heavy chains and block movement under high-energy conditions can cause scouring of the surrounding substrate.
    - *Halas mooring system*. This system employs an eyebolt that is cemented, or fixed by underwater adhesive epoxy, into a hole hydraulically drilled into the substrate. Flat, solid bedrock is the preferred substrate for the Halas system. Substrates such as sand, mud, coral rubble, or a combination of bottom types may not hold a cemented eyebolt.

- *Manta ray anchoring system*. This system combines a deep, hydraulically driven (by underwater jackhammer) anchor rod with a perpendicular resistant plate to attain sufficient holding power in the substrate. It is especially suited to sand and rubble environments, and can be used in mixed bottoms of clay, sand, gravel, broken bedrock, and coral rubble. Larger or multiple embedment anchors have been developed to accommodate larger vessels, and are used in loose or wet sediments that have reduced holding power.
- *Helical screw anchors*. Helical plate or screw anchors derive their significant holding power from the substrate into which they are embedded. They are installed using a hydraulic torque motor to screw the anchor into the substrate. Helical anchors are generally for heavy-duty, long-term anchoring and can be used in relatively high-energy, soft substrate environments. Softer sediments require more substantial screw anchors, or extensions. This design is not suitable for rock bottoms.

4.2.8 Fishing-friendly structures

Land-based fishing is the only affordable option available to many fishers in Queensland. Fishing-friendly designs for structures can provide enhanced access for fishing where appropriate. It is preferable to provide a dedicated fishing platform to avoid use conflict (e.g. boat mooring versus fishing).

Fishing platforms should be sited in suitable locations, in particular where there is sufficient water depth for fishing at all stages of the tide and where minimal damage to natural habitats is required. Maintenance requirements should be minimised so that fish and fish habitats are not affected by maintenance activities. This also reduces operational costs. Users are generally encouraged to remove offal and other rubbish from the site for disposal domestically. Fishing platforms should ideally provide suitable access and ease of use for all fishers, and incorporate at least some of the following features:

- Lighting for night-time fishing. Lights may also encourage larval recruitment and attract planktivorous fish. Caution should be exercised in areas where lights may impact on other biota such as turtle hatchlings.
- Rod holders.
- Cleaning stations with a water supply.
- Fish measuring stations and signage to promote recreational fishing education, including size and bag limits.
- Disabled access.
- Shade and safety rails for safe fishing.
- Fish-friendly design features, including artificial fish habitat modules, to provide additional fish habitat.

Case study: Hull Heads fishing platform

This location on the Hull River in Cardwell Shire is a popular fishing site for the local community, especially children. The river bank was previously armoured with a steep retaining wall, which was replaced by a sloping rock bank that prevented access for fishers to fish in suitably deep water. The fishing platform (Figure 9) was installed to reinstate fishing access. The fish-friendliness of the structure is enhanced by the gentler slope, increased surface area and interstitial spaces of the rock bank which provide better fish habitat than the previous steep retaining wall. In addition, the compact platform is removed for maintenance, which is conducted in a workshop and therefore causes no on-site impacts to fish or fish habitats. The platform has proven popular with the community and Cardwell Shire intends to duplicate it (Alf Raiti, Cardwell Shire Council, pers. comm.). It may also be used as a model for platforms in neighbouring areas. This is an example of a relatively simple and inexpensive solution to providing fishing access.

Figure 9. Hull Heads fishing platform. Photo courtesy Alf Raiti, Cardwell Shire Council.

Case study: Townsville Strand fishing pier

This large structure was installed as part of a major redevelopment to restore the structural integrity of the Townsville Strand foreshore following storm damage. The design process included consultation with community groups such as the recreational fishing and disability sectors. The pier is positioned at the deepest part of the redevelopment to maximise fishing depth and includes facilities such as catch cleaning stations (Figure 10), water supply and shade sails (Figure 11). Maintenance costs are around $2000 per annum and include (Narelle Mackaway, Townsville City Council, pers. comm.):

- Regular check of structural integrity.
- Re-screwing of the shade sail.
- Maintenance of fish cleaning stations.
- Modified/additional fishing rod holders.

The Townsville Strand fishing pier is an example of a dedicated fishing-friendly structure integrated into a larger development project.

Figure 10. Cleaning station. Photo Carla Wegscheidl DPI&F

Figure 11. Shade sails. Photo Carla Wegscheidl DPI&F

4.3 Designs for artificial fish habitat modules

The intent of this section is to provide readers with a range of options and ideas for artificial fish habitat modules to enhance aquatic infrastructure. The artificial fish habitats discussed here have a range of intended functions, including as:

- substrate for epibiota;
- fish attractors to increase angler catch and harvest;
- nursery habitat for juvenile fish;
- adult fish habitat/sanctuary; and
- spawning habitat.

Some modules may provide more than one habitat function, while others are specifically designed for a particular purpose (e.g. a spawning box for a nesting fish species). In Japan, a variety of structures are designed for specific purposes to enhance fisheries (Stone et al., 1991). For example, concrete breakwater blocks may be intended to act as a seaweed holdfast, while chambered structures may be designed to increase fish production, and bamboo rafts to attract pelagic fish. Different types of modules can be located together to provide a variety of habitat functions (e.g. both escape cover for small fish and ambush cover for larger fish). Natural materials, such as branches and brush piles, are sometimes used in conjunction with artificial structures to provide additional habitat.

Some structures are designed to be attached to existing infrastructure, while others sit independently on the substrate underneath or adjacent to infrastructure. These modules, or variants, could be incorporated into the design of new infrastructure or added to existing structures. Most of the 'independent' modules could be modified to hang from aquatic infrastructure. Modules suspended from infrastructure may take the form of a 'hanging garden' (Lennon, 2003). Modules could also be both attached to the infrastructure and anchored to the substrate to provide additional stability in higher energy environments. Module structural stability in tidal waters and in storm and flood conditions is an important consideration.

Much of the material in this section, including diagrams, is based on information from the website of the Southern Division American Fisheries Society Reservoir Committee: *Habitat manual for use of artificial fish habitat structures in lakes and reservoirs* (http://www.sdafs.org/reservoir/manuals/habitat/main.htm). Those modules designed primarily for freshwater reservoirs may require reinforcement or sturdier construction to ensure durability and safety in higher-energy tidal marine environments. Several of the modules listed below are manufactured commercially and details of suppliers are provided in Appendix 2, Contacts.

4.3.1 Fish Hab™

Fish Habs™ (Figure 12) are most commonly fitted under jetties (e.g. anchored between jetty pylons or secured to pylons) in freshwater reservoirs in the USA. They are made from recycled plastic (including old fishing line), which provides a durable and environmentally friendly structure. The prefabricated slats join together to form crate-like modules (approximately 1.2 m square) that provide additional fish habitat. Modules can in turn be joined to make various configurations. Habitat complexity can be augmented by adding structure inside the Fish Hab™. Most commonly in US reservoirs, branches are added to increase available habitat, but more durable artificial materials could otherwise be used. Barwick et al. (2004) found that catch rates of fish at piers enhanced with Fish Habs™ were greater than at unmodified piers, and that pier owners were generally pleased with pier modifications. Fish Habs™ are popular with jetty owners and fishers where they have been fitted because they are perceived to enhance fishing, are relatively inexpensive and easy to install, and do not diminish the aesthetics of the jetty. There is also a 'string' version of the Fish Hab™, consisting of individual plastic strands anchored by weights to the substrate (also shown in Figure 12).

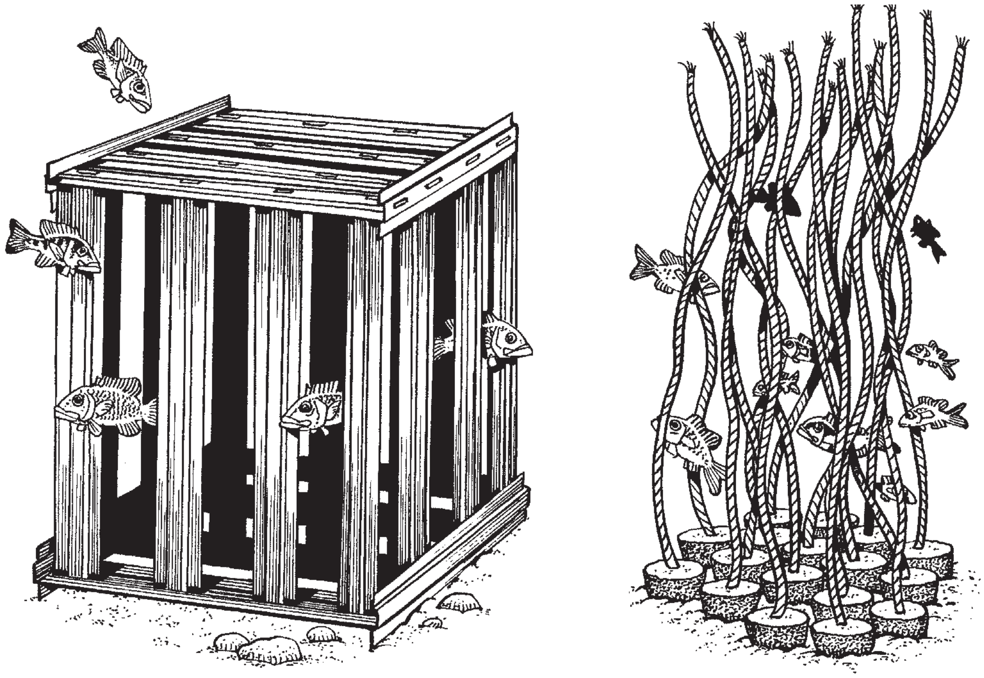

Figure 12. Fish Habs™.

Fish Habs™ may need to be customised for higher-energy marine environments (Bob Barwick, North Carolina Wildlife Resources Commission, pers comm.), including:

- The structure may need to be reinforced with additional plastic or other materials to provide extra strength.
- The structure may need additional weight (in the order of 15 kg to 20 kg) to keep it secured if positioned on the sea floor.
- The plastic material used to construct Fish Habs™ may become brittle in cold conditions, although this is unlikely to be a problem in Queensland waters.

4.3.2 AquaCrib®

The AquaCrib® is a cubic artificial fish habitat module, somewhat similar to a milk crate with a lid, designed primarily for use in freshwater reservoirs. Panels and supports are connected by plastic fasteners to create openings of different sizes at different heights that provide refuge for fish of various sizes. The corrugated plastic (Corrulite) surface of the module is designed to support epibiota. AquaCibs® can be filled with branches and are usually weighted with concrete blocks to anchor the structure to the substrate.

4.3.4 Reef Ball™

Reef Ball™ modules (Figure 13) can add contrasting substrate to areas underneath jetties, along seawalls and within rock wall spurs. These are molded concrete artificial reef modules in the form of a hollow dome with holes, which sit on the substrate. Epibiota can colonise the surface of the module, while fish can live inside and move in and out of the module. Available moulds range in size from about 3 kg to 5000 kg. Reef Balls™ are an initiative of the Reef Ball Foundation Inc., a publicly-supported non-profit environmental NGO based in Florida with a mission to '*restore our world's ocean ecosystems and protect our natural reef systems'* (http://www.reefball.org/).

Figure 13. Reef Ball™. Illustration based on photograph at www.reefball.org

Advantages of Reef Balls™ include their durability and stability — which make them suitable for relatively high-energy environments such as coasts and bays — their natural appearance, and capacity to enhance productivity (Lennon, 2003). Reef Balls™ are best suited to flat substrates, and an anchoring system may need to be considered in sloping areas. Lennon (2003) suggests that community and school groups could be engaged in fish-friendly structure enhancement by producing custom modules made from readily available materials such as buckets, and then monitoring the effects of their handiwork.

Case study: Tampa Bay seawall oyster reef program

Much of Tampa Bay's (Florida, USA) shoreline vegetation has been removed to accommodate waterfront homes and seawalls. Oyster fisheries in the Bay have been impacted by poor water quality, and harvesting is severely restricted. Tampa Bay Watch, a non-profit environmental organisation, undertakes a program to enhance coastal habitats in the Bay by placing Reef Balls™ at the foot of seawalls in residential canals. These provide habitat for oysters and other epibiota, in turn providing food sources and foraging areas for targeted finfish, crabs and prawns, and improved recreational fishing opportunities for homeowners. The hard bottom communities formed by oysters help stabilise bottom sediments, resulting in reduced turbidity levels, and lowered shoreline erosion rates, thereby protecting adjacent property owners during storm events (http://www.tampabaywatch.org/programseawalloyster.htm).

4.3.5 Other reef modules

There are a variety of modular designs for structures that emulate reef habitats. Modules may variously have pyramidal, cubical, dome or cylindrical design, and most have grid walls or openings in the side panels to allow water flow and fish access in the manner of the Reef Ball™. While there are hundreds of modular design variations, structures are usually constructed of either concrete or steel, reflecting the need for robustness and durability, particularly in higher-energy marine environments (Grove et al., 1991).

In Japan, large artificial habitat modules are distributed in a network of structures over the coastal seafloor as part of a national program to enhance commercial fisheries (Seaman and Sprague, 1991). These may consist of interlocking modular structures, all of which are variations on the basic theme of providing an artificial substrate for marine growth and interstitial spaces for fish to inhabit. This program of artificial reef deployment goes well beyond the enhancement of aquatic infrastructure proposed in these guidelines.

4.3.6 Fish 'N Trees®

Fish 'N Trees® (Figure 14) consist of flat plastic 'leaves' attached to an anchored central 'trunk' to form an underwater artificial 'tree'. The structure provides fish habitat, including cover for ambush predators. Fish 'N Trees® are durable and because the leaves are buoyant and rotate freely, fishing gear tends not to snag on the structure. Rogers and Bergersen (1999) found that Fish 'N Trees® were effective at attracting adult largemouth bass in freshwater impoundments in Colorado, USA. These structures may be prone to vandalism during exposure in fluctuating water levels. Leaves may sag when covered with epibiota or silt, reducing their effectiveness as fish habitat. A maintenance program, or design modifications to increase leaf buoyancy, may alleviate this problem.

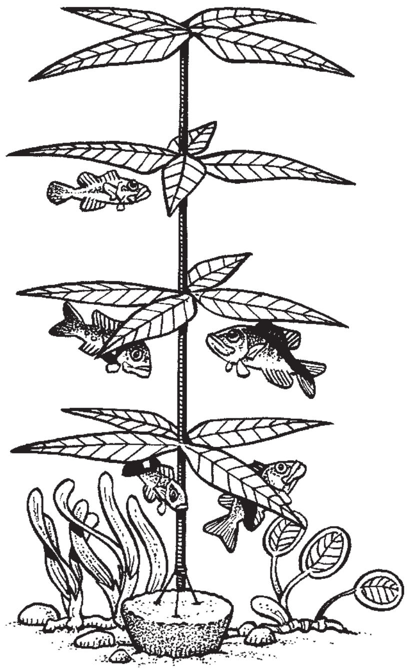

Figure 14. Fish ’N Trees®.

4.3.7 Plastic mesh structures

Structures with perforations may provide cover for small fish by excluding larger fish. Cylinders composed of plastic mesh are sometimes topped with ‘hats’ to form structures such as the ‘fish condo’ (Figure 15). The Fish Condo is designed to provide cover for small fish by emulating the shelter function that natural woody debris provides with many openings for fish to enter. The ‘hat’ prevents large predatory fish from entering the module. A weight is required to secure the module to the substrate. In higher energy environments, modules like the Fish Condo may need to be fixed to infrastructure to stay in place.

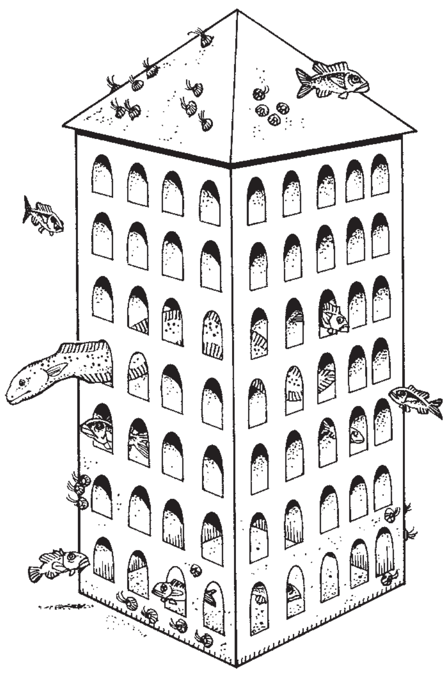

Figure 15. Fish condo.

GeoWeb is a durable honeycomb-shaped plastic material used in the construction industry to stabilise soils. GeoWeb Panels may be hung vertically or in pairs to form a tent-like structure to provide cover for adult fish.

Readily available and relatively inexpensive materials such as stacked plastic crates and structures composed of plastic netting or snow/safety fencing may also used to provide similar perforated habitat. Although convenient to obtain, strength and durability of such materials would need to be ensured. Maintenance may be required to ensure that the mesh is not blocked by epibiota or siltation, which may limit fish access.

4.3.8 Mushroom hats

Mushroom Hats are similar to the hats fitted to the Fish Condo, but instead of capping a cylinder, are attached to a line anchored to the substrate. These are normally intended to provide shade and ambush cover for predatory fish. Buoyant material may need to be fixed under the hat to provide floatation.

Mushroom hats are similar to McIntosh Sea Kites, which are larger structures usually deployed in deeper coastal waters as fish attracting devices, but have also been used near piers and jetties (http://www.reefix.com/mcintoshP2.htm). Minimising damage from prevailing physical conditions is an important consideration when selecting locations to deploy structures. McIntosh Sea Kites were deployed off Bundaberg in 1992 by DPI&F and quickly attracted epibiota, bait fish and pelagic fish. However, the structures were destroyed in heavy weather at the exposed location and were prone to fishing lure hook-up (C. Lupton, DPI&F, pers. comm.).

Low cost and readily available materials, including plastic buckets and barrels, can be tied together and suspended in the water column to provide streamer-like 'capped' habitat for fish. Ribbons may also be used to form structures similar in form to the string variety of the Fish Hab, but may be prone to sinking in silt-laden systems.

4.3.9 Stake beds

Stake beds (Figure 16) can be constructed using wooden stakes or plastic pipes set into a suitable frame and are usually anchored to the substrate using a suitable weight. These modules could also be fitted underneath infrastructure to form a hanging habitat, or project horizontally from a pylon (Figure 17). The modules are intended to promote growth of epibiota and provide a food source for small fish and protection for fish from predators. Stake beds are sometimes used in conjunction with submerged trees to provide additional fish habitat in freshwater reservoirs. Maintenance of stake beds with small interstitial spaces may be required to prevent extensive growth of epibiota from blocking fish access to the structure.

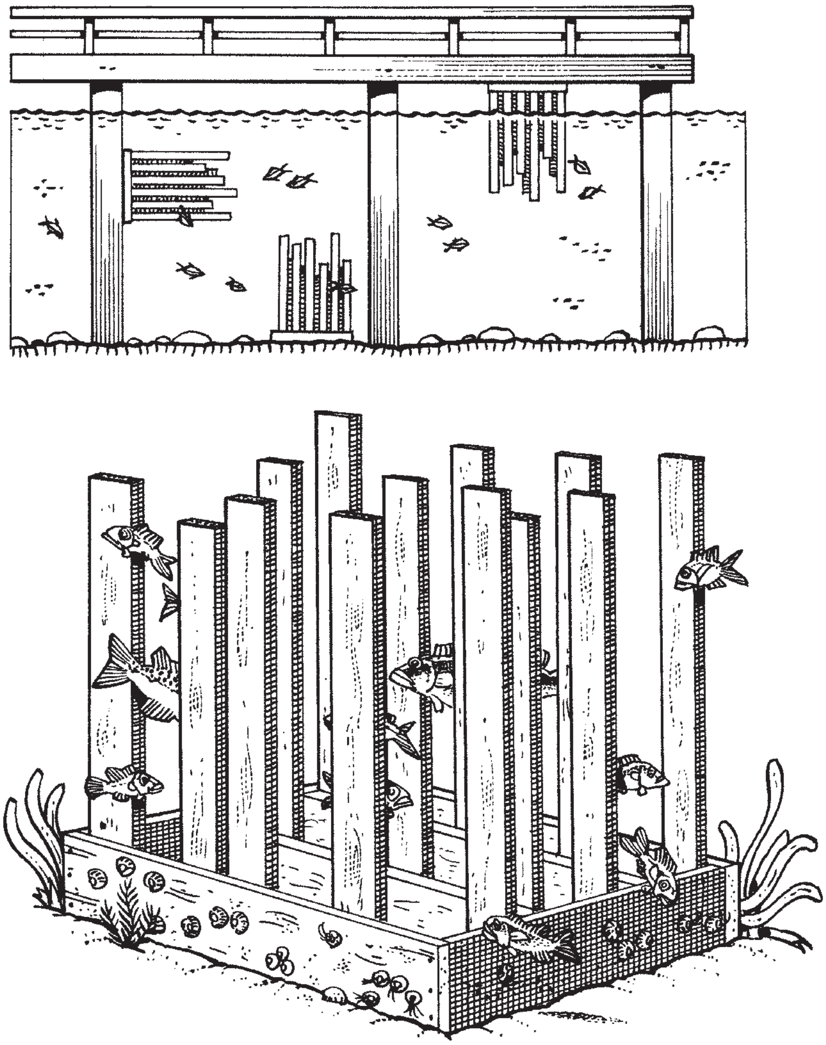

Figure 16. Stake beds.

4.3.10 Log cribs

Log cribs consist of square log structures built in alternate cross-layers (like a log cabin) to provide cover for fish. The cribs may also contain several layers of branches or logs to increase habitat complexity.
The crib corners are fastened using nails, rods, wire, etc. Cement blocks or sand bags may be used to sink and secure structures. Bassett (1994) found that log cribs filled with branches and/or several log cribs placed together supported more fish than 'empty' cribs and/or individual cribs, and that different-sized interstitial spaces within cribs attracted different species of fish. The longevity of log cribs depends largely on the durability of the type of wood used (Bassett, 1994). Similar structures could be constructed with more durable artificial materials.

4.3.11 Cross-piece structures

Robinson (2003) recommends that horizontal cross-pieces be attached in alternating directions to jetty pylons to provide additional surface area for epibiota and ambush points for predatory finfish (Figure 17). The basic design could be modified using different materials, cross sections and sizes to provide additional complexity.

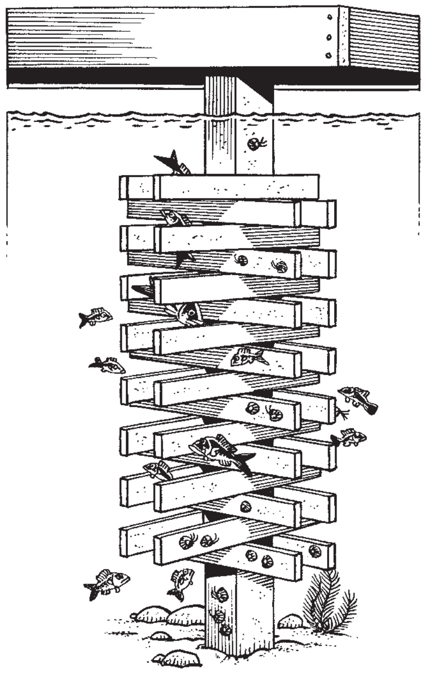

Figure 17. Pylon with cross-pieces. Diagram based on photograph in Robinson (2003).

4.3.12 Wooden pallets

These modules consist of wooden pallets that may be arranged in a variety of different forms. Pallets may be formed into a triangle or square and used as individual units or stacked to form pallet towers. Individual pallets can also be placed vertically in the water column or stacked on top of each other horizontally. Depending on the configuration, some structures may be heavy and difficult to move. Structures are sometimes combined with submerged trees in freshwater reservoirs. The robustness and durability of wooden pallets in higher-energy environments such as coastal waters are questionable.

4.3.13 Spawning structures

This category includes structures that create spawning habitat for specific species of interest. For example, the 'catfish condo' (Figure 18) provides nesting habitat for mature catfish in US freshwater reservoirs. These employ low cost, readily available materials such as PVC or concrete pipes formed into a pyramid and bound with plastic straps. Pipes may be filled at one end to provide staggered entrances and greater isolation for spawning fish, especially where fish have territorial requirements. The tubes also protect catfish eggs from exposure to sunlight.

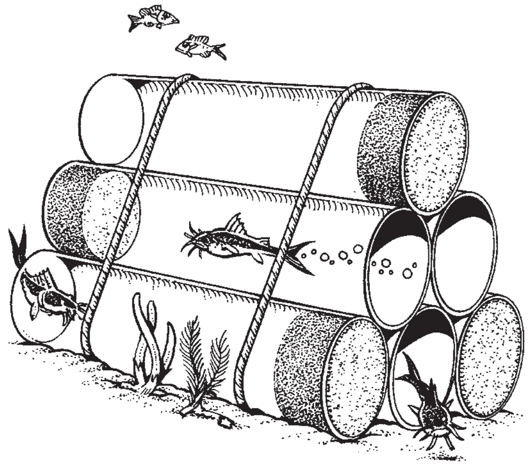

Figure 18. Catfish condo.

Other similar structures include spawning benches (a platform on concrete blocks) and spawning boxes (usually a box with an opening in one side for fish to enter). Knowledge of the spawning habitat requirements of local species is required for such structures to function effectively. For example, spawning boxes and benches placed in US lakes increased reproduction rates of smallmouth bass, which construct nests inside the boxes and under or beside the benches (Bassett, 1994).

Case study: Tampa Bay National Estuary Program

Private jetties have been used as part of a strategy to restore the ecosystem of Tampa Bay in Florida, USA. The population of edible scallops in the Bay was depleted in the 1960s due to degraded water quality and habitat (seagrass) loss. As part of a restocking program, waterfront homeowners attached small cages ('scallop condos') to their docks, in which scallops were placed to protect them from predators until they spawned. It is intended that the spawn from these 'pampered' scallops will help to replenish the depleted natural scallop population of Tampa Bay (American Oceans Campaign, 1996).

4.3.14 Patented artificial habitat modules

A number of artificial fish habitat modules have been patented in the United States. US patent information is available online at: http://www.freepatentsonline.com/

4.3.15 Substrate modifications

Various substrate types are used to enhance fish habitat, including concrete, earth mounds, rock, and shells. Enhancements may provide habitat for adult, juvenile and spawning fish. Placing gravel underneath and around infrastructure can provide spawning areas for some fish (Robinson, 2003), and may increase habitat complexity in areas of soft substrate. Rock reefs have been installed in many US lakes to encourage spawning of fish, including walleye, trout and smallmouth bass (Bassett, 1994). Substrate modifications do, however, involve replacing existing natural substrate with artificial or alternative materials and should only be carried out where there is a clear need and benefit.

5. Conceptual representations of fish-friendly structures

Figure 19 contrasts an 'ideal' fish-friendly jetty (lower diagram) with a 'minimalist' jetty (upper diagram). The ideal jetty incorporates a range of fish-friendly enhancements including a sloping revetment with variable-sized armour stone and several artificial fish habitat modules. In contrast, the flat, smooth, vertical surfaces of the minimalist jetty provide less fish habitat and support fewer fish. Note that this is a stylised diagram intended to illustrate fish-friendly concepts and is not intended to represent actual proportions.

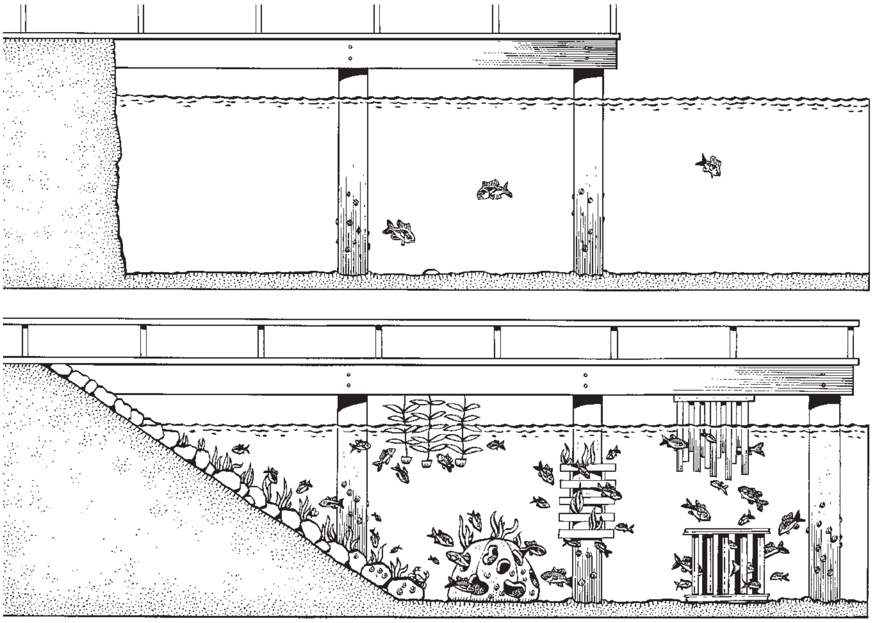

Figure 19. Conceptual jetty comparison.

A conceptualisation summarising the fish-friendly principles and design features in this guideline is presented in Figure 20. Existing natural fish habitats are maintained, while aquatic infrastructure is located away from these habitats and adjacent to existing urban development. Infrastructure is enhanced with design features to maximise artificial fish habitat and there is connectivity between natural and artificial habitats.

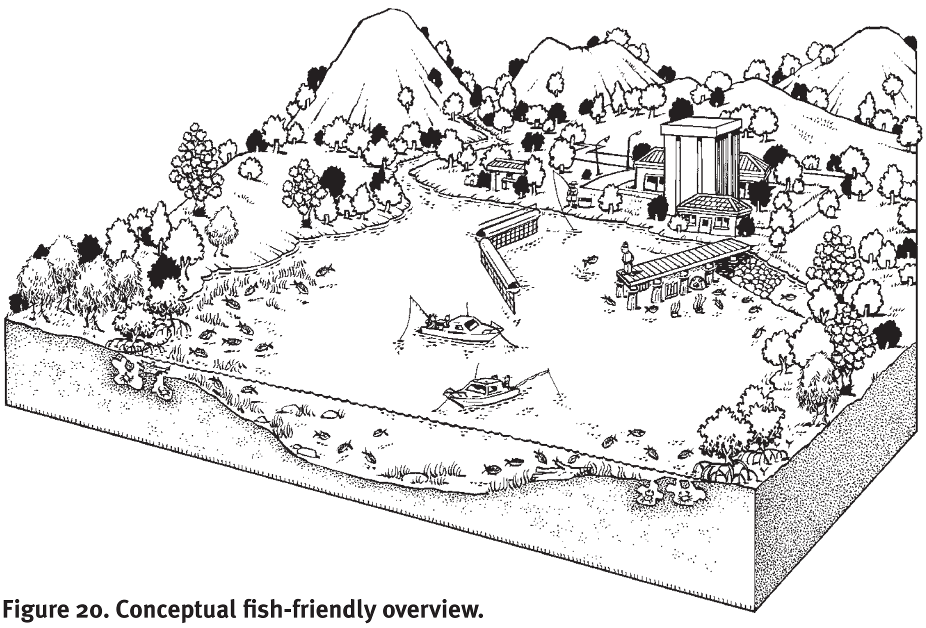

Figure 20. Conceptual fish-friendly overview.

6. Glossary

Aquatic infrastructure	Artificial (human-made) structures placed in or over water.
Artificial fish habitat	Human-made structures designed to provide a living place for fish.
Assemblage	A collection of organisms in a given habitat.
Benthic	Living on a substrate.
Biological zonation	The distribution of the different species of a community into separate zones, which are created by variations in the environment.
Biota	All of the living organisms in a given area.
Buffer zone	A separation area designated to moderate adverse influences from development construction and operation activities on fish and fish habitats.
Community	All the groups of organisms that live in a common environment and interact with each other.
Cryptic	A fish that hides among sheltering cover, and/or has camouflaging colouration.
Declared fish habitat area (FHA)	As defined in the *Fisheries Act 1994*, section 4, schedule dictionary. See also section 120 and 122 of the *Fisheries Act 1994* and part 9, section 94 and schedule 7 of the *Fisheries Regulation 1995*. FHAs protect fish habitats from alteration and degradation by strictly limiting development within and adjacent to the boundaries of the FHA.

Ecologically sustainable development	Using, conserving and enhancing the community's fisheries resources and fish habitats so that: a) the ecological processes on which life depends are maintained; and b) the total quality of life, both now and in the future, can be improved. The principles of ecologically sustainable development are: a) to enhance individual and community wellbeing through economic development that safeguards future generations; b) to provide fairness within and between generations; c) to protect biological diversity, ecological processes and life-support systems; d) in making decisions, to effectively integrate fairness and short and long-term economic, environmental and social considerations; e) to consider the global dimension of environmental impacts of actions and policies; f) to consider the need to maintain and enhance competition, in an environmentally sound way; g) to consider the need to develop a strong, growing and diversified economy that can enhance the capacity for environmental protection; h) that decisions and actions should provide for broad community involvement on issues affecting them; i) the precautionary principle. (Queensland *Fisheries Act 1994*).
Epibiota	Aquatic organisms living on a substrate. Sometimes referred to as 'encrusting' or 'fouling' growth.
Estuarine	An area where a freshwater waterway meets the ocean and where salt and fresh waters mix.
Fish	As defined under the *Fisheries Act 1994*, section 5. Includes finfish, crustaceans, molluscs, echinoderms, sponges and worms.
Fish habitat	As defined in the *Fisheries Act 1994*, section 4, schedule dictionary. Includes land, waters and plants associated with the life-cycle of fish, and includes land and waters not presently occupied by fisheries resources.

Fisheries productivity	The biomass of fish produced in a given area over a given time.
Fisheries resources	As defined in the *Fisheries Act 1994*, section 4, schedule dictionary. Includes fish and marine plants.
Habitat	The area or environment in which an organism or group of organisms lives.
Holistic	Looking at the whole system rather than just concentrating on individual parts.
Intertidal	The area of land between the extent of the highest and lowest astronomical tides.
Invasive or pest species	An organism that establishes itself in habitats outside of its natural range and threatens natural biological diversity and processes.
Littoral transport	The movement of material, by waves or currents, in the nearshore zone of the sea or a waterbody.
Macrobenthic	The larger organisms that live on a substrate and can be observed with the naked eye.
Macrofauna	The larger animals that can be observed with the naked eye.
Macroinvertebrate	Animals without a backbone that are large enough to be seen with the naked eye.
Marine plant	• a plant (a 'tidal plant') that usually grows on, or adjacent to, tidal land, whether it is living or dead, standing or fallen; • the material of a tidal plant, or other plant material on tidal land; and • a plant, or material of a plant, prescribed under a regulation or management plan to be a marine plant. 'Marine plant' does not include a declared plant under the *Rural Lands Protection Act 1985*. (Queensland *Fisheries Act 1994*)
Mitigation	Measures to moderate the severity of development impacts on fish and fish habitats.
Morwong	A chelodactylid finfish found on cool temperate reefs.
Niche	The functional position of an organism in its environment, comprising the habitat in which the organism lives, when it occurs and is active there, and the resources it obtains there.
Population	A group of organisms of the same species living within a specified region.
Propagule	A part of a plant which, when detached, can give rise to (propagate) a new plant.

Recruitment	The influx of new members into a population by reproduction or immigration. Recruitment to a fishery occurs when fish become vulnerable to capture by fishing gear.
Riprap	Stones or rubble used to secure a foundation or shoreline.
Saltmarsh	An intertidal habitat occupied mainly by herbs and dwarf shrubs, characteristically able to tolerate extremes of environmental conditions, notably waterlogging and salinity.
Sessile	Animals that live permanently attached to a surface, i.e. sedentary animals.
Substrate	The surface on which an organism lives, including the sea-bed or bed of a waterbody.
Tidal land	As defined in the *Fisheries Act 1994*, section 4, schedule dictionary. Includes reefs, shoals and other land permanently or periodically submerged by waters subject to tidal influence.
Waterway	As defined under the *Fisheries Act 1994*, section 4. Includes a river, creek, stream, watercourse or inlet of the sea.
Weep hole	A hole in a retaining wall that allows water to seep through and thus relieves pressure against the wall.

7. Acronyms

ASS	Acid sulphate soil.
DPI&F	Department of Primary Industries and Fisheries, Queensland
ESD	Ecologically Sustainable Development
FHA	Declared fish habitat area
GBRMPA	Great Barrier Reef Marine Park Authority
GCCC	Gold Coast City Council
NGO	Non-Government Organisation
The Act	Queensland *Fisheries Act 1994*
UFHMRP	Urban Fish Habitat Management Research Program

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10. List of Figures and Tables

Appendix 1: Fish-friendly structures checklist

- ESD principles were followed in project design.
- Fish-friendly considerations were integrated into the planning, design, construction and operation of infrastructure.
- Important fish habitats were avoided.
- All reasonable steps were taken to minimise disturbance of fish habitats.
- Works were scheduled to avoid critical biological events.
- Artificial structures were not used to justify impacts on natural fish habitats.
- Fish-friendly guiding principles and the full range of design features were considered to ensure that structure design maximises benefits and minimises impacts to fish and fish habitats.
- The fish habitat values of existing structures were improved.
- Fishing access was improved.
- A research/monitoring program into the effects of fish-friendly structures has been developed and implemented.
- A plan to educate and engage with the community regarding the development's fish-friendly features has been developed and implemented.

Appendix 2: Suppliers

AquaCribs® are manufactured by Great Lakes Products Inc.,
PO Box 489, Big Bend WI 53103-0489, USA.
Website: http://www.aquacrib.com/index.htm

Fish Habs® are manufactured by Berkley, One Berkley Drive,
Spirit Lake, IA 51360, USA.
Website: http://www.berkley-fishing.com/

Fish 'N Trees® are manufactured by Plastics Research and Development Corporation (PRADCO), POB 1587, Fort Smith, AR, USA.

Hazelett Elastic Mooring System, Hazelett Marine,
PO Box 600 Malletts Bay, Vermont 05446-0600, USA.
Website: http://www.hazelettmarine.com/

McIntosh Sea Kites. Website: http://www.reefix.com/mcintoshP2.htm

Reef Balls™ are available through the Australian distributor,
David J Lennon and Associates, 2/79 Champion Street, Brighton,
Victoria 3186. Reef Ball™ website: http://www.reefball.org

SunDocks™ are manufactured by Dockrider Systems™,
4114 Herschel Street, Suite 107, Jacksonville, FL 32210.
Website: http://www.dockridersystems.com/

Terrafix® geotexile fabric is manufactured by Soil Filters Australia Pty Ltd,
P.O. Box 727 Southport, Queensland, Australia, 4215.
Website: http://www.soilfilters.com.au/

Appendix 3: DPI&F Contacts

Northern Fisheries Centre	Southern Fisheries Centre
(North of Sarina inclusive) PO Box 5396 (38–50 Tingira St, Portsmith) Cairns Qld 4870 Telephone: (07) 4035 0100 Facsimile: (07) 4035 4664	**(South of Sarina)** PO Box 76 (13 Beach Road) Deception Bay Qld 4508 Telephone: (07) 3817 9500 Facsimile: (07) 3817 9555
Brisbane City (Head Office)	
Department of Primary Industries and Fisheries GPO Box 46 (80 Ann Street) Brisbane Qld 4001 Telephone: (07) 3224 2249 Fax: (07) 3239 3055	
DPI&F website www.dpi.qld.gov.au	**DPI&F Business Information Centre** Telephone **13 25 23** Email: **callweb@dpi.qld.gov.au**