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Research priorities to sustain coastal fisheries resources in the Great Barrier Reef region

A scoping study for the Tully-Murray catchment

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CSIRO

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Executive Summary

Historically, fisheries sciences have tended to focus on either freshwater or marine systems, despite the continuous gradient from freshwater, through estuarine to marine habitats. Accordingly, the interfaces between systems have received less emphasis than is warranted by their ecological and economic importance. The increasing realisation that land-based processes within catchments contribute significantly to ecological processes in rivers, estuaries and coastal environments has led to a need for a systems-scale approach that transcends traditional salinity-based boundaries of fisheries sub-disciplines. This report presents the marine catchment basin concept as a basis for integrating the different system components that link catchments, river networks, estuaries and coastal ecosystems in the Great Barrier Reef region, in a fisheries context.

Marine catchment basins consist of five broad ecological zones governed by different material transport and productivity processes: (1) montane and slopes river reaches upstream of the floodplain; (2) lowland floodplain reaches; (3) saline estuarine reaches; (4) the coastal river plume extending seaward; and (5) coastal waters outside the river plume. Prominent models describing processes governing aquatic production, habitat use by fish, fish recruitment in coastal systems, and the role of environmental disturbance in sustaining the diversity and production of fish are considered with respect to these broad ecological zones within the hierarchical habitat structure of marine catchment basins.

Development of large-scale system understanding of the responses of fish to catchment change within the GBR region is dogged by serious deficiencies in current knowledge of coastal fish ecology extending from freshwater to marine environments. Major knowledge gaps include sparse information on the patterns of faunal composition, distribution and abundance of fish assemblages and the physical, chemical and biological processes driving the patterns.

Despite persistent, widely-held beliefs that estuaries provide critical refuge and nursery habitats for many species from freshwater and marine environments, the concept of estuary dependence and the nursery function of habitats has received only superficial attention, mostly for high profile species such as barramundi and mangrove jack, and requires a more critical and sophisticated approach to improve its relevance to catchment-scale management.

Knowledge of aquatic food webs supporting fish production is limited to a small number of studies in the GBR region. Popular paradigms espousing the importance of mangroves, seagrasses, and benthic algae as the main primary producers supporting fish food webs are each supported to some degree by different studies, raising questions about the importance of spatial scale, site-specificity, and flexibility in the diets of fish. But with current catchment management strategies focussing strongly on improving water quality in aquatic systems, the implications of such changes for production in fish food webs, and the scales at which the changes are likely to be manifest, is a high research priority.

The ability of fish to move in both upstream and downstream directions and among habitats sets them apart from other ecological material transport processes dominated by downstream movement only. Connectivity among habitats over a range of spatial and temporal scales that make up the coastal habitat mosaic is vital to fish life cycles. However, the wider importance of biological connectivity has received little recognition and there has been little effort directed to integrated study at a process level, in the coastal zone of the GBR region.

The conventional dichotomy of fisheries research and management into freshwater and marine components is unhelpful in the context of improving catchment-scale land and water use. This artificial dichotomy constrains scientific thinking and fishery management to a scale below the operational focus of contemporary catchment management. If the marine catchment basin scale is to be managed effectively, then new ecological conceptual models

that deal with the whole fishery resource are required. This report has identified knowledge gaps that limit our ability to develop more appropriate conceptual models of ecological function at the marine catchment basin scale. As these gaps are addressed and conceptual models become more refined, it will be possible to develop better predictive fisheries models to explore consequences of management scenarios within marine catchment basins of the GBR.

This broader approach will empower fisheries stakeholders to become more effective in participating in management of marine catchment basins beyond the traditional fisheries jurisdictions to improve the sustainability of the fishery resources of the GBR. Conversely, this approach will also facilitate a better appreciation by catchment users and managers of downstream and system-scale implications of their decisions and actions.

Knowledge gaps emerging from this analysis fall into two types, concerning impediments to improved management to sustain coastal fisheries based on existing conceptual models, and scientific knowledge gaps that limit the applicability of existing conceptual models. The primary knowledge gaps fall into six categories:

- i. Effects of climate change;
- ii. Fishery issues for ecosystem sustainability;
- iii. Knowledge limitations in fish ecology;
- iv. Understanding of ecosystem processes reflected in food web structure and function
- v. Understanding the importance of habitats and threats to habitats for improved habitat management; and
- vi. Data limitations impeding better information integration.

Categories ii, iv, v and vi are considered to be high priority issues for the Tully-Murray system. In addressing these issues, additional knowledge gained on fish ecology will have broader relevance to major fisheries locations elsewhere.

Recommendations

- (i) Develop a conceptual model of ecological production for the Tully-Murray marine catchment basin that identifies indicators of ecosystem health pertinent to fish production for monitoring responses to catchment change. Such a model will be critical to facilitate effective participation by upstream and downstream stakeholders in priority setting within the catchment.
- (ii) Develop a quantitative model of the responses of aquatic organisms to changes in habitat availability and water quality, based on Recommendation (i), to predict risks and trade-offs for aquatic resources and fisheries associated with catchment management scenarios.

Important knowledge gaps to support conceptual and predictive model development are:

- (iii) Quantify how coastal food webs that support fisheries vary spatially within the Tully-Murray marine catchment basin between marine, estuarine, freshwater and wetland habitats, and over time between wet and dry seasons. This recommendation includes the food requirements for fish production and the implications of changing stoichiometry for fish nutrition, as well as determining how these processes are influenced by catchment change.
- (iv) Develop innovative, cost-effective technology for monitoring responses of fish populations to catchment change at the marine catchment basin scale within the Tully-Murray system.

(v) Quantify the contribution of wetlands to fish production at the Tully-Murray marine catchment basin scale to identify potential large-scale benefits of wetland rehabilitation.

(vi) Identify the importance of habitat diversity and connectivity for fish production at the marine catchment basin scale, with respect to effects of catchment change on aquatic habitats and connectivity.

(vii) Identify the processes influencing and controlling recruitment of fish to the Tully-Murray marine catchment basin, including the role of nursery habitats within the system, and risks associated with different reproductive strategies.

(viii) Undertake strategic research to quantify effects of catchment impacts and effectiveness of intervention within the Tully-Murray catchment on water quality, habitat availability, fish biodiversity, population dynamics and food web dynamics to support modelling efforts at the marine catchment basin scale.

(ix) Identify the scale-dependence of information from the Tully-Murray system and transferability to other marine catchment basins, and to other regional scales such as the Wet Tropics, and the whole GBR.

Table of Contents

Introduction

The status and trends in estuarine and coastal fishery production in the Great Barrier Reef region of eastern Australia reflect a composite of features common to similar fisheries around the world. Global fisheries production from marine, inland and aquaculture sectors is approximately 125 million tonnes per year (UN Atlas of the Oceans 2005), of which Australia produces just 276,000 tonnes, or 0.2% of the world total (ABARE 2005). Queensland production contributes 33,700 tonnes annually, of which wild capture from the Great Barrier Reef region accounts for approximately 22,000 tonnes, or 8% of the national total (Williams 2002, ABARE 2005). Many of the species caught from the GBR region depend on estuaries or nearby coastal waters for at least part of their life cycle (Robertson and Duke 1990b). In 2003, the value of commercial and recreational fisheries in the GBR was estimated at $359 million (Productivity Commission 2003). In addition to this estimate, freshwater ecosystems draining coastal catchments in the GBR support strong recreational fisheries, with many of these freshwater species also depending on estuaries for part of their life cycle.

Many fish species are held in high esteem by society for their eating qualities, angling opportunities, and conservation values, so that managing targeted species and fishers, and protecting non-target species and their habitats requires an added economic cost that is largely not reflected in estimates of landed catch value. In 2004 DPIF alone spent $44 million across all fishery resource management activities for the State. When contributions from other management agencies and research organisations are included, fisheries-related investments in the GBR region alone may greatly exceed $44 million per year in addition to the value of the landed catch.

Accordingly, although the economic value of fisheries in the GBR region may be small by global standards, fish production, recreational fishing expenditure, and investment in fish conservation measures are significant components of the economy at regional and State levels.

At a global scale, estuaries are the most economically valuable natural ecosystems by area in the world (Costanza et al. 1997), closely followed by floodplain wetlands, seagrass and algal beds, and tidal marshes and mangroves. At US$521 ha^{-1} for estuaries and US$466 ha^{-1} for tidal marshes and mangroves, the value of food production from these ecosystems is more than double the value of coral reefs, their nearest rival. In Australia, Morton (1990) estimated the value of commercial fish alone in Moreton Bay mangroves at $8000 ha^{-1}, an order of magnitude greater than the global estimate. Morton's estimate does not account for the non-commercial species consumed as prey by commercial species, nor does it include crustaceans that also have a significant commercial value. As a result, the values reported here are likely to significantly underestimate the true value of estuarine and associated ecosystems.

Historically, fisheries and related aquatic sciences have tended to focus on either freshwater or marine systems, despite the continuous gradient from freshwater, through estuarine to marine habitats. Accordingly, the interfaces between systems have received less emphasis than is warranted by their ecological and economic importance. However, with the increasing realisation that land-based processes within catchments contribute significantly to ecological processes in rivers, estuaries and coastal environments, there is an increasing need for a systems-scale approach that transcends traditional salinity-based boundaries of fisheries sub-disciplines. This report presents the marine catchment basin concept, as defined by Caddy (2000), as a basis for integrating the different system components that link catchments, river networks, estuaries and coastal ecosystems in the GBR region, in a fisheries context.

Throughout this report, coastal systems refer to aquatic ecosystems including freshwaters, estuaries, and coastal environments that are directly influenced by water and materials that come from coastal catchments. Coastal fisheries include all fishing activities occurring within this loose definition of coastal systems.

The marine boundary of this definition of coastal systems is blurred, since the extent of river plumes varies spatially between rivers, and temporally between high and low flow events. The boundary is further blurred by the varying influence of coastal currents. But the marine extent of catchment basin effects is of low importance for the purposes of this report, since the focus is on the internal interfaces between freshwater and marine habitats rather than the outer boundaries. Furthermore, the ecology of coral reef fishes and their associated fisheries is a long established specialist area of fisheries research, and will not be considered further within this review except where life history stages of reef species inhabit estuaries and coastal waters.

Global fisheries are currently exposed to a number of threats that can be briefly summarised as:

i. alteration of flow regime flushing estuaries and providing habitat connectivity;

ii. changes in transport of sediments, nutrients and other contaminants affecting water quality and primary production in food webs;

iii. land-use changes in agricultural and urbanised catchments;

iv. loss of fish habitats;

v. increased fishing pressure and over-fishing;

vi. prospects for climate change, and changes in sea level.

These categories are not independent, since increasing agricultural or urban development is likely to result in increased water demand and altered river flows, loss of fish habitats through coastal land clearing, and increased contaminant loads entering rivers. If fish stocks decline as a result of these impacts without a commensurate reduction in fishing effort, then the risk of over-fishing increases. As catchment development expands to meet the demands of human population growth, effects on regional and global climates are likely to increase, which will eventually result in altered rainfall and runoff patterns, and further changes in river flow.

Tropical estuarine fisheries worldwide are threatened by overfishing, with most fisheries being either fully exploited or over-exploited, and habitat loss or degradation resulting from human activity (Blaber 2000). These concerns are evident in the inshore fisheries of the Great Barrier Reef region with large increases in fishing effort for some species and on-going habitat degradation in estuarine and inshore habitats (Williams 2002).

Large-scale habitat degradation has been observed through changes in freshwater flows to estuaries and coastal ecosystems (Gillanders and Kingsford 2002). Caddy (2000), in his comparison of marine catchment basin effects with fisheries impacts, recognised several ecological features that are common to both overexploited and nutrient-enriched systems. He hypothesised that more eutrophic systems will have: relatively small sizes of fish and short life spans; short, simple food webs with low mean trophic level or diversity; few large, long-lived benthic organisms; predominance of small pelagic planktivorous species over demersal, piscivorous species, and hypoxic or anoxic conditions close to the bottom of the water column. Given the concerns about inshore fishery trends and nutrient loads entering the GBR lagoon from coastal rivers, Caddy (2000) provides testable hypotheses regarding fishery trends and environmental health of the GBR.

Responses to these threats involve action across a hierarchy of scales ranging from global initiatives to local rehabilitation efforts. Sustaining fishery production at global, regional and local scales in the face of these interacting forces is complex and dynamic. The Great Barrier Reef region and local-scale catchments within the region present a microcosm of the issues facing global fisheries. Conversely, identifying issues and research needs to sustain fisheries at the local and regional scales in the GBR contributes directly to the development of solutions for a global problem of natural resource sustainability. The degree of interaction among these processes means that management of individual threats without due recognition of ecosystem linkages and the scales at which these processes operate, carries a risk of unexpected side effects, and reduces the potential effectiveness of efforts through a piecemeal approach. Consequently, a unified approach is required which captures the scale of ecosystem processes and the linkages between system components so that efforts to manage threats are synergistic and not counterproductive.

Scope of this report

The scope of systems considered here is depicted as a template of the main components of marine catchment basins (Figure 1).

Freshwater reaches above the floodplain (1) transport water, sediments, nutrients and other materials coming off the catchment. In areas modified by urban and rural development, the natural hydrology is often altered with the flow carrying elevated loads of suspended and dissolved materials. These reaches are typically erosional or transport functional process zones within the river system. Physical barriers such as dams and weirs impede upstream and downstream migrations of fish and other organisms. Fishery issues in these reaches are dominated by recreational fisheries, and strong efforts in fish conservation as part of broader river health initiatives. There are no commercial freshwater fisheries in the GBR region, although some species of commercial and recreational importance migrate from the estuary and spend part of their life history in freshwater habitats.

Floodplain freshwater reaches (2) are affected by the same processes as upstream reaches, but the impacts are delivered in different ways. As floodwaters spill over the floodplain and lose their energy, they deposit their sediment load on the floodplain. Accordingly floodplain reaches are typically considered as depositional functional process zones. But where floodplain vegetation has been modified or removed, the modern floodplain may erode and become a source of new sediment to the river. Upstream changes in hydrology may lead to floodplains not being inundated as frequently, or being inundated for shorter periods, with the result that wetlands are not connected as frequently as would normally occur. These changes mean that some fish nursery habitats have disappeared, or have a diminished role, whilst freshwater fish that live in wetlands only and avoid main channel habitats may experience a decline in habitat quality and quantity. A larger number of species that inhabit floodplain reaches and floodplain habitats are important for recreational and commercial fisheries.

As waters become more saline at the head of the estuary (3), species of commercial importance become more abundant. Bi-directional tidal flushing is added to the downstream river flow, making estuarine habitats more complex hydrologically than the riverine reaches upstream. Freshwater flowing into the estuary carries a load of suspended sediment and nutrients that influence biological production in the estuary. Tidal water movement also carries this material into the intertidal zone, which may support seagrass, mangrove or saltmarsh habitats. These habitats provide some degree of protection for estuarine species from larger predators, whilst other species gain significant food resources from different parts of the estuary. Many species of freshwater fish, and marine fish, either migrate to estuaries to spawn, or rely on currents to carry their young to productive estuarine habitats. As these juveniles mature, many leave the estuary to reach their freshwater or marine adult habitats. Large estuaries are accessible to a diverse range of commercial fishing methods, and provide catches ranging from prawns to large predatory fish and sharks, as well as smaller benthic species.

River plumes (4) carry water and suspended and dissolved material from the estuary into the marine environment. Depending on the degree of mixing in the estuary and the amount of freshwater flow, the plume may carry relatively low salinity water some distance offshore, or along the coast. Where coastal waters are protected from wave energy by islands or offshore reefs, they may display conditions very similar to an estuary, with relatively high turbidity, fluctuating salinity, and low wave energy, so that they are functionally similar to estuaries and support the same range of species. Because of the more open habitat, river plumes provide access to large-scale net, trawl and line fisheries. The process by which marine species

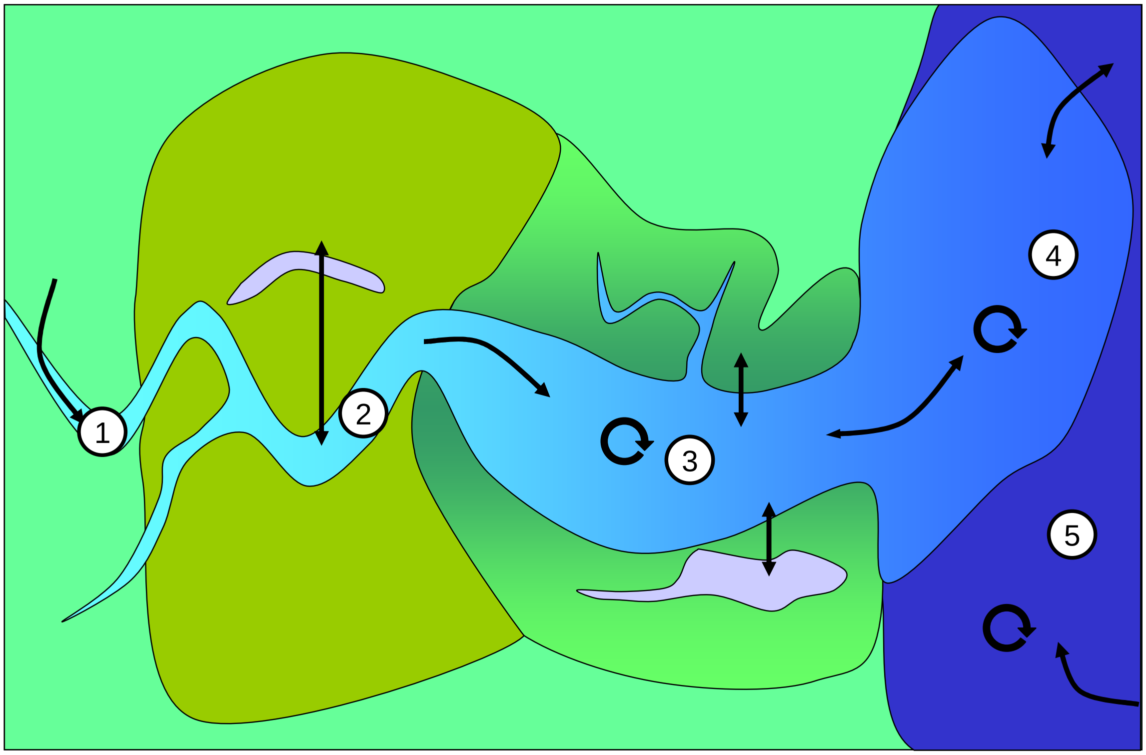

Figure 1. *Scope of this study depicted as major sub-components of the marine catchment basin template. Arrows indicate direction of major material transport within numbered zones. Circular arrows show major zones of material recycling. 1. Montane and slopes river reaches upstream of the lowland floodplain reaches, dominated by allochthonous material inputs and primary production; 2. Lowland reaches characterised by well-developed floodplain with freshwater wetlands, dominated by lateral autochthonous and allochthonus inputs and primary production; 3. Estuarine reaches with salt-tolerant riparian vegetation and brackish wetlands, dominated by allochthonous upstream inputs, tidal autochthonous inputs and autochthonous production ; 4. River plume extending seaward, dominated by catchment inputs and autochthonous production. Depending on flow conditions and tidal currents, imports of marine material may dominate catchment inputs 5. Coastal waters outside the river plume, dominated by autochthonous inputs and primary production.*

make their way into estuaries is not known, but it is likely to involve a combination of active responses to environmental gradients such as depth, salinity, turbidity, wave action, and currents, and passive dispersal.

Coastal waters outside the river plume (5) provide similar physical habitats to those found in the plume, because the timing of tidal currents, prevailing coastal currents, and freshwater flow events mean that the plume may cover different areas at different times. These waters are readily accessible to commercial and recreational fishers, whose skill in locating fish requires an understanding of fish behaviour and the way fish respond to changes in their environment.

This scoping report briefly reviews existing knowledge of the ecological processes that support ecological fish production in tropical estuaries in the Great Barrier Reef region to identify gaps in current understanding that impede implementation of environmental management strategies to sustain regional fisheries. In this context, fish production within aquatic ecosystems is distinct from fisheries production, which refers to a measure of landed catch by the fishing industry. For a fishery to be sustainable over time, fishery production

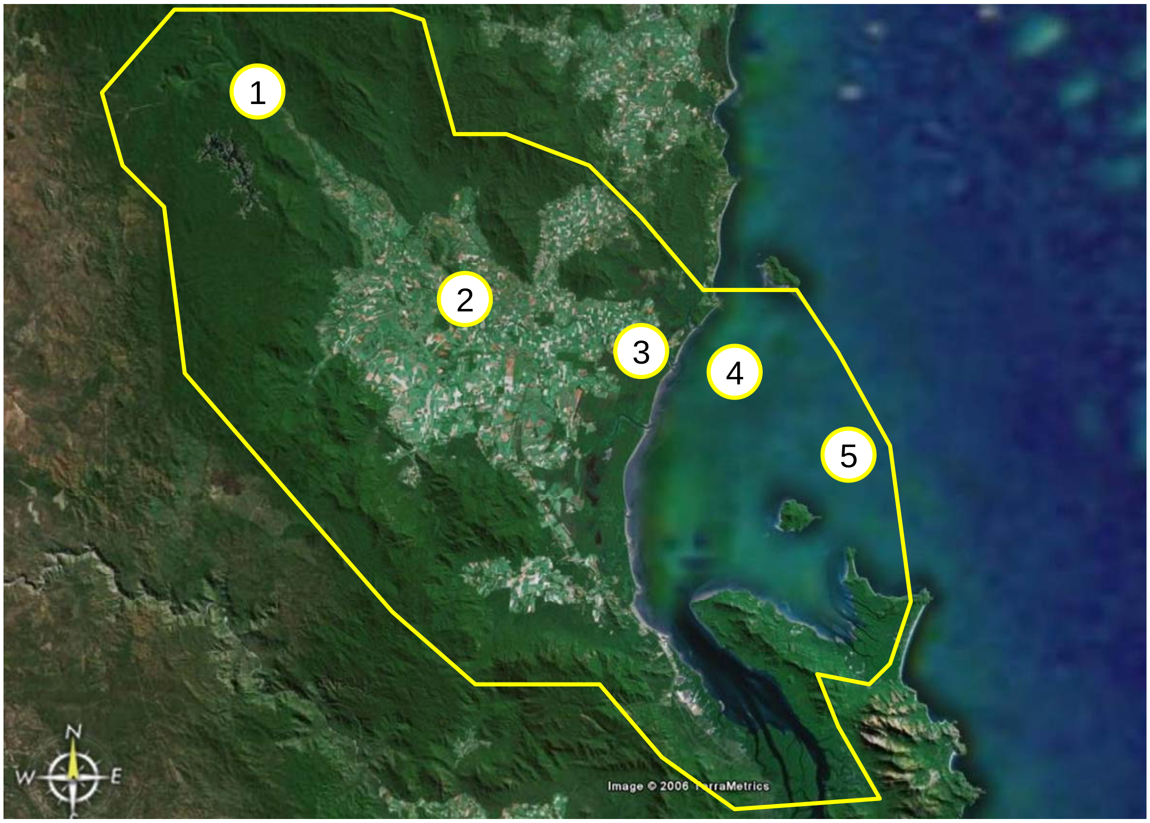

Figure2. *Approximate geographical scope of the Tully-Murray marine catchment basin, with numbered zones corresponding to Figure 1. The southern boundary in Hinchinbrook Channel is somewhat arbitrary depending on the influence of freshwater inflows and tidal dynamics from the channel network on the distribution of material within Rockingham Bay. The outer marine boundary is also arbitrary, and is determined by the bathymetry of Rockingham Bay, and the magnitude of seasonal and episodic high flow events.*

must generally represent only a small proportion of total fish production within the defined system. Accordingly, this report emphasises research needs to sustain fishery resources, and does not consider the more specific research needs of the fishing industry. We then synthesise this information into a hierarchical structure to identify research priorities to promote the sustainability of coastal fisheries in an era of coastal catchment change. To maximise the applicability of our recommendations, we have focussed on generic issues common throughout the GBR, and then refined them for specific application in the Tully-Murray marine catchment basin.

River and estuary production models for tropical fisheries

Ecological production in freshwater, estuarine and marine environments is the culmination of production at different trophic levels within aquatic food webs. The biomass of fish at any given trophic level is determined in part by a combination of bottom-up processes derived from nutrient availability, and top-down processes in the form of predation pressure. The relative influence of bottom-up and top-down processes is modified by factors such as physical habitat refuges that may reduce vulnerability to predation, and the transient nature of such refuges if they are only available for some stages of the hydrological and tidal cycles.

Several models have been developed to describe the processes that support or drive ecological production in certain ecosystems, and all have some relevance to coastal fishery resources in the Great Barrier Reef region. These existing models are introduced briefly below.

Aquatic production models

River Continuum Concept

Vannote et al. (1980) introduced the River Continuum Concept (RCC), subsequently modified by Sedell et al. (1989), to represent the dynamic transport and transformations of allochthonous and autochthonous organic material, along the river continuum.

The RCC proposes that allochthonous material from riparian vegetation dominates organic material entering the headwater reaches, and these inputs decrease downstream as the channel becomes wider. Shading by the forest canopy over narrow headwater reaches limits autochthonous primary production. As the channel widens downstream, high irradiation allows autochthonous primary production to increase in the middle reaches. Further downstream in the lowland reaches where water is deeper and more turbid, autochthonous primary production decreases again because of the limited light penetration. The RCC assumes that aquatic species diversity is positively related to primary production, and predicts that species diversity is lower in headwater and lowland reaches, with highest diversity in the middle reaches, where the variability of physical factors is greatest.

The RCC emphasises in-channel processes involving downstream transport of organic material from low-order streams with dense tree canopies and steep gradients.

The RCC may have some relevance in short streams in the Wet Tropics where the hydrology is strongly influenced by local rainfall and flooding occurs only for short periods. Whilst the RCC is relevant to the transport of sediments and nutrients from the catchment into coastal waters, it does not take into account the role of floodplain wetlands as sinks or sources of material, representing a serious limitation in many tropical rivers.

Flood Pulse Concept

The Flood Pulse Concept (FPC) proposed by Junk et al. (1989) emphasises the role of seasonal floodplain inundation and flood recession as the driving force in riverine production and the ecology of riverine fishes. Accordingly, the FPC adds a lateral dimension to the RCC by emphasizing the importance of floodplains to fisheries production. As revisited by Junk and Wantzen (2004), this model considers the floodplain as being coupled with the river as a transition zone between aquatic and terrestrial environments, that is analogous to the intertidal zone of estuarine systems, albeit with a different frequency and duration of inundation.

According to the FPC, the nutrient status of the floodplain depends on the quantity and quality of dissolved and suspended materials in the river, whilst aquatic nutrient cycles, primary and secondary production and decomposition are strongly influenced by nutrient transport between terrestrial and aquatic habitats.

Flooding acts as a disturbance factor that resets ecological succession in aquatic and floodplain communities and prevents the system from reaching full maturity whilst maintaining elevated levels of production.

A critical component of the FPC is that a large part of the primary and secondary production occurs in the floodplain, with the river acting as a transporting agent for water and dissolved and suspended matter (Junk and Wantzen 2005). In this way, the river also provides refuge for aquatic organisms during low-flow periods and serves as a corridor for active and passive dispersal (cf Sheaves 2005 for estuarine analogy).

Riverine Productivity Model

Dissatisfaction with the RCC and FPC led Thorp and Delong (1994) to introduce the Riverine Productivity Model (RPM), which recognises the contribution of primary producers within the river channel and floodplain inputs to provide most of the organic carbon assimilated in secondary production in rivers. The RPM contends that the main annual energy source supporting metazoan production and species diversity in mid- to higher-trophic levels is autochthonous primary production entering food webs via algal-grazer and decomposer pathways (Thorp and DeLong 2002). The RPM introduces a paradox that at high trophic levels, such as fish, rivers can behave in an autotrophic way because the primary source of carbon is algae, and enters the food web via grazers, whilst the whole system is heterotrophic ($P:R < 1$) because respiration in the microbial loop greatly exceeds autochthonous production.

Whilst the sources and transformations of carbon that drive aquatic food webs and culminate in harvestable protein for fisheries provide an ongoing ecological debate, it is apparent that organic matter input and production comes from a combination of upstream tributaries (RCC), from floodplain habitats (FPC), and from the river channel itself (RPM) (Junk and Wantzen 2004). The importance of each of these sources to the carbon budget of any given river system depends on the location along the river channel, the spatial and temporal scale of the system under consideration, and on the food web pathways of interest. How these processes contribute to estuarine production remains to be evaluated.

Contribution of mangrove detritus to estuarine food webs

The paradigm that mangrove detritus constitutes the major source of carbon for estuarine food webs that support coastal fisheries (Odum and Heald 1975) has gained wide acceptance as the basis for protecting mangrove forests. It promotes a carbon pathway from mangroves → leaf litter → detritus → export → offshore decomposition → detritivores → lower carnivores → higher carnivores, with the local assimilation of carbon being highest where tidal flushing is low, and diminishing down the estuary as increased tidal flushing leads to greater export of mangrove carbon. In north-eastern Australia, sesarmid crabs consume large amounts of mangrove leaf litter within mangrove forests (Robertson 1986), providing a source of food for benthic carnivores such as juvenile mangrove jack and yellow-finned bream (Morton et al 1987), and for planktivorous species such as herrings and anchovies (Robertson et al. 1988) that feed on crab zoea larvae. Thus the crabs create a short-circuit in estuarine food webs (Sheaves and Molony 2000) by allowing mangrove carbon to be rapidly directed to higher predators which may then move offshore, avoiding the longer detritus recycling pathway for mangrove carbon. Despite the existence of short-circuits such as this, it is now widely recognised that mangroves constitute only a minor source of dietary carbon to estuarine food webs.

Loneragan et al (1997) found that mangroves contributed little to the diet of prawns in the Gulf of Carpentaria, a finding that has been supported in Port Curtis and in Moreton Bay (Melville and Connolly 2003, 2005, Connolly 2006), and in the Fitzroy and Ross Rivers (Sheaves et al. 2006, Sheaves unpublished data). Similar results have led other workers to the current opinion that microalgae (combined phytoplankton and benthic microalgae) provide the strongest food web support (e.g. Fry and Smith 2002). However, Melville and Connolly (2005) found that food webs supporting fish in Moreton Bay were based on transported organic material from seagrass beds, and that mangroves and

Box 1. Source of carbon for fish production in the coastal GBR

In Hinchinbrook Channel, in the Wet Tropics region of Australia, carbon (POC) exports are six times greater than the amount of carbon that accumulates in the intertidal mangrove habitats. Since POC accumulation in mangroves equates to only 2-5% of annual carbon production by the mangroves and saltmarshes, the intertidal zone appears to act as a major source of carbon to the aquatic system, as suggested by the FPC (Wolanski et al. 1999). However this study did not quantify inputs of carbon from upstream nor autochthonus carbon fixation. Whilst mangroves are not a major source of dietary carbon for most estuarine consumers (Melville and Connolly 2005), leaf-burying sesarmid crabs represent a major food source for estuarine predators such as estuary cod and mangrove jack (Sheaves and Molony 2000). Similarly, planktivorous fish may consume as much as half of the zoea larvae produced by these crabs (Robertson et al 1988), creating a short-circuit in mangrove food chains that cuts out the dominant litter export and detritus pathways by which most mangrove carbon enters the food chain. This recycling of mangrove carbon is interrupted by predation on crabs by specialist crab predators, like mangrove jacks and estuary cod. These are the juveniles of large, offshore predators and their life-history migration away for estuaries represents movement of a proportion of the recycling mangrove carbon to offshore systems.

The Fitzroy estuary in the Dry Tropics region of Australia receives DOC from the catchment upstream during high flows (RCC), and the estuary assimilates only a small portion of the DOC it receives (Ford et al. 2005). High flow DOC inputs are approximately ten times POC inputs. In contrast, the estuary contribution to POC slightly exceeds POC inflows. During low flows inputs of DOC and POC from upstream are minor, with the estuary acting as a source of carbon that is exported in small quantities to the coast. Thus, whilst the estuary and its floodplain figure significantly in the carbon budget in both seasons (RCC and FPC), the dominant source of carbon over an annual cycle is DOC from the catchment, but most of this material is transported straight through the estuary to the coast. During high flows, the river is uniformly turbid and little primary production occurs in the estuary. In contrast, during low flows, water clarity allows phytoplankton production in low salinity at the head of the estuary, but as the water becomes turbid downstream, primary production is restricted to mangrove and saltmarsh macrophytes, and intertidal microphytobenthos, suggesting the prominence of the RPM pathways. Wetland pools in the Fitzroy delta are often isolated from the estuary and upstream freshwater habitats for long periods. They are self-sufficient systems (emphasising RPM pathways) with their faunas dominated by detritus feeding fish that derive the majority of their organic carbon from saltmarsh vegetation, and aquatic macrophytes and algae.

In another Dry Tropics example, Port Curtis to the south of the Fitzroy estuary receives relatively small freshwater inflows and supports extensive intertidal and subtidal seagrass beds. Water in Port Curtis is less turbid than in the Fitzroy estuary, with less resuspension of fine sediments because of the weaker tidal currents. Fish, prawns and crabs sampled by Connolly (2006) from Port Curtis derived most of their dietary carbon from seagrass, and not from mangroves, benthic algae or phytoplankton as other models propose.

These examples illustrate the diversity of carbon sources utilised for fish production in different parts of the GBR, and the importance of applying the most appropriate conceptual model to correctly identify knowledge gaps and threats.

microphytobenthos made only minor contributions. Furthermore, the contributions of different categories of autotrophs varied among fish feeding groups.

Webster et al (2006) adopted a material budget approach for the Fitzroy estuary in Queensland to quantify the contribution of catchment, estuarine and marine nutrient sources to material budgets and the spatial distribution of primary production. This approach uses quantitative models of hydrodynamics and biogeochemical processes to predict where and when primary production occurs, supplemented by field measurements to validate the models. Consequently, these models are based around predictable physical processes, and become less reliable at trophic levels above primary production. As a Dry Tropics estuary with low flows in winter and episodic, highly variable high flows most likely to occur during summer, the Fitzroy estuary displays biphasic behaviour, with turbid high flow conditions flushing most material straight through the estuary with little pelagic or benthic primary production. In contrast during low flows, primary production occurs mostly at the head of the estuary in clear water, and in the relatively clear waters of Keppel Bay. But within most of the estuary turbidity generated by tidal currents restricts primary production to benthic algae or microphytobenthos on the intertidal mudflats.

It seems clear that the dominant sources of dietary carbon for fish food webs in coastal waters and estuaries vary according to location within the estuary, among feeding guilds, and among estuaries. This observation matches the general observation regarding the applicability of the RCC, FPC and RPM in specific reaches of individual river systems. Further research is needed to establish consistent patterns for individual estuaries and for the coastal GBR region as a whole.

Estuarine habitat models

Estuarine Dependence

Downstream of the freshwater river reaches, the concept of an estuarine-dependent phase in the life cycle of coastal fishes has become widely and uncritically accepted (Blaber 1997, Able 2005) following on from studies in the south-eastern USA (Gunter 1967, McHugh 1967, Day and Yáñez-Arancibia 1985). However, the number of species that reside solely within tropical estuaries rarely makes up more that 10-15% of the total fish fauna. These fish, along with those for which juveniles are found only within estuaries, comprise a group of truly estuary-dependent species that may account for only about one-third of the total fauna. The remaining species may be considered as estuarine opportunists that utilise relatively protected, shallow and turbid coastal habitats with little apparent regard for whether they are located within or outside a geomorphically-defined estuary. The concept of estuarine dependence arose largely to reflect observed patterns in fish distributions, but now requires a more sophisticated and critical re-appraisal as the processes that drive distribution patterns and the roles of habitats at different scales become better understood (Able 2005).

The presumed advantages of living in an estuary, or in estuary-like coastal waters, include protection from predation, access to an abundant food supply, and sheltered habitat (Blaber 1997).

Estuaries are commonly assumed to provide refuges from predation via relatively high turbidity, shallow waters that prevent entry by large predators, and access to structural habitats such as mangroves or seagrasses that offer concealment or confined spaces for refuge. However, empirical evidence for this argument is not strong, as most predacious fish do not rely solely on vision to capture their prey. Although shallow waters may offer some protection from predacious fish, piscivorous birds feed more effectively in shallow waters, so the level of protection from predation conferred by estuaries may be illusory. A subsequent advantage of estuary living may be the availability of a rich food supply. Blaber (1997) presents arguments that estuaries contain a far greater diversity of food types than offshore habitats, including zooplankton, larvae of mangrove-eating crabs, detritus and associated microfauna, gastropods and shrimps, barnacles, bivalves, sponges and brachyurans, and polychaetes. Longhurst (1957) found that fish with empty stomachs were commoner offshore than in estuarine conditions. Baker and Sheaves (2005) found that even juvenile fish within estuaries in the GBR exert high levels of predation on other larvae. There is therefore strong evidence for estuaries serving an important role in food supply for fish. This suggestion reduces the potential importance of protection from predation to an advantage of specific microhabitats, such as mangrove stands and seagrasses (Sheaves 2005) rather than being a general advantage for estuaries.

Estuaries tend to be well protected from wave energy, by outer barrier reefs, islands, and river mouths. Within tropical estuaries, mangroves themselves and the anastomosing creek networks dissipate much of the remaining energy generated by wind and tropical storms. Tidal energy exerts a strong influence, with tropical estuaries along the GBR being tidally dominated rather than wave dominated (Harris et al 2002). In macrotidal estuaries, such as the Fitzroy, that have large tidal ranges in excess of 5m, tidal energy repeatedly resuspends and transports bottom sediments so that in-channel macrophytes are unable to become established. Mangroves, small creeks, and adjacent salt flats therefore offer the main protection from physical disturbance. In estuaries with lower tidal energy, such as Hinchinbrook Channel, extensive seagrass beds provide some shelter away from the more robust mangroves. Other low tidal energy estuaries such as the Tully have little seagrass, presumably because of the high frequency of freshwater flushing.

Some species, especially migratory freshwater species, spawn in estuaries with the young fish migrating back into freshwater. These patterns may reflect both ecological advantages of estuarine food supply for the young fish, protected habitats, or in some cases represent an evolutionary behaviour that has been retained from species that originated in coastal waters before they adopted a predominantly freshwater life cycle. In catadromous species such as Australian bass in southern Queensland and jungle perch in tropical rivers, the juvenile estuarine phase is obligatory for successful completion of the life cycle (Pusey et al 2004). For amphidromous species, the estuarine phase may be more facultative and associated with behaviours other than breeding.

The concept of estuary dependence is valuable in a descriptive sense to classify species as permanent estuarine residents, obligate estuary users at some stage of the life cycle (usually as juveniles), and opportunistic estuarine species that may venture into coastal and estuarine waters periodically, or be distributed passively with currents and take advantage of habitats at their destination (Able 2005). However, further critical analysis is required to translate patterns suggesting estuarine dependence into an understanding of the processes driving the concept and their implications for sustaining fish productivity in estuarine and coastal habitats.

Foraging Arena Theory

Vulnerability to predation as considered under the estuary dependence hypothesis is closely related to the broader Foraging Arena Theory developed by Walters and Kitchell (2001). This theory focuses on the trade-offs in natural selection between obtaining sufficient energy for growth and reproduction, and avoiding predators whilst feeding (Walters and Martell 2004). Whilst foraging arena theory was developed as a general principle, it has powerful implications in the habitat mosaic of coastal ecosystems. In simplified form, most fish use separate habitats for foraging and for refuge from predators, because in the process of accessing their own prey, they risk becoming prey for other species. Accordingly, there is an inherent risk that emerging from a refuge to forage increases vulnerability to predation. As a theoretical concept, vulnerability tends to be low in systems or trophic pathways that are driven by bottom-up nutrient processes, and high in systems or pathways dominated by top-down predation. Consequently, a species that forages and finds effective refuge in a seagrass bed is likely to be less vulnerable to predation than species that forage in a seagrass bed at low tide, and seek refuge in mangroves at high tide, or which take refuge near the bottom of deep channels at low tide and forage on sand flats or amongst mangroves at high tide. Walters and Martell (2004) applied Foraging Arena Theory to help understand the shapes of stock-recruitment relationships that underpin many aspects of modern fisheries management, and the dynamics of predator-prey interactions in structuring aquatic food webs.

Fish recruitment models

Match – Mismatch Hypothesis

The match-mismatch hypothesis was developed by Cushing (1990) to describe the dependence of fish recruitment on the temporal synchrony between the occurrence of fish larvae when they commence feeding and their food supply. If larvae exhaust their yolk supply and commence exogenous feeding at a time when food, such as zooplankton blooms, is abundant and of the right size for them to ingest, then this matching in time will ensure high survival to recruitment. In contrast, if climatic factors result in either accelerated or delayed zooplankton abundance, then larvae may require high food abundance either too late, or too early for them to take advantage of zooplankton succession, and this mismatch may result in low survival to recruitment. The hypothesis originated to explain recruitment variability in North Sea cod as a function of the abundance of the copepod prey of juvenile cod, but is equally applicable in estuaries and coastal habitats. An example of this hypothesis operating in tropical estuaries comes from Alligator Creek where Robertson and Duke (1990a) recorded the recruitment peak for juvenile fish corresponding closely to the time of maximum abundance of the zoeal stages of mangroves crabs.

Member – Vagrant Hypothesis

Whereas the Match-Mismatch hypothesis emphasises temporal synchrony between fish larvae and their prey, the Member-Vagrant Hypothesis (Sinclair 1988) focuses on spatial patterns and advection currents. Fish larvae that are transported by prevailing currents to retention habitats with abundant food, such as convergence or upwelling zones, will find abundant prey and survive to become members of the recruiting cohort. Conversely, larvae that are dispersed elsewhere have a lower probability of encountering prey, and exist as vagrants with reduced likelihood of survival. Examples from tropical estuaries may include barramundi which spawn in estuaries, with larvae carried into shallow wetlands and salt flats during spring tides (Russell and Garrett 1983) before entering a freshwater phase. However, some vagrant individuals appear to survive in coastal waters, without ever entering freshwater habitats (McCulloch et al 2005). Similarly, juveniles of species such as mangrove jack and estuary cod are found only in estuaries, whilst mature adults are caught only from offshore reefs (Sheaves 1995). The absence of vagrant juveniles from other habitats suggests their chances of survival are low, with the corollary that dispersal mechanisms to enter estuaries may be highly efficient.

Environmental disturbance models

Intermediate Disturbance Hypothesis

The role of disturbance in maintaining ecosystem function has been explored by Connell (1978), who contended that species diversity was low in systems with either high or low frequencies of environmental disturbance, and achieved a maximum at some intermediate level of disturbance. This concept has become known as the Intermediate Disturbance Hypothesis. In coastal aquatic systems, disturbance occurs on several temporal and spatial scales. On a daily basis, estuarine tidal movements result in repeated inundation and exposure of the intertidal zone, facilitating the development of a rich habitat mosaic of seagrasses, mud or sand flats, mangroves, saltmarshes, and connecting creeks that supply carbon for estuarine food webs and productive ecological communities. On an annual scale, wet season rains impose a cyclic behaviour on stream hydrology with implications for longitudinal delivery of carbon (RCC) and floodplain inundation (FPC). At larger scales, episodic cyclones cause damage to riparian vegetation and large amounts of runoff, flushing the river and estuary with large volumes of fresh, turbid water, mobilising sediment and providing large quantities of new detrital material (debris from damaged riparian vegetation, mangroves, seagrass etc.) to reinvigorate detritus-based food webs. The role of frequency of disturbance has been well-developed in coral reef, rainforest, and to a lesser extent, arid zone river systems. But the concept has to date had only limited application in coastal catchments and estuaries. Gehrke et al (1995) found that the stabilising effect of river regulation on river flows was strongly correlated with reduced species diversity and increased abundance of introduced pest species such as carp in the Murray-Darling basin. Many estuarine and coastal organisms display strong responses to disturbed river flow regimes (see reviews by Gillanders and Kingsford 2002, Robins et al 2005), with reduced abundance, diversity or fish catches corresponding to reduced flow to the coast. Similarly, large flow events often correlate strongly with improved recruitment and increased fishery catches. However the upper extreme of disturbance, such as the effects of destructive cyclonic events, has not been considered in most studies. Considering the climate-change scenarios predicting increased severity and reduced frequency of monsoons and cyclones in the GBR region, understanding coastal responses to disturbance is likely to become increasingly important in sustaining coastal fisheries resources.

Towards a unified model

The primary challenge for coastal fisheries research in the context of the Reef Water Quality Plan is to identify approaches to sustain fish production in the face of plans to reduce the load of pollutants entering reef waters, and to rehabilitate habitats within the GBR catchments that have a role in removing water-borne pollutants. In this context, the main pollutants of concern are sediments and nutrients, followed by pesticides, with wetlands considered as the main habitats that have a role in pollutant removal.

This challenge requires an overarching conceptual model to place existing knowledge into a systems context and help identified knowledge gaps. A useful conceptual model must therefore contain a number of key features including: it must (i) cover the hierarchy of spatial habitat scales over which fish move to complete their life cycles; and (ii) reflect the diversity of processes of ecological production that support fish production at different locations and scales within the coastal system. Whilst numerous conceptual models have been proposed to date, none explicitly cover the range of habitats occupied by the suite of species encountered within the Wet Tropics region of the GBR. A comprehensive conceptual model must therefore include elements from freshwater, estuarine and marine habitats to cover the needs of resident and migratory species. Such a model framework would therefore be more useful than existing models that address riverine, floodplain or estuarine habitats alone.

The smallest spatial scale that provides all of these required elements is the marine catchment basin, recognising that in addition to movements among habitats within a given basin, many coastal fish species also migrate at larger scales between marine catchment basins to maintain population distributions over larger spatial scales. Marine catchment basins may therefore be considered as modular, hierarchical habitat templates that adjoin each other along the GBR coastline to form a mosaic of physically independent, but ecologically interdependent management units.

Because of the limited number of studies of tropical fish ecology in rivers and estuaries in the GBR, a model combining freshwater, estuarine and coastal processes will necessarily need to draw heavily on conceptualisations from other systems with different seasonal patterns, different climates, different suites of species, and perhaps lower species richness than occurs in the GBR. Furthermore, models based on concepts such as nursery habitat use or estuary dependence are derived from paradigms that are not well-supported by empirical data, and explicit assumptions may not apply in tropical Australian systems. Accordingly, such a broad conceptual model will establish a number of hypotheses that will need to be tested in subsequent studies.

Developing a conceptual model based on a Wet Tropics template allows the high rainfall climate to set one extreme for the range of climates over which the model template may apply. Accordingly, whilst patterns of sediment and nutrient delivery to the coast may differ between Wet Tropics and Dry Tropics climatic zones, wet season dynamics might be hypothesised to be similar between rivers such as the Tully and Fitzroy.

Beyond describing the processes supporting fish production, a useful model also needs to capture the processes that are likely to change under foreseen future scenarios, such as large-scale catchment intervention, and episodic disturbance from cyclones.

When viewed together, the preceding production models attempt to account for external and internal sources of nutrients including carbon; the diversity of primary producer groups and the different food web pathways they supply; the physical properties of estuarine systems and their constituent habitat units; temporal and spatial processes governing the availability of resources; the role of disturbance, whether by natural episodic events or resulting from human activities; and the periodicity of cyclic processes. However, as Walters and Martell (2004) caution, attempting to explain ecological systems based on physical processes alone, without considering ecological risks and natural selection, runs a high risk of over-simplified models that just don't work in the real world.

We argue here that marine catchment basins provide the unit of geographical scale that most appropriately captures the physical, chemical and biological processes that culminate in aquatic production for harvest by coastal fisheries. Within such basins lie hierarchical scale units such as individual patch habitats (e.g. macrophyte beds, fallen trees) within broader habitat types such as wetlands, and river reaches, which in turn fall within river geomorphic categories within the freshwater, estuarine and marine environments.

It has been amply demonstrated that the processes governing fish community structure and production differ among spatial scales from microhabitat to catchment or landscape scales (e.g. Fausch et al 2002, Boys 2006, Boys and Thoms 2006), and that these processes are strongly influenced by the hierarchical organisation of habitats in a watershed context (Frissell et al 1986). Accordingly, the factors that influence fish abundance within individual wetlands, such as snag density, may be of little consequence at larger scales among geomorphic habitat zones that are more strongly influenced by processes such as flow regime, hydrodynamics and material transport. The challenge for developing a useful model of fish production is to identify the scales at which fish production and fishing activity occurs, and to identify the processes with the strongest influence on production at those scales. This is not a trivial exercise.

Rather than being daunted by the complex dynamics of interacting physical, chemical and ecological interactions at differing scales, we have attempted to identify knowledge gaps across all scale units, and assembled them in relevant categories as they relate to ecological production of fish at the marine catchment basin scale (Section 6). Habitat scales are stated explicitly to provide a framework that positions small-scale and large-scale research issues firmly within an ecosystem context at the marine catchment basin scale.

Within a given marine catchment basin, it is important for the conceptual model to be able to accommodate local issues including processes structuring habitat form and availability, local ecosystem health values and objectives, habitat use by local species, and trophic responses to nutrient delivery.

Current understanding of ecology and function of coastal and estuarine fish assemblages in the Great Barrier Reef region

Context

The role of ecological science is to increase understanding of the interactions between different organisms, and between organisms and their environment, in a complex set of interactions known as ecosystem function. It is the functioning ecosystem that delivers ecosystem services and which provides a variety of human needs, such as food, living space, and oxygen, in the face of increasing pressure from global climate change, modified hydrological cycles, habitat loss, and other stresses caused by human activities. Tropical estuaries and other coastal systems are complex entities for which comprehensive ecosystem understanding is a long way off. However, in considering fisheries related aspects of coastal GBR systems there are two major, interrelated paradigms that seem particularly important: (1) tropical coastal, estuarine and riverine habitats are widely recognised as nursery grounds for fish and decapod crustaceans, and (2) the complex mix of habitats and the position of estuaries and coastal systems at the interface between terrestrial and marine ecosystems makes biological connectivity a crucial issue at a broad range of spatial, temporal and conceptual scales. And it is the nursery role of coastal systems and biological connectivity that are most likely to be affected by human-induced change. In an ecological context understanding both these paradigms depends on an in-depth understanding of faunal composition and pattern, and of the functional trophic webs with which the lives of organisms are framed.

Faunal composition, distribution and abundance

There has been extensive evaluation of the freshwater fish faunas of east coast rivers (Hortle and Pearson 1990, Pusey et al. 1995a, Pusey and Kennard 1996), including some integrated whole-of-river evaluations (Sheppard and Helmke 1999). Together they provide a picture of species rich faunas of both freshwater and marine spawners compared to temperate Australian systems. Similarly a number of studies have described species rich faunas from the region’s estuaries (Blaber 1980, Robertson and Duke 1987, 1990a, b, Sheaves 1992, Coles et al 1993), with additional relevant faunal surveys from Gulf of Carpentaria estuaries (eg. Blaber et al. 1989).

Whilst these studies give a broad picture of the fauna only a few attempts have been made to understand spatial patterning or relate distribution to physical or biological processes. Early studies (eg. Robertson and Duke 1987, Sheaves 1998) identified faunal differences between estuaries but did not have the spatial replication to investigate the scale of those differences. Coles et al (1993) provided a detailed description of fish assemblages within a single habitat, seagrass beds, but did not provide comparisons with non-seagrass habitats. Recently, substantial variability at an estuary-to-estuary scale has been identified (Sheaves 2006) with specific faunal differences maintained from year-to-year. Estuary fish are known to penetrate through mangroves at high tide (Robertson and Duke 1987) although their reasons for accessing mangroves are unclear (Sheaves 2005).

There have also been some advances in relating within-system differences to physical and biological factors (eg. Sheaves 1998) and estuary-to-estuary differences to tidal regime, catchment, mangrove area and hydrology (Ley 2005). Turbidity gradients are also likely to influence faunal composition and distribution, as they do in estuaries in South Africa and the Gulf of Carpentaria (Cyrus 1992), however the nature of these effects may depend on the spatial scale of turbidity gradients and their variability over time (Johnston and Sheaves unpublished data).

Overall, understanding of the structure of estuarine fish faunas in the GBR region is still remarkably superficial, with need for additional detailed knowledge to fill the many gaps. Beyond descriptions of the fish fauna of selected systems, there have been no attempts to develop a community perspective of estuarine fish faunas, or community-scale responses to disturbance. For example, despite changes in flood frequency and intensity being predicted under many global climate change scenarios, and the demonstrated importance of flooding in southern Queensland estuaries (Read et al. 1992), the impact of floods on estuary faunas has not been studied in the GBR region.

At the population level, basic biological aspects are even more poorly understood. Genetic studies of population structure are few and limited to high profile species like barramundi (Shaklee et al. 1993) and mangrove jack (Ovenden and Street 2003) or selected small species from coastal streams (McGlashan et al. 2001). The stock structures of other species are unknown even though many are important recreational or commercial species and are often major components of bycatch in coastal net fisheries.

Similarly there are few in-depth reproductive studies specific to the GBR region (eg. Tobin et al. 1997, Molony and Sheaves 2001), with most understanding based on extrapolation from elsewhere (Pollock 1980, Pollock 1984, Morton 1985, Pollock 1985). Another glaring gap, that relates to both nursery ground function and biological connectivity, is an almost total lack of relevant recruitment studies. At present understanding relies on extrapolation from southern Queensland (Warburton and Blaber 1992), or general ideas on larval supply from reef studies (Thorrold and Williams 1996). Settlement cues have received recent attention on nearby reefs (Atema et al. 2002) but are unknown for estuaries or other coastal systems.

There has been little in-depth investigation of species or habitats of conservation importance in the GBR coastal zone, however an understanding of a requirement for the endemic freshwater jungle perch, *Kuhlia rupestris*, to spawn in marine waters (Hogan and Nicholson 1987), has led to moves to understand its distribution and conservation status (Hutchison et al. 2002). Limited investigation of unique coastal habitats has identified a specific community of fish in pools in the dunefields of the Cape York coast (Pusey et al. 2000).

Nursery ground function

Tropical estuaries are widely considered to be crucial nursery grounds for fish (Robertson and Duke 1987, 1990a,1990b). In the simplest terms, nursery grounds are habitats that contribute disproportionately to the production of adults within a population (Baskin et al. 2003). This function requires that putative nursery habitats should (i) contain elevated densities of juveniles; (ii) support elevated growth rates; (iii) promote higher survival; and (iv) contribute to adult populations through connectivity to adult habitats (Able 2005). However, despite the occurrence of large numbers of juvenile fish and decapods in GBR estuaries (Blaber 1980), except in the case of high profile species like mangrove jack, *Lutjanus argentimaculatus*, (Sheaves 1995), there have been few convincing demonstrations of nursery ground usage. The reasons for this are many, but two are particularly important. Firstly, actually demonstrating nursery ground function requires detailed comparisons between populations over the whole range of possible juvenile habitats. Secondly, in a broader sense there is little understanding of the life-histories of any but a few high profile species such as mangrove jack (Sheaves 1995) and barramundi (e.g. Garrett 1987), with much understanding based on extrapolation from similar species in southern Queensland (e.g. Pollock et al. 1983). The nursery function is very important to other coastal and offshore fisheries, because events (e.g. predation pressure) in nursery habitats can profoundly influences the size of populations in spatially different adult habitats (Sheaves 2005) and because juveniles moving offshore translocate coastal productivity to offshore populations (Deegan 1993). For example, open water pelagic baitfish are the main prey of many important offshore predators such as the Spanish mackerel, *Scomberomorus commerson*, (McPherson 1987). However, even though juveniles of many pelagic species are found in estuaries and near coastal waters of the GBR (Williams and Cappo 1990) there is no detailed understanding of the ways juvenile baitfish use these nurseries. Nursery ground value is thought to be conferred by the availability of abundant or specialised food supplies (Sheaves and Molony 2000) or because of reduced predation (Paterson and Whitfield 2000). However, until recently these propositions have not been examined critically (Sheaves 2001) and it now appears that the idea of few predators must be re-evaluated (Baker and Sheaves 2005).

With the exception of some work on the sharpnose shark, *Rhizoprionodon taylori* (Simpfendorfer 1993), elasmobranchs have received almost no attention along the coast of the GBR region, despite wide recognition of their ecological status as apex predators, economic value to the inshore net fishery and their conservation value. However, it is known that small juvenile blacktip reef sharks, *Carcharhinus melanopterus*, are found in estuaries and near-coastal waters, and occur regularly as by-catch in gill net fisheries.

Food webs

Food webs are the functional contexts in which organisms operate (e.g. Figure 3). For example, issues of nutrition and predation are central both to determining nursery ground value, and driving the need for and outcomes of biological connectivity. However, besides a single published study of mangrove food webs (Sheaves and Molony 2000) and a small number of current studies (e.g Connolly 2006, Sheaves et al 2006]) there has been little work on estuarine and coastal food webs in the GBR region. A major reason for this is a lack of basic understanding of faunal composition, and patterns of spatial and temporal change that needs to be redressed before food web studies can be constructed with anything beyond the most basic resolution.

There is a considerable relevant literature relating to the direct and indirect movement of mangrove carbon (eg. Alongi et al. 1998, Alongi and McKinnon 2005) and the nutrition of some meiofaunal communites (Alongi and Christoffersen 1992) but these cannot begin to represent the diverse range of habitats in GBR coastal systems. Some of this work is directly relevant to fish. For instance, in contrast to many parts of the world, meiofauna are seen as important prey of juvenile estuarine fish on the Queensland coast (Coull et al. 1995) with meiofaunal copepods high in essential fatty acids needed by fish (Coull 1999).

Food web studies directed at estuarine and coastal fish of the region are patchy in their coverage. There are quality dietary studies from freshwater rivers (Pusey et al. 1995b), and dietary studies of marine benthic feeding fish have a long history in the GBR region (Beumer 1978, Gunn and Milward 1985), with recent studies moving to include temporal (Wilson and Sheaves 2001), spatial and ontogenetic change (Wilson and Sheaves unpublished data). The diets of some predators, such as mangrove jacks (Sheaves and Molony 2000) and barramundi (Russell and Garrett 1985), are understood but most species have received no study. Recent work in the Fitzroy estuary (Sheaves et al 2006) and around Townsville (Sheaves unpublished data) have emphasised the importance of detritus feeders, as opposed to herbivores, in channelling productivity to higher trophic levels, and together with studies from southern Queensland (Connolly 2003), have demonstrated the extent to which autotrophs at the base of food webs differ between coastal systems. Whilst there is some movement to advance the studies of the region’s food webs, this work only covers a fraction of the diverse fauna present in the complex mosaic of habitats that comprises the GBR coastal zone, and at present much understanding must be extrapolated from compositionally, and probably functionally, different faunas elsewhere (Morton et al. 1987, Morton et al. 1988, Sumpton and Greenwood 1990).

Whilst some obvious feeding relationships have received preliminary study (Sheaves and Molony 2000, Baker and Sheaves 2005) the importance of many potentially important components remain to be assessed. For instance, massive swarms of the small shrimp, *Acetes sibogae australis*, occur in boom-and-bust cycles in near-shore waters (Omundsen et al. 2000), but despite considerable targeting of these swarms by predators no work has been done linking them to fish production cycles. Understanding of the relationship between feeding history and nutrition of estuary fish is also limited to a handful of studies (Molony

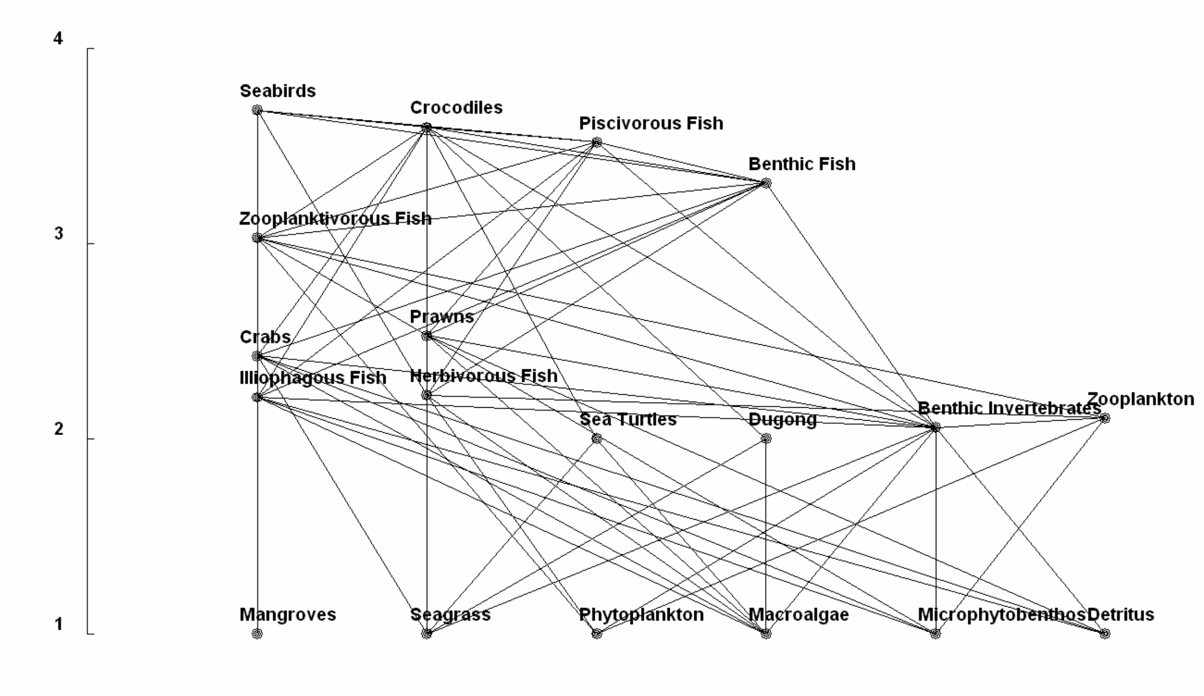

Figure 3. *Connectance plot showing food web pathways and common model structure for coastal GBR models. Flows to detritus are not shown. The contribution of different material pools within trophic level 1 to higher trophic levels varies considerably among coastal systems. Scale on the left indicates trophic level.*

1993, 1996). Leiognathids comprise an important component of the diet of many estuarine piscivores, but information on the biology of these and other crucial forage species is limited, with current knowledge only available from the Gulf of Carpentaria (Staunton-Smith et al. 1999).

In an effort to synthesise available but patchy information, current research by Gehrke (unpublished data) has made comparisons of coastal food webs in the Wet Tropics, Burdekin-Dry Tropics, Mackay-Whitsundays, Fitzroy, and Burnett-Mary regions by applying quantitative modelling approaches. These models are constrained by the patchy nature of available data, and by the numerous assumptions required to extrapolate available data to the regional scale, however they provide a number of testable hypotheses for future studies to fast-track some of these knowledge gaps. A critical issue in quantifying the pools of material and fluxes within food webs is the degree of aggregation of species and life history stages required to represent complex linkages in a simplified and meaningful way, without loss of information about food web structure and function.

Biological connectivity

Biological connectivity, the linking of habitat units in the lives of organisms at a diversity of spatial, temporal and conceptual scales, is manifest in coastal systems in aspects as diverse as the migration of juveniles in and out of nursery grounds, the regulation of benthic community structure by fish moving into the intertidal zone to feed, and the translocation of coastal productivity to offshore waters. Whilst biological connectivity is conceptually similar the world over, its dependence on the interplay of local hydrology, geomorphology and climate, and the ecology of the particular species inhabiting a region, makes location-specific understanding more vital than for most other major ecological processes. Connectivity is also strongly scale-dependent, with a hierarchy of linkages at increasing spatial scales (Figure 4). On a daily or tidal basis, fish move in multiple directions between habitats to feed or to take refuge from predators to meet their basic needs for survival. Over the course of their life cycle, most fish will migrate over a larger scale from nursery and juvenile habitats to their adult and spawning habitats, and these habitat use patterns vary among sub-populations. For example, the way juvenile barramundi enter and utilise wetlands differs between the Gulf of Carpentaria, where access depends on seasonal high tides (Russell and Garrett 1983), GBR wet tropics estuaries where consistent rainfall becomes more important (Russell and Garrett 1985), and central Queensland dry tropics where tides, general flooding and local rainfall are all important (Sheaves et al 2006). For species like barramundi, these migrations can take them from estuaries to freshwater rivers and wetlands and out into coastal marine environments, potentially covering hundreds of kilometres. At the population scale, movements of fish connecting sub-populations in nearby rivers and estuaries are important to maintain the genetic integrity of the entire population extending beyond the coastal GBR region across tropical Australia. Besides these studies directly relating to connectivity within the life-cycle of barramundi, information pertinent to biological connectivity in GBR coastal systems comes from movement studies and studies of habitat relationships.

Fish movements

Studies of movements of coastal and estuarine fish in the GBR region are restricted to a few question-specific studies (Russell and Garrett 1988, Sheaves 1993, Sheaves et al. 1999, McCulloch et al 2005) and general movement information from the ANSA tagging program (Russell and McDougall 2005). Other studies of fish movement relate to fish passing through fishways at major weirs (Kowarsky and Ross 1981, Cotterell and Jackson 1999, Stuart and Berghuis 1999, Stuart and Mallen-Cooper 1999). At a general level, these studies emphasise the importance of connectivity among habitats in allowing migratory behaviour to maintain connectivity between successive stages of the life cycle of coastal fish species.

The coastal habitat mosaic

The coastal and estuary zone of the GBR region comprises a vast mosaic of habitats: coastal wetlands, salt marshes, mangroves, intertidal sand and mud banks, seagrasses, narrow channels, beaches, inshore reefs and open water pelagic environments, that is the setting for connectivity at a myriad of scales. At present there has been little integrated work on the relationships among these habitats at any spatial scale. One notable exception is the study of McCulloch et al (2005) who demonstrated the facultative use of freshwater habitats by barramundi in the Burdekin-Dry Tropics region. There are many approaches to understanding habitat relationships but all rely on a detailed understanding of the ecology of the organisms involved and the habitats they occupy. Gehrke et al (1999, 2002) demonstrated gradients within fish communities progressing upstream from the estuary in coastal rivers in New South Wales and the impacts of flow modification on the habitat mosaic. Similar gradients are a feature of fish assemblages in tropical marine catchment basins (e.g. Russell and Hales 1997, Russell et al 1998, Russell et al 2000), but the patterns have not been well-described.

Important and complex linkages between seagrass, mangrove and unvegetated habitats have been established in a series of studies in the Caribbean (e.g. Nagelkerken et al. 2001). There has been little comparative work in the GBR regions despite vast geographical and faunal differences, and a macro-tidal as opposed to micro-tidal regime. Novel approaches to understanding fish/habitat relationships, such as that recently applied in southern Queensland (Pittman et al. 2004), are potentially useful in understanding complex coastal systems but have not been applied in the GBR region. There is a range of information specific to particular habitats (eg. seagrasses, mangroves; see below) but our understanding is generally location-specific, lacking generality and detail, and most habitats have received little study.

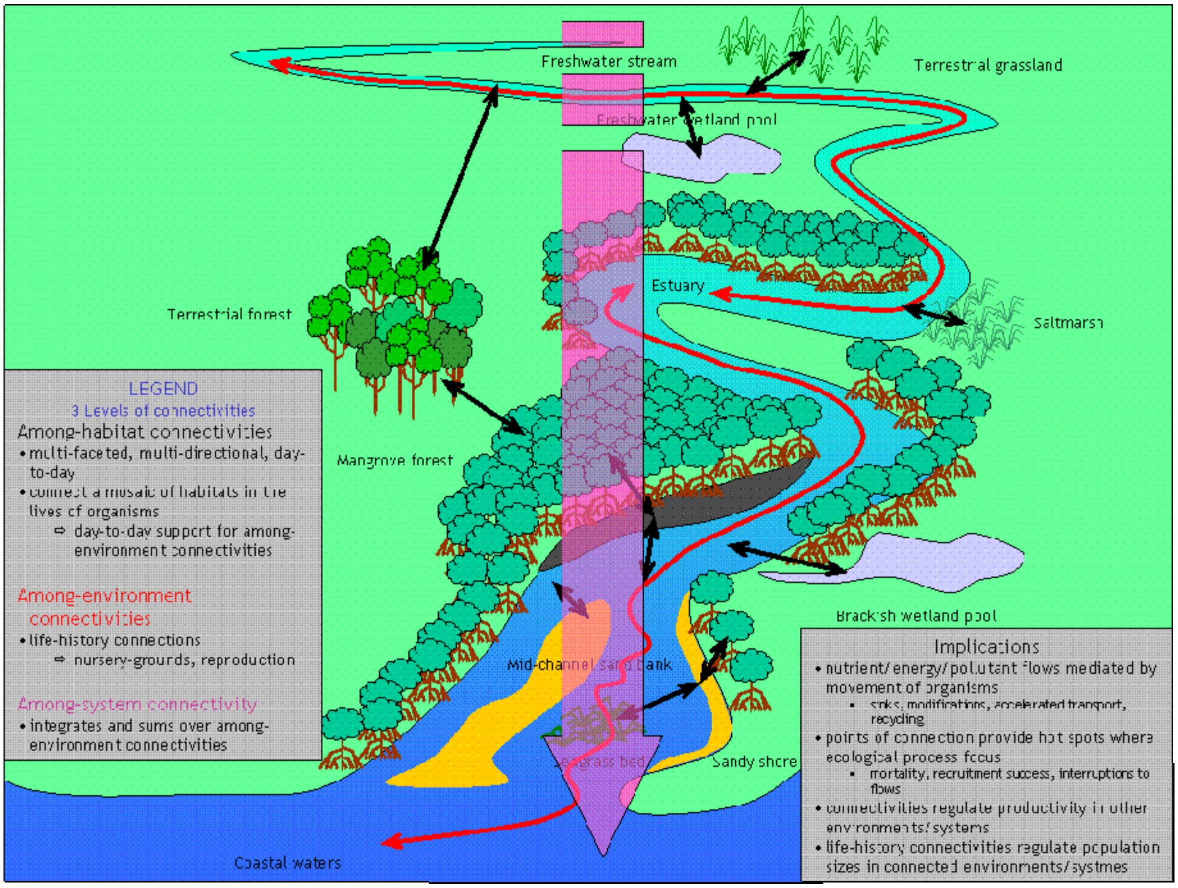

Figure 4. *Scales of connectivity among aquatic habitats. Short-term, tidal or daily connectivity allows fish to move among habitats to meet their basic survival needs, often over distances of 10-100 m (black arrows). Larger scale movements among marine, estuarine and freshwater environments require connectivity at scales of 10-100 km to complete species life cycles (red arrows). Less frequent connectivity among marine catchment basins at scales of 100-1000+ km is required to maintain the genetic integrity of populations.*

Seagrass: Extensive seagrass bed mapping and preliminary work on seagrass fish and penaeid communities (Coles et al. 1992, Lee Long et al. 1992, Coles et al. 1993) provides a basis for nutrient supply and production studies, important given the increasing awareness of the importance of seagrasses in coastal food webs and their influence on fisheries productivity, particularly for prawns (Halliday 1995, Haywood et al. 1998). Studies from the Gulf of Carpentaria and southern Queensland show seagrass beds are crucial habitats for juvenile penaeids (O'Brien 1994, Haywood et al. 1998), and in line with this observation, one of the few detailed studies of animal/seagrass relationships in the GBR region showed that temporal changes in fish and decapods correlated with changes in seagrass biomass and abundance of food organisms (Kwak and Klumpp 2004).

Mangroves: There have been a number of studies of fish community composition and distribution within Queensland’s mangroves over the last decade but most have been centred south of the GBR region (Morton 1990, 1992, Laegdsgaard and Johnson 1995, Halliday and Young 1996) and are of limited relevance to the tropics. The role of invertebrates in mangrove recycling and structuring mangrove forests has received some detailed study (eg. Robertson 1986, Robertson et al. 1990) in GBR region but little work has been directed to linking mangrove invertebrates to fish, although mangrove fauna are important in supporting juvenile populations of recreationally important fish (Sheaves and

Molony 2000). There is little detailed information on the way fish use mangrove water bodies. However, it is known that small and juvenile estuary fish penetrate through mangroves at high tide (Robertson and Duke 1987) and, when forced from the mangroves by the falling tide, congregate along shallow banks, and only move to mid-channel areas when water depth falls below about 1.5 m (Johnston and Sheaves unpublished data). The extent to which small fish feed in mangrove forests is unclear but large predators, such as mangrove jacks, enter mangroves at high tide to feed (Robertson and Duke 1987, Sheaves and Molony 2000).

Estuarine wetlands: There is some understanding of the community composition and ecology of fish using estuarine and coastal wetlands (Sheaves et al. 2006), but the information is location specific and may not represent the situation in wet tropics estuarine wetlands which are influenced by quite different rainfall and tidal regimes.

Other habitats: Most other habitats have received little study. For instance, although coastal beaches comprise the majority of the mainland coast of the GBR there have been almost no studies of fish fauna or ecosystem processes in tropical beach habitats, even though specialised surf-zone species are important ecologically, economically and recreationally in other east coast waters (McPhee et al. 1999). Similarly, the food resources of sandy habitats have not been studied in the tropics even though they are heavily impacted by human usage in southern Queensland (McPhee and Skilleter 2002). In much the same way, salt marshes are important habitats for intertidal fish (Thomas and Connolly 2001) but have only been studied at the very southern end of GBR region. Smaller-scale habitat relations have received even less study, although they are diverse and complex in the GBR region (eg. Sheaves 1996). Veitch and Sawynok (2005) provided an assessment of freshwater wetland habitats for fish in the GBR coastal region, and concluded that most wetland complexes have been degraded, isolated or lost in some way and that fish connectivity to these wetlands was seriously threatened. But the processes by which fish use freshwater wetlands, and the contributions of individual wetlands and wetland complexes to fish production at the marine catchment basin scale requires much more detailed investigation.

In temperate Australia, changes in riparian vegetation and nutrient enrichment have been demonstrated to affect quality of physical habitat, the composition of fish assemblages, and the size structure of individual species in coastal rivers (Growns et al 1998, 2003). Brooks et al (2004) demonstrated that at the reach scale within freshwater coastal rivers, reintroduction of structural woody habitats can improve habitat complexity resulting in a local-scale increase in fish numbers. However Boys (2006) has recently demonstrated that similar fish responses to habitat modification are unlikely to be repeated at larger spatial scales where geomorphic and hydrological processes exert a stronger influence than habitat availability.

Despite a preliminary understanding of many of the components of connectivity, the wider importance and role of biological connectivity has received little recognition (Sheaves 2005), and there has been little effort directed to integrated study at a process level, in the coastal zone of the GBR region.

Description of fisheries resources

This section provides a brief overview for readers not acquainted with fisheries resources in the GBR. More detail can be obtained from Pusey et al (2004) for freshwater species, and from Williams (2002) for commercial marine and estuarine species.

Principal commercial fishery species in the coastal GBR region include prawns (endeavour, king, tiger, banana), mud crabs, sharks, saucer scallops, coral trout, bugs, mackerel, barramundi, threadfin salmon, and mullet. The wild harvest fishery is divided into sectors representing trawl, inshore net, line, and pot gear types. The fishery is geographically divided into Far North, Northern Wet, Northern Dry, Swains, and Capricorn management regions. The Fraser-Burnett fishery management region lies at the southern end of the Great Barrier Reef World Heritage Area, but is not included by QDPI&F within the reef fishery. The coastal fisheries of the GBR consist predominantly of the inshore net fishery, pot fishery within estuaries, and small inshore portions of the trawl and line fisheries. Table 1 summarises the economic value of major species caught within coastal waters in the GBR region. For the purposes of this calculation, coastal waters were taken as the nearest inshore catch reporting grids represented in the CHRIS web site operated by the Queensland Department of Primary Industries and Fisheries (http://chrisweb.dpi.qld.gov.au/chris). The Tully region, including Hinchinbrook Channel, contributes a significant percentage of the total annual catch of crabs, sharks, mullet, garfish, threadfin and barramundi within the GBR. In the Tully region, crab pots account for 46% of the value of the catch, with prawns caught in otter trawls accounting for 31% and fish in the net fishery making up 20% of the total catch value. The contribution of different fishing gear types to the total catch is given in Table 2.

Table 1. *Summary of fisheries catches as gross value of product for 2003. Values for the Tully region are taken from catch reporting grid I19, and include a large portion of Hinchinbrook Channel. Values reported for the coastal GBR include fisheries grids from Cape York to Hervey Bay in the Fraser Burnett region. Values for the whole GBR World Heritage Area exclude the Fraser Burnett region, so that some values in the coastal GBR column are greater than 100% of the total catch from the GBR region as defined by DPI Fisheries.*

Rank	Tully			Coastal GBR			GBR WHA	
	Species	Value $	% of GBR	Species	Value $	% of GBR	Species	Value $
1	Crabs (2 spp)	807,170	9.70	Prawns	45,983,800	73	Prawns	63,132,300
2	Prawns	531,200	0.84	Crabs (2 spp)	13,095,670	157	Coral trout	17,783,500
3	Shark	156,200	2.01	Shark	7,423,300	96	Shark	7,761,500
4	Mullet	48,800	7.69	Saucer scallops	5,223,400	128	Crabs (3 spp)	8,325,480
5	Garfish	46,500	6.09	Coral trout	2,741,700	15	Mackerel (6 spp)	6,740,100
6	Threadfin (2 spp)	42,300	3.46	Bugs	2,476,500	48	Bugs	5,186,800
7	Barramundi	38,000	1.94	Mackerel (5 spp)	3,837,500	57	Lethrinid emperors	4,585,300
8	Mackerel (2 spp)	32,900	0.49	Barramundi	1,898,600	97	Saucer scallops	4,093,700
9	Coral trout	27,500	0.15	Mullet	1,772,500	92	Mixed reef fish	1,984,700
10	Bugs	20,500	0.40	Threadfin (2 spp)	1,126,900	276	Barramundi	1,955,400

Table 2. *Gross value of product for fishery catches by gear type for 2003 for selected regions within the Great Barrier Reef region. Values for the Tully region are taken from catch reporting grid I19, and include a large portion of Hinchinbrook Channel. Values reported for the coastal GBR include fisheries grids from Cape York to Hervey Bay in the Fraser Burnett region. Values for the whole GBR World Heritage Area exclude the Fraser Burnett region, so that some values for the coastal GBR column are greater than values from the GBR region.*

Fishery	Tully $	Coastal GBR (incl. Hervey Bay) $	Whole of GBR $
Line	55,100	6,435,400	34,544,100
Net	363,900	15,768,300	14,811,900
Pot - Crab	807,100	12,892,200	8,182,400
Pot - Spanner		1,015,000	1,787,500
Trawl – Beam		1,057,900	1,383,700
Trawl – Otter	553,070	56,143,670	78,660,480
Total	**1,779,170**	**93,317,570**	**139,370,080**

Commercially and recreationally important fish and shellfish species

Primarily marine species

Prawns – Family Penaeidae

Penaeid prawn species share common life cycles in which adults spawn in deep offshore habitats, with the eggs hatching into a planktonic nauplius larva that is followed by several other larval stages until reaching the post-larval stage that inhabits shallow nursery habitats such as seagrasses, mangroves and salt flats (Kailola et al 1993). After three to four months they migrate from their protected estuary habitats into deeper waters where they are targeted by the fishery. Prawns feed on a variety of benthic prey including bacteria, small molluscs and crustaceans, and algae.

King prawns are an exception to this generalisation as they use coral reef flats as nursery habitats. These species are fished in deep offshore waters to 250m deep, and fall outside the scope of this study.

Tiger prawns (*Penaeus monodon*, *P. esculentus* and *P. semisulcatus*) and endeavour prawns (*Metapenaeus endeavouri* and *M. ensis*) are caught mostly in coastal waters less than 20m deep, between Torres Strait and Mackay. Banana prawns (*Fenneropenaeus indicus* and *F. merguiensis*) are caught in shallow inshore waters to around 12m deep from Hervey Bay in the south to Cairns in the north.

Prawns are important species in coastal food webs, with both juveniles and adults forming a significant part of the diet of estuarine benthic fish such as bream and whiting, as well as larger piscivores such as sharks, queenfish and trevallies, mangrove jack, barramundi and threadfin.

Crabs – Family Portunidae

Mud crabs (*Scylla serrata*) are harvested from tidal estuaries throughout the GBR region, using baited pots. Major commercial fishery areas include mangrove systems around Missionary Bay and Hinchinbrook Channel in the Tully region, the Fitzroy and Port Curtis estuaries in central Queensland, and Hervey Bay.

After mating, female mud crabs migrate offshore to release their eggs, which hatch into planktonic larvae. Over a four-week period the larvae progressively move inshore and settle in estuarine habitats as small adults, where they spend much of their time in burrows among mangroves. (Kailola et al. 1993).

Mudcrabs consume a variety of molluscs, crustaceans, plant material and debris (Hill 1976).

Blue swimmer crabs (*Portunus pelagicus*) occur throughout the coastal GBR region, but most commercial catches are restricted to the southern waters around Hervey Bay. Spawning occurs throughout the year, with pelagic larvae eventually returning to coastal waters to settle in sandy, muddy, algal or seagrass habitats. Blue swimmer crabs are benthic carnivores feeding on other invertebrates such as small crustaceans and molluscs, polychaetes and echinoderms. Crabs fall prey to a number of large predators with crushing jaws and teeth, such as estuary cod, and saltwater crocodiles.

Adult mud crabs and blue swimmer crabs are keenly sought by recreational fishers using baited pots and dillies.

Bugs – Family Scyllaridae

Bugs, also known as bay lobsters, are found throughout the GBR coastline. They are not specifically targeted by fishers, but are landed as a popular by-catch of the prawn and scallop fisheries. In parts of the GBR bugs may account for 80% of the total catch by prawn trawlers, making them an economically important component of the catch. Two species most commonly encountered are mud bugs (*Thenus indicus*) in more turbid coastal waters between 10m and 30m deep, and sand bugs (*Thenus orientalis*) in clearer waters to 60m deep. Pelagic larvae are carried by ocean currents for up to three months before they settle to the sea floor. Bugs feed on benthic animals such as molluscs, but will also capture live prey such as fish and crustaceans (Kailola et al. 1993).

Barramundi – Family Latidae

Barramundi are one of the icon species of inshore waters in throughout tropical Australia, being keenly sought by recreational fishers and commanding high market prices. They are fished commercially in tidal estuarine waters using gillnets. The largest catches from GBR waters in 2003 came from the Townsville, Shoalwater Bay and Fitzroy regions. Catch per unit effort has shown an increasing trend since current recording systems were introduced in 1988, doubling to more than 40 kg/ boat day in 2003.

Male barramundi migrate from freshwater to mate with resident females in estuaries and on tidal flats (Kailola et al. 1993) at the start of the wet season. Eggs and larvae require brackish estuarine waters during early development. Juveniles migrate into freshwater wetlands and creeks, and mature firstly as males at around 3-5 years of age. Between 3-7 years of age, barramundi undergo sex inversion to become functional females. Larvae and juveniles feed on zooplankton and progressively take larger prey items until they adopt the adult diet of fish, prawns and similar crustaceans. Cannibalism on juveniles is common. Despite the general lifecycle described here, some individuals have been found to spend their entire lives in coastal marine waters (McCulloch et al. 2005).

Barramundi may grow to 180 cm and weigh 60 kg.

Mackerel – Family Scombridae

Three species of mackerel, grey mackerel (*Scomberomorus semifasciatus*) school mackerel (*S. queenslandicus*) and spotted mackerel (*S. munroi*) are commonly caught in the inshore net fishery of the GBR. The larger Spanish mackerel (*S. commerson*) is caught predominantly by the line fishery outside the narrow coastal zone. All species are popular targets for anglers. The commercial catch of grey mackerel alone nearly doubled to 140 kg/boat day from 1988 to 2003.

Spanish mackerel spawn off reef slopes in early summer, producing pelagic eggs and larvae (Kailola et al. 1993), with juveniles up to 10 cm finding their way into tidal creeks and sheltered coastal waters, and start moving into deeper waters and reefs by 40 cm. Some individuals migrate up to 1000 km south after spawning, and return the following winter.

Little is known about the biology of other mackerel species, but it is believed they spawn earlier than Spanish mackerel, and in inshore waters. Spotted mackerel occur in coastal estuarine habitats less frequently than grey and school mackerel, preferring clearer, more oceanic water. Spotted mackerel also have a post-spawning migration (Williams et al 2003).

Juvenile mackerel of all species feed on small fish such as sardines, ponyfish and garfish, and some small crustaceans. Larger individuals and adults consume a larger proportion of fish, including juvenile mackerel.

Spanish mackerel may reach a maximum length of 240 cm fork length and weigh 70 kg. Of the other species, spotted mackerel may reach 104 cm and 10 kg, grey mackerel 120 cm and 8.4 kg, and school mackerel 100 cm and 12 kg.

Sharks – Family Carcharinidae

Blacktip sharks, *Carcharhinus tilstoni*, and spot-tail shark, *C. sorrah*, support a coastal tropical shark fishery across much of northern Australia, with other species making minor contributions. In the GBR region most of the catch is taken in gill nets, with smaller quantities caught by the line fishery. The catch per unit effort within the GBR has more than doubled since 1988 to 120 kg/ boat day in 2003. Sharks are also targeted recreationally by some game anglers.

Both species breed once a year (Kailola et al. 1993), giving birth live young in litters ranging in size from 1 to 8 pups. Blacktip sharks mature at 3-4 years of age at a length around 110 cm, and grow to a maximum size of 200 cm total length and 52 kg. Spot-tail sharks mature at 2-3 years of age at around 90 cm length, and grow to 160 cm total length and 28 kg.

Like most similar sharks, both species are predators that feed predominantly on other fish, as well as squid, octopus, cuttlefish and some crustaceans.

Mullet – Family Mugilidae

Striped mullet, *Mugil cephalus*, also commonly known as sea mullet, and diamond-scale mullet, *Liza vaigiensis*, along with other unspecified mullet species, support an important fishery centred upon the coast of northern New South Wales and southern Queensland, but which still provides economically significant catches from coastal GBR waters. The southern fishery targets large migrating schools using beach seines, whilst the more northerly fishery uses gill nets and other net types (Kailola et al. 1993, Williams et al. 2003). Despite the fishery for mullet occurring in coastal marine or estuarine waters, striped mullet are commonly described as freshwater species because they spend much of their life in freshwater rivers. For this reason, some authors consider the common name of sea mullet a misnomer.

Striped mullet form large aggregations in lower estuaries during Autumn and early winter before spawning at sea, presumably near the surf zone of ocean beaches. Adults display a pronounced ‘river-hopping’ behaviour, migrating north after spawning to enter new estuaries as far as 740 km from their original estuary. They then either remain in the estuary or continue their migration well-upstream into freshwaters. Juvenile mullet enter estuaries and continue upstream to grow and mature in freshwater habitats, with some individuals remaining in estuaries.

Most mullet species feed on small benthic organisms such as diatoms, algae, cyanobacteria, small invertebrates and detritus, and form an important step in aquatic food webs by assimilating energy from these largely microbial food sources. In turn, they become an important prey for larger predators such as flathead, barramundi, mackerel, sharks, seabirds and dolphins.

Striped mullet mature at approximately three years of age, at a length of around 30 cm, and may grow to 76 cm total length and 8 kg.

Garfish – Family Hemirhamphidae

Unlike the large commercial fishery for garfish in southern Australia, the northern GBR fishery targets garfish for bait on a more opportunistic basis, with some of the catch ending up in seafood markets. Snub-nosed garfish, *Arrhamphus sclerolepis*, and eastern river garfish, *Hyporhamphus regularis ardelio*, are the most common species.

Little is known about the biology of garfish. Most species are predominantly herbivorous as adults, feeding on seagrass leaves, algae and small quantities of invertebrates (Kailola et al

1993. Juvenile eastern river garfish feed on zooplankton, and progressively reduce their zooplankton intake as they grow and consume greater quantities of seagrass (Carseldine and Tibbetts 2005). Garfish are one of the few groups of herbivorous fish in coastal GBR waters, and provide a direct trophic link from the vegetation they feed on as adults to higher predators such as mackerel, trevallies and queenfish, seabirds and dolphins.

Other species of *Hyporamphus* in southern Australia grow to a maximum size between 40 and 52 cm total length (excluding protruding lower jaw), and weigh up to 0.6 kg, however the northern species tend to be smaller. Whilst garfish are targeted by anglers in southern States of Australia, recreational catches in the GBR tend to be either incidental or for use as bait for other species.

Threadfin – Family Polynemidae

Blue threadfin, *Eleutheronema tetradactylum*, and king threadfin, *Polydactylus sheridani*, make up a significant component of the inshore net fishery throughout tropical Australia. They are commonly caught in gillnets in coastal GBR waters, with catch per unit effort nearly doubling from 1988 to 2003. Threadfin are also popular species targeted by anglers.

Like barramundi, threadfin are protandrous hermaphrodites, maturing firstly as breeding males before becoming females (Kailola et al. 1993). King threadfin above 95 cm are nearly all females. Blue threadfin complete the transition from male to female between 28 and 72 cm. Spawning occurs during summer in inshore waters away from freshwater flows, producing pelagic eggs. Juveniles appear over tidal flats and in estuaries from October to May.

Both species take long coastal migrations up to 150 km (blue threadfin) or 550 km (king threadfin). Threadfin are opportunistic carnivores, feeding on a wide range of benthic and pelagic estuarine fish, especially ponyfish, crustaceans such as prawns and crabs, and molluscs including snails, bivalves, octopus and squid. In turn, threadfin are preyed upon by sharks, barramundi, crocodiles and larger threadfin.

In Australia, king threadfin have been estimated to reach 170 cm fork length and 40 kg, with the largest individual recorded at more than 150 cm. Blue threadfin have been recorded at 82 cm fork length, but outside Australia they may reach 200 cm and 145 kg.

Coral trout – Family Serranidae

Coral trout, *Plectropomus leopardus*, are highly prized by commercial fishers, anglers and spearfishers, and are mostly targeted by the line fishery in offshore GBR waters. They do not generally inhabit coastal or estuarine waters. The catch by the recreational fishery has been estimated to at least equal the commercial catch. There are a number of similar species.

Coral trout are protogynous hermaphrodites, maturing firstly as females between 21 and 60 cm before becoming males (Kailola et al. 1993). Strongly associated with coral reefs, spawning occurs during spring and summer over reef habitats, with the pelagic eggs floating in reef waters for 3-4 weeks. Juveniles inhabit shallow reef habitats, with their pelagic early stages carrying some individuals into inshore reef habitats.

Juvenile coral trout feed on small fish, crustaceans and squid, with adults consuming a larger proportion of fish from a wide range of species.

Coral trout grow to at least 80 cm fork length and 4 kg, and individuals up to 120 cm have been reported.

Saucer scallops – Family Pectinidae

Ballot's saucer scallop, *Amusium balloti*, are caught largely by prawn trawlers operating between Townsville and Hervey Bay in waters from 25 to 55 m, with northern saucer scallop, *Amusium pleuronectes*, also caught by prawn trawlers operating from Princess Charlotte Bay to Bowen (Kailola et al 1993).

Northern saucer scallops are functional hermaphrodites, but Ballot's saucer scallops have separate sexes. Spawning in Queensland occurs between May and September, broadcasting pelagic eggs. Adults of both species are active swimmers, but migrations are not known. They inhabit bare sand, rubble or soft bottoms in water from 10 to 75 m deep, forming discrete scallop beds. Ballot's saucer scallops may reach an approximate shell diameter of 14 cm, with delicate saucer scallops growing to about 8 cm.

Like most bivalves molluscs, saucer scallops are filter feeders, filtering microorganisms and edible particles from the water. Filter feeders play an important ecological role in clearing suspended particles from the water column, but the distribution of saucer scallops in deeper waters mean that they have little impact on water quality in coastal and estuarine habitats. Threadfin are known predators of saucer scallops.

Other species

Many other species make up small but important components of the coastal catch in both commercial and recreational fisheries. Carangids, including queenfish and trevally are spectacular angling species that are keenly sought by recreational fishers. But despite reaching large sizes and, as top predators, consuming large amounts of smaller fish, little is known of their biology and their contribution to coastal fish communities and food webs.

Other coastal fishery species, many of which are also targeted by anglers, include grunters (Haemulidae), jewfish (Sciaenidae), whiting (Sillaginidae), bream (Sparidae), flathead (Platycephalidae), milkfish (Chanidae), dart (Carangidae), estuary cod (Serranidae), fingermark and mangrove jack (Lutjanidae), pilchards and sardines (Clupeidae), wolf herring (Chirocentridae), stingrays (Dasyatidae), and fork-tailed catfish (Ariidae). Despite their modest commercial importance, these species occupy important niches in coastal food webs as predators structuring local fish communities, or as prey species funnelling energy from primary producers to higher trophic levels.

Small species such as damsel fish, butterfly fish, angel fish, clown fish, wrasses are collected mostly from reef habitats for the aquarium market valued at $4million per year.

Primarily freshwater species

Popular freshwater recreational species include saratoga, barramundi, tarpon, golden perch, Mary River cod, jungle perch, sooty grunter, Tully grunter, spangled perch, with other species such as eel-tailed catfish occasionally targeted. A comprehensive account of freshwater species in the region is given by Pusey et al (2004). Several species, such as barramundi, fork-tailed catfish and mangrove jack, that occur in freshwater habitats migrate into estuaries or coastal waters where they may be caught by commercial fishers, but there is no commercial fishery operating in freshwater habitats of the GBR.

Profiles are given here only for freshwater species targeted by recreational fishers, with information sourced largely from Pusey et al (2004).

Saratoga – Family Osteoglossidae

Saratoga, *Scleropages leichardti*, are endemic to the major tributaries of the Fitzroy River system, and have been stocked outside their natural range into some impoundments in southeast Queensland parts of the Burdekin system. Growing to around 100 cm, but more commonly 50 cm, their limited distribution restricts access to anglers for this spectacular species, but they are popular with keen anglers prepared to travel. Saratoga feed on a wide range of prey including insects, crustaceans frog and fish at or near the surface, and can be caught by anglers using similar baits, lures and flies. Saratoga tend to live in deep waterholes and lagoons, and produce small numbers of large eggs that the female incubates in her mouth until the hatched juveniles become independent.

Tarpon – Family Megalopidae

Tarpon, *Megalops cyprinoides*, are a smaller relative of the much larger Florida tarpon, only growing to 150 cm and 18 kg but usually caught at less than 50 cm. Widely distributed within the Indo-West Pacific region, tarpon are relatively common throughout the GBR region. Tarpon spawn in coastal or estuarine environments, with the larvae either migrating or being carried into tidal wetlands by currents. Older juveniles then migrate upstream into freshwaters. Tarpon feed on a wide variety of prey including insects, crustaceans and fish. They are often caught on light gear with lures or flies, and may leap high out of the water, sometimes throwing the hook as they do so. Tarpon are commonly encountered in freshwater or brackish creeks or floodplain lagoons near the head of the estuary, and may aggregate below overflowing weirs during high flows.

Barramundi – Family Latidae

Barramundi, *Lates calcarifer*, are popular target species with anglers in coastal waters throughout the GBR. They are caught in lagoons, freshwater river reaches, estuaries and along open shorelines by anglers using live and dead baits, lures and flies. They often leap spectacularly when hooked, and put up a strong fight. Barramundi have been known to aggregate below overflowing weirs and crossings, presumably in an effort to migrate upstream, during flow events. Because they spawn in brackish waters, barramundi populations upstream of barriers such as dams and weirs die out unless upstream-migrating fish can negotiate the barrier either during high flows or by using a properly designed fishway. Stocking programs for barramundi are used to maintain populations in some impoundments fished by anglers, and to rejuvenate natural populations that have become depleted in some rivers.

Basses and cods – Family Percichthyidae

Golden perch

Golden perch occur naturally in the Fitzroy River system only, as a sub-species, *Macquaria ambigua oriens*, of the more widely distributed Murray-Darling form, *M. ambigua*. They have been recorded as growing to 76 cm and 23 kg, but fish of 40 – 50 cm and 3 – 5 kg are more common. A freshwater species only, they do not venture into estuarine waters. Golden perch have extensive migrations that may extend over 1000 km, with juveniles especially moving upstream in large numbers. Spawning generally occurs after migration, often timed to coincide with flooding, but floods may not be an obligatory cue. Pelagic eggs and small larvae are dispersed widely by flow, and may enter floodplain habitats connected during floods, and riverine backwaters.

Golden perch have been translocated by stocking into other GBR river systems in the Burdekin and Burnett-Mary regions, although translocation is now prohibited to protect the genetic integrity of local populations.

Golden perch are predators, feeding on a wide variety of crustaceans, fish and insects, and are caught by anglers using lures and live baits.

Australian bass

Australian bass, *Macquaria novemaculeata*, are a highly prized recreational species in coastal rivers in southern States, but their northerly distribution extends only as far as the Burnett-Mary region. They are stocked into a number of impoundments to support recreational fisheries. Accordingly, they are targeted by only a relatively small number of anglers in the GBR region. Growing to over 60 cm and 4 kg but more common at 30 – 40 cm and 1 kg, Australian bass are aggressive predators feeding on terrestrial insects falling onto the water, aquatic insects, small crustaceans and small fish. Australian bass spawn in estuaries, and both adults and juveniles then migrate back upstream into freshwater. Because they do not breed in freshwater, local populations upstream of weirs, dams and other man-made barriers die out if mature adults cannot access estuaries, or if juveniles cannot migrate upstream past the barriers. They are most commonly sought by anglers using lures or natural baits.

Mary River cod

Mary River cod are recognised as a sub-species, *Macculluchella peelii mariensis*, of the more widely distributed Murray cod, *M. peelii peelii*, from the Murray-Darling basin. Smaller than Murray cod, Mary River cod may reach 40 kg but fish larger than 70 cm and 5 kg are exceptionally rare. Naturally occurring only in the Mary River, they are now stocked as an angling species into selected impoundments and other rivers in southeast Queensland where they may also have occurred. Despite its listing as endangered under Commonwealth legislation, and total protection in Queensland, anglers are permitted to catch and release one fish. The remnant natural population is estimated at less than 1000 individuals.

Mary River cod are believed to spawn in microhabitats like to hollow logs, producing adhesive eggs that stick to the substratum. Males guard the eggs and larvae until they begin feeding independently. The only known movements covered relatively short distances of 20 – 30 km upstream or downstream entirely within freshwater. The fish are strongly associated with structural woody habitat within river channels, and appear to avoid open water. Diets have not been formally studied, but include a wide range of smaller fish and crustaceans. Most keen anglers targeting Mary River cod use lures.

Jungle perch – Family Kuhliidae

Jungle perch, *Kuhlia rupestris*, have a large Indo-West Pacific distribution and are common coastal rivers of the GBR region south to the Burdekin River. Their occurrence further south appears to be more spasmodic, although they have been recorded from the Richmond River in New South Wales. Growing in 45 cm and 3 kg, jungle perch are more commonly encountered at less than 28 cm. Typical habitat for this species is fast-flowing rainforest rivers, from hundreds of kilometres upstream, where fish are predominantly female, to coastal freshwater reaches just above sandy surf beaches, where males are more abundant. Spawning presumably occurs in lower estuaries or coastal waters after both sexes migrate downstream, since sperm are not viable in freshwater. Larvae or juveniles subsequently enter freshwater habitats and begin moving upstream. Like other freshwater species needing saline habitats for spawning, jungle perch populations are particularly susceptible to abrupt declines where upstream migration is blocked by dams and weirs. Terrestrial foods including insects, other invertebrates, and even fruit make up more than 50% of jungle perch diets, with aquatic insects and crustaceans also contributing significant amounts. A popular angling species in fast-flowing rivers, jungle perch are commonly targeted by using surface lures resembling insects and crustaceans.

Grunters – Family Terapontidae

Sooty grunter and Tully grunter

Sooty grunter, *Hephaestus fuliginosus*, occurs in freshwaters from the Daly River in the Northern Territory, possibly into New Guinea, and south to at least the Burdekin river system. It has been stocked into some rivers in the Mackay-Whitsundays and Fitzroy regions. The species distribution is fragmented along the GBR coast, being absent from many east coast rivers on Cape York, and commonly confused with Tully grunter, *Hephaestus tulliensis*, which is endemic to the Wet Tropics region. Sooty grunter may reach 50 cm and 3.5 kg, with most individuals below 40 cm. Tully grunter are smaller, reaching 33 cm and 1 kg but more common at less than 22 cm. Both sooty grunter and Tully grunter occur in habitats ranging from moderately flowing headwater rivers in small catchments to low gradient channels in larger catchments. The behaviour of this species varies considerably between river systems, reflecting differences in climate, geomorphology, and hydrology. Sooty grunter migrate from dry season refuge habitats into ephemeral wet season habitats to spawn, which may involve either upstream or downstream movement. Spawning occurs either before or during the onset of wet season flows, in shallow slack-water habitats near riffles or rapids, producing adhesive demersal eggs. Larvae or juveniles, and adults subsequently make their way back to suitable dry season habitats to avoid becoming stranded. The diet is dominated by aquatic insects, followed by algae and other aquatic plants, crustaceans, and small amounts of terrestrial fruit, fish and terrestrial insects. Anglers pursuing these species may use a variety of natural baits or lures resembling large aquatic insects or small fish and shrimps.

Spangled perch

Spangled perch, *Leiopotherapon unicolor*, are one of the most widely distributed native species of freshwater fish in Australia, inhabiting river systems from the tropics south to a latitude of approximately 30 S. Whilst they are a small species, growing to a maximum of 35 cm and 1 kg, they are rarely caught larger than 200 cm. As befits their wide distribution, spangled perch tolerate extremes of temperature, low dissolved oxygen, and may actively pursue water flowing into habitats by swimming along flowing wheel ruts during thunderstorms, aiding their dispersal. They migrate extensively both within river channels and laterally over floodplains during high flows, occasionally leaping over small cascades to make their way upstream. They inhabit and breed successfully in both flowing and standing waters, spawning in small tributaries and around wetland margins. Whilst these fish are capable of tolerating salinities near seawater,

Because of their small size, spangled perch are mostly targeted only by young anglers and take a wide variety of baits such as worms and shrimps, and small lures.

Silver perch

Silver perch, *Bidyanus bidyanus*, do not occur naturally in the GBR catchments, but have been stocked in a number of impoundments in the Burnett-Mary region to improve freshwater fishing opportunities. Commonly growing to 40 cm and 1.5 kg, but recorded to 8 kg, silver perch require riverine conditions to breed and do not normally establish self-maintaining populations in impoundments. They feed on aquatic insects, worms and small crustaceans, and consume increasing amounts of algae and other plant material as they grow. Despite their more herbivorous tendencies, adults are caught by anglers using natural baits such as worms and shrimps, and lures.

Alien and translocated species

Concern over the introduction of non-native fish in the GBR region is largely focussed on alien freshwater species such as tilapia, *Oreochromis mossambicus* and *Tilapia mariae*, gambusia, *Gambusia holbrooki*, other poecillids, carp, *Cyprinus carpio*, and goldfish, *Carassius auratus*, and native species that have been translocated outside their natural range, such as barred grunter, *Amniataba percoids*. A number of other imported ornamental species have established breeding populations near human population centres. Alien and translocated species bring a range of threats to resident fish communities that will not be dealt with here, but a useful summary can be found in Koehn et al. (2000). The threats can generally be recognised as competing with native species for food and habitats, preying on more highly-valued native species, introducing diseases to native fish populations, and altering the balance of aquatic food webs. Species such as carp have also been claimed to physically alter aquatic habitats by increasing turbidity, damaging aquatic plants and disrupting physical habitats.

Rare and threatened species

A total of 55 fish species occurring within the freshwaters or estuarine and marine waters of the continental shelf region of the GBR, from Cape York to Hervey Bay, have been recognised as threatened under Commonwealth or State legislation, or by the Australian Society for Fish Biology (2004) and World Conservation Union (IUCN 2006) (Table 3). Listings of threatened species are constantly being updated as more information becomes available on the conservation status of individual species, and their distributions. Accordingly, separate lists rarely correspond exactly. An additional complication occurs where the distribution of rare species is poorly known, with the result that authors of some regional lists include species that have not been confirmed within that region. This conservative approach is appropriate for conservation management, but results in inflated estimates of the number of threatened species within the region. To avoid this problem, the list presented in Table 4 includes only those species confirmed as occurring in continental shelf waters of the GBR region from Cape York to Hervey Bay. For this reason, the number of threatened species considered here is most likely an underestimate of the true number of species under threat.

The status of individual species is not always clear under legislation, with some species listed as protected under fisheries legislation, but not listed as threatened by the corresponding conservation legislation for that jurisdiction. For example, the Queensland lungfish and Mary River cod are protected in Queensland under the Fisheries Act 1994, not considered threatened under the Nature Conservation Act 1992, but listed as vulnerable and endangered, respectively, under the Commonwealth Environment Protection and Biodiversity Act 1999. In other cases, a species may be recognised as threatened only within part of its distribution, such as populations of *Ambassis agassizii*, which is regionally extinct in Victoria and listed as threatened under the Flora and Fauna Guarantee Act 1988, but not in Queensland.

Table 3. *Number of threatened fish species known from GBR waters. Oceanic species occurring outside the continental shelf have been excluded.*

Category	Freshwater	Estuarine / Marine	Total Species
Extinct	-	-	-
Critically Endangered	-	2	2
Endangered	3	2	5
Vulnerable	5	3	8
Lower Risk – Conservation Dependent	-	4	4
Lower Risk – Near Threatened	2	7	9
Lower Risk – Least Concern	1	7	8
Data Deficient	3	16	19
Total	**14**	**41**	**55**

Table 4. *Fish species occurring within the GBR region which have been listed as threatened (Australian Society for Fish Biology 2004, EPBC Act 1999, Nature Conservation Act 1992, IUCN Red List 2006). Where classifications for individual species differ among sources, the most recent is given. Species are listed as occupying freshwater (F) or marine (M) habitats. Species found on other ists that could not be confirmed as occurring in GBR shelf waters are not shown.*

Scientific name	Common name	Source	Habitat (F/M)
Extinct			
No species			
Critically Endangered			
Glyphis sp. A*	Speartooth shark	EPBC	M
*Carcharias **t**aurus*	Grey nurse shark	EPBC, NCWR	M
Endangered			
Maccullochella peelii mariensis	Mary River cod	EPBC	F
Melanotaenia eachamensis	Lake Eacham rainbowfish	EPBC	F
Nannoperca oxleyana	Oxleyan pigmy perch	EPBC NCWR	F
Pristis clavate	Dwarf sawfish	ASFB	M
Pristis zijsron	Green sawfish	ASFB	M
Vulnerable			
Bidyanus bidyanus	Silver perch	ASFB, IUCN	F
Brachaelurus colcloughi	Colclough's shark	ASFB	M
Cairnsichthys rhombosomoides	Cairns rainbowfish	ASFB	F
Epinephelus daemelii	Black rockcod	ASFB	M
Guyu wujalwujalensis	Bloomfield River cod	ASFB	F
Neoceratodus forsteri	Queensland lungfish	EPBC	F
Pseudomugil mellis	Honey blue-eye	EPBC NCWR	F
Rhincodon typus	Whale shark	EPBC	M
Lower Risk - Conservation Dependent			
Cheilinus undulates	Humphead maori wrasse	ASFB, IUCN	M
Cromileptes altivelis	Barramundi cod	ASFB IUCN	M
Epinephelus lanceolatus	Queensland grouper	ASFB IUCN	M
Epinephelus tukula	Potato cod	ASFB	M
Lower Risk – Near Threatened			
Carcharhinus obscurus	Dusky shark	ASFB IUCN	M
Carcharhinus plumbeus	Sandbar shark	ASFB IUCN	M
Dasyatis fluviorum	Estuary stingray	ASFB	M
Glossogobius n.sp.*	Mulgrave goby	ASFB	F
Halophryne queenslandiae	Sculptured frogfish	ASFB	M
Hippocampus dahlia	Low-crown seahorse	ASFB	M
Redigobius bikolanus	Bigmouth goby	IUCN	M
Scleropages leichardti	Saratoga	ASFB IUCN	F
Urogymnus asperrimus	Porcupine ray	ASFB IUCN	M
Lower Risk - Least Concern			
Dunckerocampus dactyliophorus	Banded pipefish	ASFB	M
Epinephelus coioides	Estuary rockcod	ASFB IUCN	M
Epinephelus cyanopodus	Purple rockcod	ASFB	M
Epinephelus fuscoguttatus	Flowery cod	ASFB IUCN	M
Epinephelus malabaricus	Malabar grouper	ASFB	M
Epinephelus polyphekadion	Camouflage grouper	ASFB	M
Epinephelus tauvina	Greasy grouper	ASFB	M
Mogurnda adspersa	Southern purple-spotted gudgeon	ASFB	F
Data Deficient			
Ambassis agassizii	Agassiz's perchlet	IUCN	F
Bolbometopon muricatum	Humpheaded parrotfish	ASFB	M
Carcharhinus limbatus	Common blacktip shark	ASFB	M
Epinephelus ergastularius	Bar cod	ASFB	M
Hexanchus griseus	Sixgill shark	ASFB	M

Scientific name	Common name	Source	Habitat (F/M)
Hippocampus bargibanti	Gorgonian seahorse	ASFB IUCN	M
Hippocampus hendriki	Eastern spiny seahorse	ASFB	M
Hippocampus queenslandicus	Queensland seahorse	ASFB	M
Hippocampus procerus	Highcrown seahorse	ASFB	M
Hippocampus taeniopterus	Common seahorse	ASFB	M
Hippocampus tristis	Sad seahorse	ASFB	M
Hippocampus zebra	Zebra seahorse	ASFB	M
Ogilbyina novaehollandiae	Multicolour dottyback	ASFB	M
Orectolobus ornatus	Banded wobbegong shark	ASFB	M
Pristis pectinata	Wide sawfish	ASFB	M
Scortum hillii	Leathery grunter	ASFB	F
Scortum parviceps	Small-headed grunter	ASFB	F
Solegnathus hardwickii	Pallid pipehorse	ASFB	M
Syngnathoides biaculeatus	Alligator pipefish	ASFB	M

Synthesis of conceptual models

It can be seen from the preceding accounts that existing understanding of the roles and values of fish in coastal ecosystems of the GBR region is strongly subdivided into freshwater and marine components, based largely on the nature and distribution of fishery effort. This dichotomy is unhelpful in the context of improving land and water use practices within catchments to sustain the ecological integrity of adjacent coastal and coral reef ecosystems. Because of the unidirectional movement of water and materials transported from catchments to the coast, and the bidirectional movements of fish and other aquatic organisms within and between freshwater and marine environments, this artificial dichotomy constrains scientific thinking and fishery management to a scale below the operational focus of contemporary catchment management. If the marine catchment basin scale is to be managed effectively, then new ecological conceptual models are required that deal with the whole coastal fishery resource and fish habitats.

Such models need to take into account the hierarchy of habitat units at different geographical scales, climatic zones, topographical influences on hydrology, hydraulics and habitat geomorphology, sources of nutrients and primary production for higher food webs, transport of materials within the marine catchment basin, as well as the biology of individual species and their ecological interactions at community and food web scales. Where existing knowledge allows, models need to show consideration for specific needs of highly valued species discussed in the previous section to ensure applicability of the models for managing fisheries resources.

Current research for fisheries management in the GBR region places a strong emphasis on stock assessment for individual species and fisheries to manage fishing effort within the concept of ecological sustainability. Most of this effort is targeted at reef or offshore species (including prawns) which comprise the bulk of the catch. Because of the economic and social importance of the fishery, this direction of effort is likely to continue for the foreseeable future.

But the lower emphasis on coastal ecosystems that support inshore fisheries acts as an impediment to developing integrated conceptual ecosystem models at the scale of marine catchment basins.

Many issues linking coastal water quality and catchment land-use are repeated among catchments throughout the GBR, with subtle differences according to climate, topography and type of land-use. But to protect the coastal ecosystems of the GBR requires a conceptual understanding at least of how these processes apply at the GBR scale. Based on existing knowledge, such an ecosystem model is likely to be so simplistic that its applicability for individual catchments would be limited.

Accordingly, the process of developing a new conceptual approach that explicitly includes freshwater and coastal dynamics is more appropriately focussed on the individual catchment scale. As this approach becomes more refined, it can be scaled up to the whole GBR scale and tested against other catchments for more general applicability.

Beyond establishing the need for a new conceptual approach, we have not attempted to develop such a model in this report. Rather, we have identified existing knowledge gaps that limit our ability to develop more appropriate conceptual models of ecological function at the marine catchment basin scale. As these gaps are addressed and conceptual models become more refined, it will be possible to develop predictive quantitative models to explore broad ecological consequences of land and water management scenarios within marine catchment basins of the GBR.

It is anticipated that this broader approach will empower fisheries stakeholders to become more effective in developing policies and in operational management of marine catchment basins beyond the traditional fisheries jurisdictions to improve the sustainability of the fishery resources of the GBR. Conversely, this approach will also facilitate a better appreciation by catchment users and managers of downstream and system-scale implications of their decisions.

Knowledge gaps impeding improvement of conceptual models

Two broad drivers of knowledge gaps emerge from this analysis of information needs. The first concerns impediments to improved catchment and natural resource management to sustain coastal fisheries based on existing conceptual models of coastal fish production. The second concerns specific knowledge gaps that weaken and limit the applicability of existing conceptual models. These drivers reflect the more tactical or operational requirements of research to assist fisheries management, and more strategic scientific research with a broader focus to underpin improved knowledge of coastal and estuarine ecosystems.

Table 5 identifies knowledge gaps for coastal and estuarine fisheries ecology in the GBR region which are likely to impede capacity to predict responses of fish populations, and possible fishery consequences, of changes in catchment management and land use. The primary issues fall into six categories reflecting concerns about:

i. Effects of climate change;
ii. Fishery issues for ecosystem sustainability;
iii. Knowledge limitations in fish ecology;
iv. Understanding of ecosystem processes reflected in food web structure and function
v. Understanding the importance of habitats and threats to habitats for improved habitat management; and
vi. Data limitations impeding better information integration.

Each category contains a hierarchy of finer scale issues and knowledge gaps.

The spatial scale of gaps is most commonly reflected at the individual system level, which is then repeated in other systems and summed across increasing scales to GBR and global levels. However the consequences of each system impact are more likely to be multiplicative. For simplicity, the table shows the spatial scale at which direct effects occur. Similar issues exist with the significance of temporal scales, as actions that affect short-term processes such as tidal cycles may have long-lasting effects on wider systems, such as through limiting the distribution of seagrass habitats or connectivity of wetlands. The table shows the time scale over which direct effects at the indicated spatial scale are likely to occur.

Climate change effects are largely restricted to impacts on coastal habitats and consequences for fish production. These changes are likely to be widespread throughout the GBR and beyond, and will occur over a relatively long time frame so that their priority within the Tully region alone is relatively low.

Knowledge gaps on fishery issues for ecosystem sustainability cover a range of ecological principles, of which habitat disturbance, habitat connectivity, fish production processes, scales of migration and predictive capacity are highly relevant for the Tully-Murray system to determine the effects of changed land and water use at the marine catchment basin scale.

Fish ecology knowledge gaps tend to have a lower priority in the Tully-Murray region simply because the region is not a major fishery location. Despite this short-coming, however, the Tully-Murray system has high levels of connectivity with the neighbouring Hinchinbrook region, so that fish ecology aspects dealing with the effects of hydrology, reproduction requirements, and use of habitat and food resources rank highly among local priorities in the Tully region, as well as addressing broader issues of concern elsewhere in the GBR.

Better understanding of catchment effects on food web structure and function is a particularly high priority for the Tully-Murray system because of the amount of existing effort directed toward hydrology and material transport within this system, without placing the physical and chemical aspects of this work into an ecosystem context. Accordingly, the scale of trophic linkages, contributions of primary producers to food webs, and the sources of nutrients for aquatic food webs, along with the processes to integrate this knowledge at a system scale, have high priority in the Tully-Murray system.

Habitat management priorities for the Tully-Murray floodplain region focus on integrating previously identified habitat needs of freshwater species in the floodplain reaches (Tait 1994, Hogan and Graham 1994) with needs of estuarine species downstream to develop the concept of landscape habitat mosaics to sustain coastal fisheries. This approach to developing a habitat template for fishery management at the marine catchment basin scale is a high priority for the Tully-Murray system, and has potential to provide a powerful casse study that can be repeated elsewhere in the GBR region.

The ability to make better use of existing data on fishery resources throughout the GBR is dogged by the patchiness of available information, its accessibility and applicability for specific locations and purposes. An integrative framework that uses all available information to identify data limitations, uncertainty created by using data from other systems, and monitoring needs to assess ecosystem and fishery responses to intervention is therefore a high priority for the Tully-Murray system, and for the broader GBR region.

A critical gap arising from the limited integration across all categories is the limited understanding within the scientific, management and local stakeholder communities of the downstream ecological effects of catchment intervention within freshwater, estuarine and coastal marine environments. As a consequence of these limitations, current operational and research efforts are focussed predominantly on remedial processes within catchments and managing risks to reef ecosystems, with reduced emphasis on ecological responses within the wetland, riverine and estuarine systems that act as a conduit of material from catchments to offshore reef waters. Not surprisingly then, downstream coastal responses to catchment management is underrepresented in priority works and research investment programs, and aquatic stakeholders are constrained in their ability to influence catchment remediation priorities. Establishing a broad conceptual model at the marine catchment basin scale that reflects the hierarchy of aquatic ecosystem health issues will be a major step forward to achieving better understanding of downstream effects among catchment stakeholders, and for empowering downstream stakeholders to be more effective in negotiating priorities for catchment intervention to improve water quality.

Table 5. *Summary of broad issues and knowledge gaps impeding management of coastal fishery resources in the Great Barrier Reef region. Spatial scale indicates the scale at effects are observed, even thought many issues may be repeated elsewhere globally. Timescale indicates the time over which effects are observed. Issues addressing strategic knowledge gaps or tactical information for management are indicated as K or M. Threat indicates whether the issue pertains to (i) flow regime; (ii) material transport; (iii) land-use change; (iv) habitat loss; (v) increased fishing pressure; or (vi) climate change (refer to list of threats on page 2). The final column indicates the priority of each issue at the scale of the Tully-Murray marine catchment basin.*

Issue / Knowledge Gap	Spatial Scale	Temporal Scale	Knowledge / Management Gap	Threat	Tully Priority
1. Climate Change	**Global**	**10-100y**	**K**	**i,ii,vi**	**Low**
a. Habitat impacts					
i. Effects of climate change on geomorphic habitat processes, and value of habitats for fish.	regional	10-100y	K	i	Low
ii. Changes in turbidity and effects on visual predators.	marine catchment basin	Event-based changes over 10-100 y	K	ii	Low
iii. Changes in habitat access and connectivity resulting from sea level change.	regional	100-1000y	K	vi	Low
2. Ecosystem Sustainability	**Marine catchment basin to region**	**Sub-annual to 100+y**	**KM**	**i,ii,iii,iv**	
a. Ecosystem health					
i. Inadequacy of ecological theory to develop relevant conceptual model framework for ecosystem structure to allow comparison among systems, without oversimplifying inherent complexity. How to capture the true structure and processes of coastal ecosystems?	marine catchment basin to GBR	10-100y	M	-	Moderate
ii. Lack of standard metrics of ecosystem scale and condition, derived from key measurable processes in conceptual model	marine catchment basin to GBR	10-100y	M	-	Moderate
b. Habitat disturbance					Moderate-High
i. Role of natural pulse disturbance (flood, drought, cyclones) in maintaining species diversity and biological productivity.	marine catchment basin	Event-based disturbance with 1-10y recovery	K	i,ii	Moderate
ii. Response of coastal systems to press disturbances (tidal barrage, mangrove clearing, nutrient enrichment).	habitats within marine catchment basin	1-10+y	KM	i,ii,iii,iv	High
c. Connectivity					
i. Regional ecosystem effects of loss of connectivity, (physical barrier, hydrological alteration, wetland drainage, corridor blockage)	habitats within marine catchment basin	1-100+y	KM	i	High
ii. Sensitivity of species and critical life history stages to loss of connectivity.	determined by population distribution, from habitats within marine	tidal cycle to 100+y	KM	i	High

Issue / Knowledge Gap	Spatial Scale	Temporal Scale	Knowledge / Management Gap	Threat	Tully Priority
	catchment basin to GBR				
d. Fish production					
i. Rudimentary understanding of ecosystem processes linking fish production with other trophic levels.	marine catchment basin	seasonal to annual	M	ii	High
e. Migration effects					
i. Implications of migration and migration scale on conceptualisation of ecosystems, connectivity, and appropriate scales for management.	marine catchment basin to GBR	Tidal to ~10y	M	i,iv	High
f. Predictive capacity					
i. Rudimentary knowledge of coastal ecosystem ecology within GBR to allow reliable prediction of responses of fish resources.	regional to GBR	1-10y	K	all	High
3. Fish Ecology	**marine catchment basin to GBR**	**Event to 10y**	**KM**	**i,ii,iii,iv,v**	**Low – High**
a. Predator-prey interactions					
i. Variation among species in importance of synchrony between life history events, such as spawning or larval feeding, and environmental processes such as habitat connectivity, or prey availability.	marine catchment basin	Event-based around tidal, lunar, annual recurrence	M	i,ii	Low
ii. Influence of life cycle events such as spawning aggregations, migration bottlenecks, larval aggregations on vulnerability to mortality from predation or capture.	marine catchment basin	Event-based around tidal, lunar, annual recurrence	M	i,iii	Low
b. Flow ecology					
i. Influence of hydrological cycles on fish assemblages, food web processes and fish production.	marine catchment basin	1-10y	M	i	High
c. Population genetics					
i. Effects of fishing, barriers to migration, loss of habitat and other disturbances on genetic integrity of fish populations.	GBR	10y	K	i,iv,v	Low
d. Reproduction requirements					
i. Susceptibility of species with differing reproduction strategies, such as offshore, estuarine or freshwater spawners, to threats from catchment change.	marine catchment basin	1-10y	K	i,ii,iv	High
e. Resource management					
i. Links between habitat and food web processes to biodiversity conservation and fishery production.	marine catchment basin	1-10y	KM	i,ii,iv	High
f. Species biology					
i. Rudimentary knowledge of some taxonomic groups, such as sharks	population distribution	10y	K	iv,v	Low

Issue / Knowledge Gap	Spatial Scale	Temporal Scale	Knowledge / Management Gap	Threat	Tully Priority
and carangids, and key species e.g. prey species of value for fishery and environmental management at a broader scale.	(GBR)				
4. Food Webs	**marine catchment basin to region**	**Sub-annual to 10y**	**KM**	**i,ii,iii,iv,v**	**Low – High**
a. Food web dynamics					
i. Role of spatial and temporal dynamics and scale, from habitat patch to GBR system and tidal to long term climate cycles, in trophic structure of aquatic ecosystems.	marine catchment basin to GBR	Sub-annual to 10y	K	i,ii,iv	High
ii. Contributions of different primary producers to fishery food webs, and dynamics of relative contributions among systems and over time.	marine catchment basin	1-10y	K	ii,iii	High
iii. Nutrient budgets and sources for aquatic food webs, and dynamics among systems and over time.	marine catchment basin to region	1-10y	K	ii,iii	High
iv. Foraging strategies of coastal fish among habitats and during life history to meet nutritional requirements, and implications of altered stoichiometry for fish production.	marine catchment basin to region	1-10y	K	ii	Moderate
b. System integration					
i. Limited knowledge of food web processes linking tropical coastal species to ecosystem scale.	marine catchment basin to region	1-10y	K	i,ii	High
ii. Limitations in food web theory and empirical data for developing models to draw together available information.	marine catchment basin to region	1-10y		NA	High
iii. Relevance of ecological redundancy in tropical aquatic food webs, with respect to species that perform similar ecosystem functions.	marine catchment basin to region	1-10y	KM	iii,v	Low
iv. Importance of complexity: species richness, diversity and multiple species with similar niches, in maintaining stability and resilience in tropical aquatic ecosystems.	marine catchment basin to region	1-10y	KM	all	Low
v. Effects of taxonomic resolution and aggregation on understanding of food web processes and dynamics in simplified models.	marine catchment basin to region	1-10y	KM	v	High
5. Habitat Management	**marine catchment basin to region**	**1-10y**	**M**	**i,ii,iii,iv,v**	
a. Role of habitats in coastal ecosystems					
i. Importance of estuaries and estuarine habitats at different life history stages for freshwater, estuarine and marine resident	marine catchment basin	1-10y	KM	iv	High

Issue / Knowledge Gap	Spatial Scale	Temporal Scale	Knowledge / Management Gap	Threat	Tully Priority
species.					
ii. Effects of catchment–scale changes in water quality and flow-on effects on aquatic habitats for coastal species.	marine catchment basin	1-10y	M	iii,iv	High
iii. Data requirements to confirm habitat roles e.g. predation refuges, feeding habitats, protection from harsher environments, versus opportunistic aggregations produced by advection processes.	marine catchment basin	1-10y	K	iii,iv	Low
iv. Identification of so-called “critical habitats” for individual species or species groups, in an ecosystem context. Obligate and facultative requirements, and surrogate habitats.	marine catchment basin	1-10y	K	iii,iv	Low
v. Conservation of unique habitats to preserve local-scale biodiversity, such as unique species. Role of unique species and their habitats in the broader function of aquatic ecosystems. c.f. 4b(iii)	marine catchment basin	1-10y	M	iii,iv	Low
vi. Role of habitat diversity and hierarchical structure in the landscape-scale coastal habitat mosaic in maintaining biodiversity, ecological productivity, and ecosystem functionality. C.f. 4b(iv).	marine catchment basin	10-100y	M	iii,iv	High
vii. Contribution of coastal wetlands (as habitat complexes) to fish production and fishery harvests..	marine catchment basin to region	1-10y	M	iii,iv	High
b. Threats to habitats					
i. Identify components of coastal systems prone to loss of connectivity, e.g. from changed hydrology, changed geomorphology, climate change, and physical intervention (weirs and barriers, levees, road and railway banks, behavioural barriers, removal of “corridor” habitat).	marine catchment basin	1-10y	M	iv	High
ii. Solutions to restore biological connectivity at generic, and specific locations.	marine catchment basin	1-10y	M	i,ii,iii,iv	High
iii. Effects of high flows and turbidity on benthic production under historical and contemporary conditions.	marine catchment basin	1-10y	M	ii	Moderate
iv. Prospects for habitat change under different climate scenarios, c.f. 1a(i)	regional	10-100y	M	vi	Low
v. Implications of changes in habitat distribution and composition on fish behaviour, abundance and production.	marine catchment basin	1-10y	M	iv,v	High
vi. Effects of changes in water circulation patterns caused by coastal development on fish distribution, e.g. supply of larvae to	marine catchment basin	1-10y	M	iv	High

Issue / Knowledge Gap	Spatial Scale	Temporal Scale	Knowledge / Management Gap	Threat	Tully Priority
nursery areas.					
6. Information Integration					
a. Data assimilation					
i. Development of models of aquatic responses to catchment change to support target setting, priority setting, and trade-off analyses for coastal fisheries, in a data-poor environment, reflecting risks and uncertainty associated with identified scenarios.	marine catchment basin, region and GBR	1-10y	M	All	High
b. Data limitations					
i. Evaluation of models to identify data weaknesses, priorities for future data investment, (more data, better data, or better use of existing data), and implications of assumptions.	marine catchment basin, region and GBR	1-10y	M	All	High
ii. Identify valued aquatic ecosystem components including physical, biological, social, economic and cultural values, for inclusion in models.	marine catchment basin	1-10y	M	All	High
iii. Identify effects of catchment impacts and intervention on water quality, biodiversity, population dynamics and food web dynamics to support system-scale modelling efforts.	marine catchment basin to region	1-10y	M	ii	High
c. Data transferability					
i. Identification of transferability of system-specific information within and among GBR regions	region to GBR	1-10y	M	All	Moderate
d. Monitoring needs					
i. Development of agreed suite of indicators of fish responses, including icon species, to enhance impact of communication on local communities c.f. 2a(i), 2a(ii), 6a(i)	region to GBR	1-10y	M	All	Moderate
ii. Development of technology (e.g. biological sensor networks) to monitor impacts of catchment change on fish for input into models and decision frameworks.	region to GBR	1-10y	M	All	Moderate
iii. Testing remediation approaches at catchment scale to encourage wider adoption, using adaptive management approach.	marine catchment basin	1-10y	M	All	High

Priorities to sustain fisheries resources in the Tully-Murray system

The high priority knowledge gaps identified for the Tully-Murray system in the preceding section are presented here as a sequence of research tasks with specific objectives for the Tully-Murray marine catchment basin (Table 6).

Whilst the focus of these research tasks is on developing ecosystem knowledge at the marine catchment basin scale, one additional limitation is that humans tend to think at the scale we can observe and measure. Two consequences of this behaviour are that much effort in catchment rehabilitation is undertaken on small scale works, and that ecosystem approaches at the marine catchment basin scale are beyond the observational scale of many people working in catchment management. Accordingly, many detailed investigations of fish in selected habitats at observed scales fail to capture the vital concept of connectivity among different elements of the habitat mosaic (Fausch et al 2002). For this reason, the application of new sensor technologies and appropriate sampling designs for collecting data on fish resources at the marine catchment basin scale is imperative to allow collection of data on ecological responses to match the scale of physical and chemical processes included in predictive ecological models. Available resource in most system-scale studies of fish ecology determine that it is more useful to gather low resolution data from a large number of sites than to collect high resolution data from only a small number of sites that may not be representative of the whole system. Advances in hydroacoustic and video image processing technology, for example, have potential to facilitate high resolution, high frequency data collection at a large number of sites, providing unprecedented capacity to generate detailed information on ecosystem behaviour. At a time when instream instrumentation and grid computer technology offer increased resolution of water quantity and quality within river networks, it is highly desirable to apply comparable technology to monitor fish movements and population dynamics at a systems scale. The current focus on the Tully-Murray system provides an opportunity to expand the technological cutting edge of systems ecology.

Each of these tasks has relevance to the local focus on the Tully-Murray system, but also deals with issues of broader relevance throughout the GBR, and globally as fishery managers, coastal scientists and catchment managers grapple with the complexities of integrating terrestrial, freshwater and marine systems into marine catchment basins with provision for the human social, cultural and economic dimensions.

Table 6. *Research tasks to improve the sustainability of fisheries in the Tully-Murray Marine Catchment Basin.*

Task ID	Research Task	Objectives	Fishery Relevance
1	Develop conceptual model of ecological processes supporting coastal fish production, and their responses to catchment change	1 Develop a conceptual framework of aquatic ecosystem structure and processes for comparison of systems in the GBR region, with sufficient detail for application within individual systems.	Provide ecosystem framework linking catchment condition to fishery resource condition
		2 Identify valued aquatic ecosystem components including physical, biological, social, economic and cultural values, for inclusion in models.	Ensure relevance of conceptual model to stakeholders
		3 Develop indicators of ecosystem condition and fish resources for monitoring responses to catchment change, including icon species.	Performance indicators for catchment management to sustain fisheries resources
		4 Identify sensitivity of indicators to catchment change, and timescale for response, and review indicator suite.	Refine performance indicators
2	Predictive modelling of fish responses to habitat and catchment change in a tropical aquatic ecosystem	1 Development of models of aquatic ecosystem responses to catchment change to identify risks and trade-offs for fisheries associated with Best Management Practice scenarios.	Provide tools to empower fishery sectors in setting targets and priorities for catchment management
		2 Quantify model sensitivity, uncertainty and data gaps for future data investment	Strategic model improvement
		3 Assess effects of taxonomic resolution and aggregation on understanding of food web processes and dynamics in simplified models.	Maximising cost-efficiency of data collection
		4 Extend ecological theory of food web processes, and associated data requirements.	Improve understanding of links between catchment and fishery resource condition
		5 Identify limitations in existing data linking knowledge of tropical coastal species to ecosystem scale	Improve value of existing and future data collection
		6 Evaluate effects of catchment-scale changes in water quality on coastal habitats.	Facilitate setting targets for water quality to sustain fish habitats
		7 Evaluate implications of changes in habitat distribution and composition on fish behaviour, abundance and production.	Predict responses in fish production resulting from habitat changes
		8 Establish links between habitat and food web processes, to biodiversity conservation and fishery production.	Identify complementary approaches fishery conservation and sustainability
		9 Identify strategic knowledge gaps in coastal ecosystem ecology within GBR for research investment	Strategic improvement in knowledge to empower fishery sector
		10 Testing remediation approaches at catchment scale to encourage wider adoption, using adaptive management approach.	Selection of successful approaches for application in other marine catchment basins to sustain aquatic biodiversity and fish production.
3	Spatial and temporal dynamics of fishery food webs in a tropical aquatic ecosystem	1 Quantify the spatial and temporal dynamics and scale, from habitat patch to GBR system and tidal to long term climate cycles, in trophic structure of	Assist management of habitats and ecosystem processes within the

Task ID	Research Task	Objectives	Fishery Relevance
		estuarine ecosystems.	natural range over time
		2 Quantify the contributions of different primary producers to fishery food webs, and dynamics of relative contributions among systems and over time.	Understand fishery consequences of regime shifts in primary production
		3 Develop nutrient budgets and sources for aquatic food webs, and dynamics among systems and over time.	Understand implications of nutrient loads for fish production
		4 Quantify ecosystem processes and pathways linking fish production with other trophic levels.	Sustaining fish production by ensuring food requirements are met (quality and quantity)
		5 Quantify responses of food webs and fish production to hydrological cycles and alteration in a tropical aquatic ecosystem	Support development of operating rules for flow management
		6 Identify effects of aquatic stoichiometry on fish foraging strategies to meet nutritional requirements, and implications for fish production.	Implications of altered nutrient ratios for food quality to support fish production
4	Development of cost-effective technology for monitoring fish populations in tropical river networks.	1 Development of an automated, video-based fish identification, counting and measurement system for remote monitoring of fish stocks in catchment networks.	Facilitate low-cost monitoring of performance indicators for fisheries management
		2 Application of hydroacoustic methods for remote monitoring of fish in turbid coastal environments.	Facilitate low-cost monitoring of performance indicators for fisheries management
5	Contribution of coastal wetlands to fish production in tropical ecosystems	1 Quantify the contribution of coastal wetlands to fish production and fishery values at the catchment scale	Promote cumulative value of wetlands for their contribution to fish production
		2 Quantify the benefits of wetland rehabilitation coastal to fish production	Facilitate cost:benefit analysis of wetland loss, preservation, and restoration
6	Importance of habitat diversity and connectivity among habitats for fish production in tropical aquatic ecosystems	1 Quantify the importance of aquatic mesohabitats (e.g. wetlands, macrophytes, mangroves, sandy beaches, saltmarshes) to different life history stages for freshwater, estuarine and marine fish.	Understanding trade-offs in managing ecosystem habitat mosaic
		2 Determine the value of habitat diversity in the landscape-scale coastal habitat mosaic in maintaining biodiversity, ecological productivity, and ecosystem functionality	Assist design of landscape mosaic to sustain biodiversity and fish production
		3 Identify types and scale of connectivity among habitats, and risks of loss of connectivity (e.g. from changed hydrology, geomorphology, physical barriers, behavioural barriers, or removal of "corridor" habitat	Identify habitats requiring intervention to sustain spatial footprint of fish production
		4 Quantify effects of loss of different types of connectivity on fish production within system	Assist priority setting for protection and restoration of connectivity
		5 Identify sensitivity of species and critical life history stages to loss of connectivity.	Sustaining populations of fish with specific habitat needs
		6 Develop solutions to restore or sustain biological connectivity among	Cost-effective methods to manage

Task ID	Research Task	Objectives	Fishery Relevance
		habitats	connectivity to conserve biodiversity and sustain fish production
		7 Quantify ecosystem effects of loss of connectivity on range, abundance and production.	Ensure connectivity to allow fish access to habitats
		8 Identify the scales of fish migrations, and implications of connectivity on conceptualisation of ecosystems	Matching scale of management to ecosystem processes
		9 Identify implications of habitat use on fish behaviour, vulnerability and survival	Improved management of connectivity for fish conservation and production
7	Environmental factors regulating fish recruitment	1 What processes regulate fish recruitment to tropical ecosystems, regarding larval supply and post recruitment connectivity with nursery habitats?	Understand physical processes driving population dynamics
		2 Identify the role of the Tully-Murray marine catchment basin as a fish nursery, and its particular nursery ground values	Conservation of habitats to sustain resident and migratory fish species
		3 Susceptibility of species with differing reproduction strategies, such as offshore, estuarine or freshwater spawners, to threats from catchment change.	Identify high risk species and habitats
8	Impacts of catchment change on fish biodiversity, population dynamics and food webs in a tropical system	1 Quantify effects of catchment impacts and catchment intervention on water quality habitats habitat availability, fish biodiversity, population dynamics and food web dynamics to support modelling efforts.	Ensure models are robust to challenge and legally defensible if contested
9	Scale-dependent assessment of aquatic ecosystems and fish production in the Great Barrier Reef region	1 Identification of transferability of system-specific information within and among GBR regions	Ensure applicability of results to other systems for cost-effective research

Recommendations for future research

The research priorities identified here cover a number of user-driven and science-driven needs. User-driven needs focus on developing a capability to predict the responses of fish resources to ecosystem changes arising through catchment changes or habitat alteration. Science-driven needs target the different levels of information required to deliver the user-driven needs within an acceptable range of uncertainty. These requirements are combined below to develop a summary list of recommendations for future research in the Tully-Murray system to address local needs for fishery research which at the same time address broader needs at GBR and global scales in leading development of the marine catchment basin approach to managing coastal systems. These recommendations recognise that the Tully-Murray system does not itself support a major commercial fishery, however, the marine catchment basin includes the northern Hinchinbrook Channel, which supports an extensive fishery.

It is significant, but not surprising, that the recommendations complement the findings by Kroon (2004) in the Douglas Shire, another group of Wet Tropics catchments. The main outcomes from Kroon (2004) were recommendations to improve conceptual understanding of ecological processes underpinning aquatic biodiversity, and capacity to predict aquatic outcomes of alternative land-use and landscape composition scenarios at the catchment scale.

Supporting objectives for each recommendation are listed in Table 6.

Recommendations

(i) Develop a conceptual model of ecological production for the Tully-Murray marine catchment basin that identifies indicators of ecosystem health pertinent to fish production for monitoring responses to catchment change. Such a model will be critical to facilitate effective participation by upstream and downstream stakeholders in priority setting within the catchment.

(ii) Develop a quantitative model of the responses of aquatic organisms to changes in habitat availability and water quality, based on Recommendation (i), to predict risks and trade-offs for aquatic resources and fisheries associated with catchment management scenarios.

Important knowledge gaps to support conceptual and predictive model development are:

(iii) Quantify how coastal food webs that support fisheries vary spatially within the Tully-Murray marine catchment basin between marine, estuarine, freshwater and wetland habitats, and over time between wet and dry seasons. This recommendation includes the food requirements for fish production and the implications of changing stoichiometry for fish nutrition, as well as determining how these processes are influenced by catchment change.

(iv) Develop innovative, cost-effective technology for monitoring responses of fish populations to catchment change at the marine catchment basin scale within the Tully-Murray system.

(v) Quantify the contribution of wetlands to fish production at the Tully-Murray marine catchment basin scale to identify potential large-scale benefits of wetland rehabilitation.

(vi) Identify the importance of habitat diversity and connectivity for fish production at the marine catchment basin scale, with respect to effects of catchment change on aquatic habitats and connectivity.

(vii) Identify the processes influencing and controlling recruitment of fish to the Tully-Murray marine catchment basin, including the role of nursery habitats within the system, and risks associated with different reproductive strategies.

(viii) Undertake strategic research to quantify effects of catchment impacts and effectiveness of intervention within the Tully-Murray catchment on water quality, habitat availability, fish biodiversity, population dynamics and food web dynamics to support modelling efforts at the marine catchment basin scale.

(ix) Identify the scale-dependence of information from the Tully-Murray system and transferability to other marine catchment basins, and to other regional scales such as the Wet Tropics, and the whole GBR.

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