The life-cycle habitat requirements of coastal fisheries species; identifying key knowledge gaps and research needs

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JAMES COOK UNIVERSITY AUSTRALIA

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FRDC FISHERIES RESEARCH & DEVELOPMENT CORPORATION

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1.0 NON TECHNICAL SUMMARY

2012/037 The life-cycle habitat requirements of coastal fisheries species; identifying key knowledge gaps and research needs

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OBJECTIVES:

1. Review all available literature to identify key knowledge gaps and refine a potential field research program; focussing on (a) critical habitats necessary for the life-cycles of key fisheries species using estuarine and nearshore nurseries, (b) connectivities supporting that utilisation, (c) the relative importance of different nursery grounds, (d) the relative value of different habitats for life-history requirements, and (e) habitat-specific food webs and trophic interactions supporting fisheries species life-cycles.
2. Develop a "business case" for future investment, considering the risks, opportunities to protect, repair, offset etc., and developing a decision support system based on these opportunities and risks.

NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED TO DATE

The project produced a Literature Review that details our current state of knowledge of fish-habitat relationships around Australia’s coasts and identifies key gaps in our knowledge that need to be filled if our fisheries habitats are to be managed effectively into the future. This has led to the development of new research proposals to begin to address these key knowledge gaps. The information is pivotal for organisations such as DAFF fisheries, EHP and GBRMPA in valuing marine and estuarine habitats, supporting management of fisheries habitats, assessing habitat condition and current human impacts, reviewing development proposals and determining appropriate development offsets. Both commercial and recreational fishing sectors will benefit by greatly informed management of critical habitat resources.

The project also produced a Business Case that identifies potential opportunities to obtain the funds needed to fill the research gaps identified in the literature review, including opportunities for investment from both Government and external funding sources.

This project involved two components (i) a Literature Review detailing our current knowledge into the fish-habitat relationships of key fisheries species around Australia's coasts, and (ii) a business case exploring the potential for future investment into increasing fisheries habitat knowledge.

Understanding fish habitat relationships is complex because coastal fisheries species require a series of connected habitats to complete essential life-history functions. So reviewing our current understanding was necessary to provide clear, centralised documentation of what we know and to identify gaps in our knowledge that inhibit effective management of fish habitats. Managers need to understand how fish use habitats because of the many ways information on fish habitats feeds into management; they need to be able to determine areas of habitat that need to be protected, what type of protection is needed, where development can be allowed and where it should be prohibited, how and where to direct offsets for habitats lost during development etc. The research needed to develop this information is expensive and far beyond what government fisheries organisations can fund. As a result, understanding how to obtain co-investment into fish habitat research is important; hence the need to develop a business case to explore these opportunities.

The review achieved the major project objective of detailing our current knowledge of the habitat relationships of key fisheries species; information needed if our fisheries habitats are to be managed effectively into the future. It determined that our knowledge of fisheries habitats is very incomplete, with key information such as exact spawning locations poorly understood for many species, and the series of habitats required during different stages of juvenile growth unknown for a majority of species. In fact the series of life-history stages that key species undergo has rarely been fully determined. One important issue stemming from this lack of knowledge is that the relative values of alternative nurseries to fisheries stocks have not been determined, so we lack the ability to quantify the economic contributions of different habitats to fisheries production. For instance, many habitats without apparent direct functional roles are vital as conduits between habitats critical for life-history needs. This issue of our inability to accurately value the contributions of habitats is a continuing problem that greatly reduces our ability to determine what the key habitats are and to protect them. As well as determining 18 key knowledge gaps the review identified two key elements to filling those gaps; gathering together the knowledge of commercial, recreational and indigenous fishers about fish habitat relationships, and combining that with research directed to gaining knowledge of life stages not usually caught by fishers.

The business case identified a range of potential opportunities to obtain the funds needed to fill the research gaps identified in the literature review, including opportunities for investment from both Government and external funding sources.

Overall, the project provided the background knowledge needed to develop precise understanding of the life-cycle habitat requirements of fisheries species, the relative values

of different nursery habitats, the locations of spawning habitats and the key connectivities among them. This information will be critical in directing future research and research investment into fish-habitat relationships. While it identifies that considerable further research is required, it provides a blueprint for both the work needed and the approach to access the funds needed to conduct the research.

KEYWORDS: Fish, Habitat, Life-cycle, Knowledge Gaps

2.0 ACKNOWLEDGMENTS

We thank Mike Ronan from EHP for his helpful advice that greatly improved outcomes of the project. We also thank the QFRAB and FRDC for their continued support and encouragement through this project, as well as Colin Creighton for his support and facilitation of workshops related to the project. In addition, the following people provided critical input that has helped shape this review: Donna Audas (GBRMPA); Rod Connolly (GU); Pat Dale (GU); Jim Higgs (ex DERM); Jeremy Hindell (Vic. DSE); Hsuan Lammers (EHP); Neil Loneragan (Murdoch); Brett Molony (WA Fisheries); Ivan Nagelkerken (AU); Andrew Olds (GU); Rebbeca Sheppard (QDAFF). We are also grateful to the Fisheries Research Development Corporation for their financial support.

3.0 BACKGROUND

This project was developed in response to a recognised need for improved understanding of fish-habitat relationships in tropical estuaries and nearshore waters, particularly in terms of nursery ground utilisation and the relative contributions of different nurseries to adult stocks. The project involved consultation with many staff from QDAFF Fisheries Habitat Research, GBRMPA Coastal Ecosystems and Water Quality, and Ecosystem Conservation and Sustainability Use teams, DERM/Queensland Wetland Program Connectivity project team, DERM/Marine Policy Estuarine Habitat Mapping and Classification team, NQ Dry Tropics, Healthy Waterways, Sustainable Coasts and Biodiversity staff, commercial and recreational fishing representatives, and Townsville City Council. The project was further developed in a Fisheries Research and Development Corporation (FRDC) facilitated meeting which included key end users and interested groups: QFRAB, DERM, DEEDI, GBRMPA, Sunfish, QSIA, NQBP, Townsville Council, Cairns Council, NT DPIF, and Cardno.

4.0 NEED

Coastal fisheries species require a series of connected habitats to complete essential life-history functions. Key habitats, such as nursery areas, are known for some species but the sequence of habitats used by juveniles is poorly known for most. Even where nurseries are known the relative values of alternative nurseries have not been determined, so we lack the ability to quantify the economic contributions of different habitats to fisheries production. Many habitats without apparent direct functional roles are vital as conduits between habitats critical for life-history needs. Similarly, spawning and forage sites are unknown for many species. The project provides the background to develop research detailing the life-cycle habitat and connectivity requirements of coastal fisheries species, so is the vital first step in gaining the knowledge needed by managers to understand and protect coastal habitats. It fills critical knowledge gaps identified in the DERM/QWP's "Connectivity" project, and supports habitat classification and mapping work (e.g. QWP/DEEDI Coastal-wetlands mapping, OzCoasts). It will provide the basis for enhanced quantification of the ecological and economic importance of the chain of habitats necessary for healthy fisheries, thus addressing QFRAB 2011/12 priority 4 and priority 3. This will allow more precise management of species valuable to all fishing sectors, and provide pivotal information needed to incorporate fisheries values into impact and offset assessments for development proposals. Thus the work provides crucial information needed by Fisheries Queensland, QDAFF Fisheries Habitat Research, GBRMPA's Sustainable Fishing, Species Conservation and Coastal Ecosystems sections, and contributes to the long term ecological and economic health of Northern Australia's fisheries.

5.0 OBJECTIVES

1. Review all available literature to identify key knowledge gaps and refine a potential field research program; focussing on (a) critical habitats necessary for the life-cycles of key fisheries species using estuarine and nearshore nurseries, (b) connectivities supporting that utilisation, (c) the relative importance of different nursery grounds, (d) the relative value of different habitats for life-history requirements, and (e) habitat-specific food webs and trophic interactions supporting fisheries species life-cycles.
2. Develop a "business case" for future investment, considering the risks, opportunities to protect, repair, offset etc., and developing a decision support system based on these opportunities and risks.

6.0 METHODS

The project aimed to gain a detailed understanding of the current state of knowledge and issues around fish habitat relationships of Australia's coastal fisheries species. This involved a review of all available authoritative literature focussing on (a) critical habitats necessary for the life-cycles of key fisheries species using estuarine and nearshore nurseries, (b) connectivities supporting that utilisation, (c) the relative importance of different nursery grounds, (d) the relative value of different habitats for life-history requirements, and (e) habitat-specific food webs and trophic interactions supporting fisheries species life-cycles. The review was conducted by experts in coastal fish habitats and ecological interactions and addressed issues from spawning and nursery habitats, through connectivity and relative nursery ground value, to the role of natural and artificial structures, and habitat-specific food webs. A "business case" was developed to highlight areas where potential future investment could be obtained in parallel to the review, utilising the specialist skills of a consultant, expert in the practices of developing environmental engagement by large business and the interaction of ecological science and industry. The business case was informed by consultation with senior staff from key industry organisations such as ports, resource sector as well as the three levels of Government. The business case considered how best to involve external funding outside of "normal" fisheries research, which aimed at maximising the opportunities to protect and repair habitats, minimise risks of habitat loss and offset any losses that do occur. The literature review fed into the development of the business case.

7.0 RESULTS/DISCUSSION

The Literature Review concluded that many aspects of the relationships between fisheries species and specific habitats are well known by commercial and recreational fishers, and that if this knowledge can be formalised into an organised knowledge base it can provide a substantial resource of key information. However, even with this knowledge there are substantial gaps in our understanding of critical parts of fish life-cycles, and in exactly how fish use habitat resources. It is well known that coastal ecosystems (estuaries, tidal wetlands and shallow coastal waters) play key roles in the provision of critical spawning, feeding and nursery grounds to fisheries species. Despite this general understanding, the specific spawning habitats of many species are unknown and the nursery grounds for most key species have not been identified, resulting in very incomplete understanding of the nursery habitat needs for even common Australian fisheries species. Critically, there is almost no information about the first habitats used by very small juveniles, even though the availability and quality of these habitats has been identified as a vital bottleneck determining nursery ground success. Not surprisingly details of the way fish use habitats and resources within the habitats is also lacking. This detailed information on fish-habitat relationships and the processes that support habitat utilisation is needed because it is often a critical gap preventing well-directed and effective management.

Just as understanding how fish use natural habitats is important, detailed understanding of how fish use man-made habitats is needed. Structures such as training walls and jetties have the potential to provide valuable refuge, feeding, spawning and nursery habitats for fish but they need to be designed and engineered appropriately. Consequently, understanding how the value of these habitats can be maximised is an area in need of detailed research.

Although there are many areas of concern the review identified 18 major knowledge gaps relating to general fish-habitat issues, and specific issues related to spawning and nursery habitats. These gaps are detailed in the review document (Appendix 3) and include:

- Mapping, baselines and monitoring
- Formalising fisher knowledge on fish habitat utilisation
- Environmental conditions that facilitate or impair connectivity
- Connectivities supporting life-history functions
- How the habitat value of artificial structures can be maximized
- Information on non-target species
- Habitat values of deeper and unvegetated habitats
- Habitat resource utilisation
- Detailed identification of spawning habitats
- The exact settlement process
- The range of nursery habitats utilised
- The habitats utilised at different stages of nursery residence
- Synergies among habitats that support nursery function

- Non-habitat nursery resources requirements
- Stage-specific habitat and non-habitat resource requirements
- Geographic variation in nursery ground value
- Relative contributions to adult stocks from different nursery habitats
- Processes regulating growth and survival of juveniles in nursery grounds

The results of the review were presented at an FRDC/QFRAB led workshop on and 30 April 2013, and led to the development of FRDC proposal: *MS031 Life history specific habitat utilisation of tropical fisheries species*, aimed at addressing some of these gaps. This project aims to develop understanding of the life-history habitat needs of coastal and estuarine fisheries species to provide the basis for strategic decisions on the optimal siting of developments, direct the development of coastal infrastructure, and direct environmental offsets to optimise their benefits to fisheries.

The Business Case identified potential opportunities to obtain the funds needed to fill the research gaps identified in the literature review, including opportunities for investment from both Government and external funding sources.

Traditional fisheries research funding bodies such as the FRDC, Australian Research Council, Commonwealth and State Departments of Agriculture, Fisheries and Forestry; Commonwealth Scientific and Industrial Research Organisation all have increasingly limited funds to support the extensive research needed into fish habitats. Principal opportunities for targeting additional funding are via proponents proposing development within the coastal and marine zones, and via access to monies paid for offsets through both the Commonwealth and Queensland Governments. Both levels of Governments have offset policies that allow research to be integrated into a project's offset requirements as an indirect offset. The business case identifies a number of priorities from the Literature Review that industry would be likely to see benefit in supporting. Extensive engagement with potential funders is recommended, beginning at the stage where proponents are seeking to engage consultants to undertake work associated with their projects, including for example, when there is the first discussion of a project and particularly prior to the preparation of both the referral and/or initial advice statement for their environmental impact assessments. Early engagement is of potential benefit for both the proponent and the researcher. For early engagement to be successful, it is essential that researchers develop an understanding of the actual proposed projects themselves and the details of likely potential impacts.

The business case was presented at an FRDC/QFRAB led workshop on and 30 April 2013, and led to the development of FRDC proposal: *MS034 Revitalising Queensland's Estuaries*, that proposes the development of a consortium with the central goal of facilitating a net increase of fisheries habitat and productivity along the Queensland coast by to develop strategies for obtaining co-investment to support fish habitat research and foster habitat repair and remediation activities.

8.0 BENEFITS AND ADOPTION

This project will ultimately benefit all fisheries sectors by determining the need and priorities for future fish habitat research, as well as developing a business plan for accessing co-investment in improving knowledge, and ultimately the health, of fisheries habitats. Consequently, the project has been successful in providing the benefits identified in the original application for all beneficiaries. A test of the value of this project will be the successful funding of the two applications flowing from it.

9.0 FURTHER DEVELOPMENT

Further development from this project has already occurred through the development of two funding applications *MS031 and MS034*. However, these represent only a first step in addressing the gaps identified in the project. More effort will be required in gaining funds to support detailed fish habitat research including engagement with industry and participation in major Government funding initiatives such as Reef Rescue.

10.0 PLANNED OUTCOMES

The project was successful in achieving its planned outcomes by providing the background needed to develop precise understanding of the life-cycle habitat requirements of fisheries species, the relative values of different nursery habitats, the locations of spawning habitats and the key connectivities among them. This information will be pivotal for organisations such as QDAFF, EHP and GBRMPA in valuing marine and estuarine habitats, supporting management of fisheries habitats, assessing habitat condition and current human impacts, reviewing development proposals and determining appropriate development offsets. Importantly, all fishing sectors will benefit by improved understanding of fish habitat needs that will lead to greatly informed management of critical habitat resources.

Two-way communication continued throughout the project via direct interactions with commercial and recreational fishers and management groups such as DAFF fisheries, EHP, GBRMPA and Northern Territory DPIF. This dialogue was used to inform participants of outcomes, to gather key information about the direction of the project, and to validate information gathered in the literature review. Primary communication products include a formal review report and parallel plain language summary, a formal literature review; *The life-cycle habitat requirements of coastal fisheries species: identifying key knowledge gaps and research needs*, a business case; *The life-cycle habitat requirements of coastal fisheries species: a business case for obtaining funding for future research*, an investigation of the form of a decision support system to support the on-going development of fish habitat research; *Decision Support System to Direct Investment to Research Needed to Support Long-Term Sustainability of Coastal Fisheries Habitats*, and PowerPoint presentations, fact sheets and conceptual diagrams that will be made available through the JCU Estuary and Tidal Wetland Ecosystems Research Group website which is curated and regularly updated. This comprehensive set of modes of communication, that emphasises plain-language summaries as well as a technical review, is designed to provide a body of information, in a timely fashion and in forms that can be quickly and easily understood by end users, helping ensure that the outputs are useful, relevant and widely adopted.

11.0 CONCLUSION

The project developed a literature review that addressed the original objectives of the project, leading to a great advance in understanding of the specific needs for fish habitat research in Australia. In particular it identified serious gaps in knowledge of details of specific habitat requirements at particular life-history stages, highlighting the large range of key research needed to support healthy and productive fish habitats into the future, especially in the face of continued pressure from coastal development. The recommendations developed provide a clear direction for future research and investment in research. The associated business case developed a manifesto for obtaining the co-investment needed to fund the large body of fish habitat research that is required.

Not only will the outputs of this project lead to improved understanding of fish habitat requirements, benefiting all fishing sectors through improved understanding of fish habitat needs leading to greatly informed management of critical habitat resources, but the understanding developed will be pivotal in the management of fisheries habitats by organisations such as QDAFF, EHP and GBRMPA. It will greatly assist those organisations to effectively value marine and estuarine habitats, providing information needed as a basis for informed assessment of habitat condition and the effects of human impacts. Importantly, the outputs will help direct the development of new co-funding relationships needed to support future research into the habitat needs of key fisheries species.

12.0 LIST OF ACROYNMS

Cardno	An ASX-200 professional infrastructure and environmental services company
DEEDI	Queensland Department of Employment, Economic Development and Innovation
DERM	Queensland Department of Environment and Resource Management
EHP	Queensland Department of Environment and Heritage Protection
FRDC	Fisheries Research and Development Corporation
GBRMPA	Great Barrier Reef Marine Park Authority
JCU	James Cook University
NQ Dry tropics	A community based not-for-profit company charged with managing the environment in north Queensland's dry tropics
NQBP	North Queensland Bulk Ports
NT DPIF	Northern Territory Department of Primary Industry and Fisheries
OzCoasts	Australia's online coastal information website managed by Geoscience Australia and providing comprehensive information about Australia's coast, including its estuaries and coastal waterways.
QDAFF	Queensland Department of Agriculture, Fisheries and Forestry
QFRAB	Queensland Fisheries Research Advisory Body
QSIA	The Queensland Seafood Industry Association
QWP	The Queensland Wetland Program
Sunfish	Queensland's peak recreational fishing group

APPENDIX 1: Intellectual Property

This project has developed a detailed literature review and business case that together provide key knowledge required by FRDC and FRDC researchers in developing future research priorities, research and co-funding activities. While these have no specific monetary value they are extremely valuable in knowledge terms.

APPENDIX 2: Staff

The project involved Associate Professor Marcus Sheaves, Dr Kátya Abrantes and Mr Ross Johnston from James Cook University; Randall Owens and Mark Read from GBRMPA; Dr Thor Saunders from NT Department of Resources, Fisheries; and Mr Peter Wulf from AWOFTAM Enviro and Legal.

APPENDIX 3: Outputs

Outputs include:

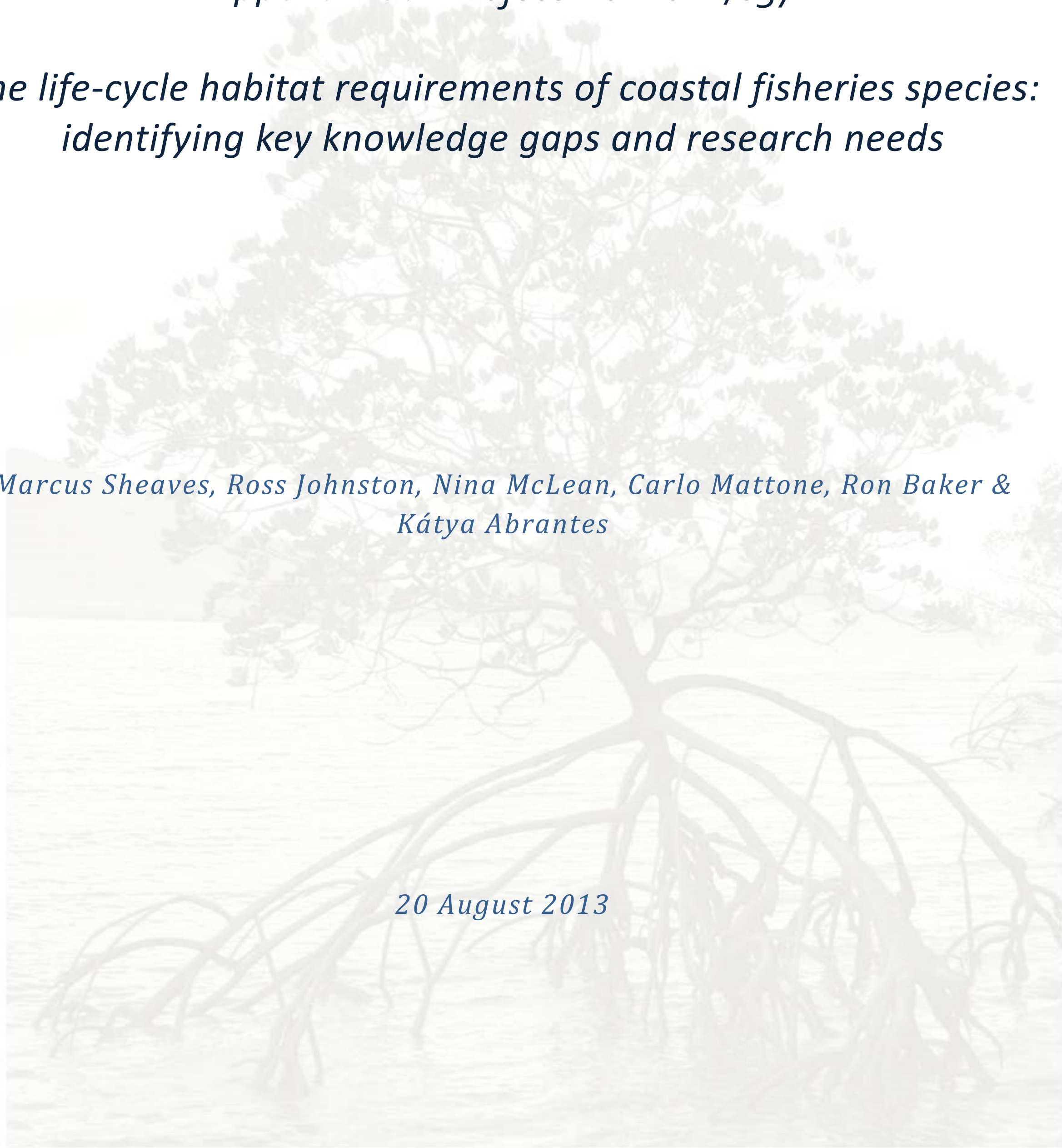
Appendix 3a: The life-cycle habitat requirements of coastal fisheries species: identifying key knowledge gaps and research needs,

Appendix 3b: A business case for obtaining funding for future fish-habitat research,

Appendix 3c: Decision Support System to Direct Investment to Research Needed to Support Long-Term Sustainability of Coastal Fisheries Habitats.

Appendix 3a: Project No. 2012/037

The life-cycle habitat requirements of coastal fisheries species: identifying key knowledge gaps and research needs



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TropWATER Centre for Tropical Water and Aquatic Ecosystem Research
Estuary & Tidal Wetland Ecosystems Research Group

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Executive Summary

- Habitats used by exploited components of fisheries stocks are well known by fishers, and their knowledge has the potential to provide a large amount of information on fish habitat relationships, if it can be formalised into a centralised knowledge base. However, there are substantial gaps in knowledge for critical parts of fish life-cycles, such as spawning habitats that are only used for short periods of time, and nursery habitats that are often inaccessible to traditional fishing gears. There are also significant gaps in our knowledge of exactly how fish use the resources habitats provide; information that is often the most critical for well-directed and effective management.

- Coastal ecosystems (estuaries, tidal wetlands and shallow coastal waters) provide spawning, feeding and nursery grounds to fisheries, with their critical spawning and nursery roles recognised as vital contributors to healthy fish stocks around the world. The quality of spawning habitats is vital to support reproductive output, while nursery habitats provide juveniles with refuges from predation, rich feeding areas and areas where hydrodynamic structures provide energetic advantages.

- While there is a general understanding of the spawning areas of many species, specific spawning habitats are much less well known. Even when specific spawning habitats are known, often only a few of many potential spawning habitats have been investigated. More detailed research into spawning habitats and their values is necessary given the importance of spawning to the maintenance of fish stocks.

- Nursery grounds have been identified in detail for very few Australian inshore fisheries species resulting in very incomplete understanding of the nursery habitat needs for even common Australian fisheries species. Most studies have only reported where juveniles have been found, which reflects where studies have been done not nursery value, so there is no comprehensive information about the range of habitats occupied or their relative importance. Critically, there is almost no information about the first habitats used by very small juveniles, even though the availability and quality of these habitats has been identified as a critical bottleneck determining nursery ground success.

- Despite advances in understanding of nursery grounds greater clarity in their definition is required. A recent key advance is the recognition that nursery grounds comprise mosaics of interacting habitats, so can't be simply evaluated on a case-by-case basis. Evaluating nursery value based simply on occupation fails to account for the complexity of nursery ground contributions. Measuring outputs (proportional contribution) is a substantial advance but fails to account for non-numeric factors like differential fitness or include understanding of processes that contribute to nursery value. Effective management needs to be based on an understanding of all these factors because it is the processes that support nursery function that need to be managed if nursery function is to be maintained in the face of impacts and change.

- Recent advances in understanding that nursery ground value is provided by complexes of interacting habitats has highlighted the importance of understanding the diverse connectivities that support nursery value. In fact the health and integrity of connectivities is critical to almost all aspects of fish life-histories but, because of its importance has only recently become clear, our understanding of connectivity is not extensive.

- Structurally complex habitats, such as fallen trees and rocky reefs, provide key refuge habitats in coastal nurseries. Structures built by humans in the marine environment have the potential to provide valuable structural complexity that can provide refuge, feeding, spawning and nursery habitats, if they are engineered appropriately. There is a considerable need for detailed research to determine how the ecological value of artificial structures can be optimised.

- Because access to rich feeding environments is one of the key contributors to nursery ground value improved understandings of food webs and how they vary over space and time is critical to supporting nursery ground value. This need for detailed food web understanding extends to other life-cycle stages because it is a key component of the values conferred by habitats at different life-history stages.

- There are a variety of critical knowledge gaps relating to fish habitats that need to be filled before coastal and estuarine fisheries can be managed effectively. This is particularly the case for crucial spawning and nursery habitat functions, and detailed habitat mapping. There is also an important need to incorporate fisher knowledge into formal fish-habitat understanding.

1. Introduction

Whether they are salt marshes, mangrove forests, seagrass beds, floodplain swamps, beaches, headlands, fringing reefs, coastal wetlands or estuaries, coastal ecosystems are among the most valuable on the planet (Costanza et al. 1997). Despite this they are among the most threatened (Duke et al. 2007). They occupy locations at the interface of land and sea that are also highly prized by humans, leading to unprecedented and rapidly increasing threats from climate change, intense population pressure, and rapid, large-scale development (Edgar et al 2000, Worm et al. 2006, Corn & Copeland 2010). This conjunction of high value and intense threats makes a detailed understanding of the functioning of coastal wetlands essential if they are to be managed and protected for future generations (Sheaves et al. 2006). In some parts of the world (e.g. USA; Heck et al 2003, Minello et al 2003) resources are being directed towards this understanding, yet relative to their immense value, coastal wetlands remain largely overlooked.

The Australian coastline, with its contrasting geology, geomorphology, oceanography and climate, includes a diversity of coastal ecosystems (estuaries, bays, coastal lagoons, sandy or rocky beaches). These ecosystems comprise ensembles of disparate habitat types, including seagrass beds, algal reefs, intertidal banks, rocky shores, mangroves and saltmarshes and floodplain forests, interacting together to form a variety of interconnected habitat mosaics or seascapes. Almost all coastal fisheries species require occupation of particular components of these seascapes, during particular life stages, to complete essential life-history functions. Consequently, understanding the way fish use coastal habitats throughout their life-cycles is fundamental to effective management. Indeed, it has been shown repeatedly that the risk of management failure is high when life-history understanding is not incorporated as a basis for planning, legislation, implementation and regulation (Hilborn et al. 1995, Walters & Martell 2004). Key habitats, like nurseries, are known for some species but the sequence of habitats used by juveniles is poorly understood for most. Even where nurseries are known the relative values of alternative nursery habitats have not been determined, so we lack the ability to quantify the economic contributions of different habitats to fisheries production. In addition, many habitats without apparent direct functional roles are vital as conduits between habitats critical for life-history needs. Similarly, spawning and forage sites are unknown for many species.

Habitat destruction is a major threat to commercial and recreational fisheries (Kearney et al. 1996), with habitat modification, degradation and loss key contributors to fisheries declines (Stobutzki et al. 2006), so it is critical to protect high value habitats such as those used as spawning or nursery areas (Koenig et al. 2000). Not only is fisheries habitat protection mandated under Australian law and policy (Turner et al. 1999), but characterizing fish-habitat associations is a fundamental step in fish habitat management (Bond & Lake 2003). Moreover, it is critical to understand fish habitat interactions and their relationships to healthy fish stocks and fisheries, as fish and fisheries adjust to environmental change, sea level rise-induced habitat shifts, and climate change-related range shifts (Last et al. 2011).

Estuaries and nearshore environments are among the most anthropogenically degraded habitats (Edgar et al. 2000). Human impacts take the form of degraded water quality, such as increased turbidity from terrestrial inputs from sewage, stormwater runoff, agricultural runoff etc. (Tanner 2005, Milbrandt et al. 2012), loss of connectivity due to barriers such as flood gates (Boys et al.

2012), and direct interactions between fishing gears and habitats (Duarte 2002). Many fisheries species are associated with habitat-forming benthic organisms such as sponges, corals and seagrass (Burfeind et al. 2009), making them major contributors the quality of habitats for marine fish (Rooper et al. 2011). Consequently, direct impacts that damage or destroy these organisms have major impacts on habitat quality. Trawling is recognised as having deleterious impacts on benthic habitats (Freese et al. 1999, Ball et al. 2003, Gage et al. 2005, Guyonnet et al. 2008, Rooper et al. 2011), and is a key factor driving changes in fisheries species compositions and abundances (Sainsbury et al. 1997). However, most gears cause damage when they come into contact with habitats or remove components of the biota. Effects range from direct damage from gears like clam and scallop dredges (Jenkins et al. 2001, Gaspar et al. 2003), to alteration of predator and scavenger populations due to bycatch and discards (Jenkins 2004) or increased access to benthic prey damaged or killed by fishing gear (Ramsay et al. 1998, Malecha & Stone 2009). Such damage is not confined to effects of fishing, with aggregate extraction one of the primary causes of physical disturbance to seabeds of the United Kingdom (Foden et al. 2009). Repeated disturbance of the seabed can lead to long-term habitat change (Kaiser & Spencer 1996, Tanner 2005, Hily et al. 2008) and cumulative damage (Pitcher et al. 2009) that are often followed by fisheries declines (Feyrer et al. 2007). Although large-scale habitat change is widely reported, few studies have directly measured the extent of damage or monitored recovery (Pitcher et al. 2009). Monitoring of change is particularly important for seagrass ecosystems, which are in severe decline due to multiple human impacts (Duarte 2002) because understanding change is a key to predicting fisheries impacts in the short and long term.

A previous major FRDC projects (Cappo et al. 1998) identified major knowledge gaps relating to the nature and location of fisheries habitats at scales useful for research and management including fish/habitat relationships, key ecosystem processes and life-history information for both fished species. Considerable research has been conducted in the 15 years since this work, so in order to update this understanding we conducted a comprehensive review all available literature to identify key knowledge gaps focussing on (a) critical habitats necessary for the life-cycles of key fisheries species using estuarine and nearshore nurseries, (b) connectivities supporting that utilisation, (c) the relative importance of different nursery grounds, (d) the relative value of different habitats for life-history requirements, (e) habitat-specific food webs and trophic interactions supporting fisheries species life-cycles.

The review provides the background to develop research detailing the life-cycle habitat and connectivity requirements of Australia's coastal fisheries species, so is the vital first step in gaining the knowledge needed by managers to understand and protect coastal habitats. It fills critical knowledge gaps identified in the Department of Environment and Heritage Protection/Queensland Wetland Program's "Connectivity" project, and supports habitat classification and mapping work (e.g. Coastal-wetlands mapping, OzCoasts). It provides the basis for developing research aimed at enhanced quantification of the ecological and economic importance of the chain of habitats necessary for healthy fisheries. By coalescing the disparate information on this topic, the review will provide the basis for development of research aimed at allowing more precise management of species valuable to all fishing sectors, and provide pivotal information needed to incorporate fisheries values into impact and offset assessments for development proposals. Thus the work provides crucial information needed by Fisheries Departments around Australia, the Great Barrier Reef Marine Park Authority's Ecosystem Conservation and Sustainable Use Group and Coastal

Ecosystems and Water Quality sections, and contributes to the long term ecological and economic health of Northern Australia's fisheries.

2. Fish-Habitat relationships

Habitats used by exploited components of fisheries stocks are well known by fishers, and their knowledge has the potential to provide a large amount of information on fish habitat relationships, if it can be formalised into a centralised knowledge base. However, there are substantial gaps in knowledge for critical parts of fish life-cycles, such as spawning habitats that are only used for short periods of time, and nursery habitats that are often inaccessible to traditional fishing gears. There are also significant gaps in our knowledge of exactly how fish use the resources habitats provide; information that is often the most critical for well-directed and effective management.

Fish-Habitat Information: At one level coastal and estuarine fish habitats are well known, with key fishing grounds for exploited species recognised by fishers, however, this information needs to be organised into a formalised knowledge base. Where this has been done it has yielded valuable information. Fisher knowledge has been used to select sites for benthic habitat evaluation (Bax et al. 1999), as a basis for detecting biogeographic breaks in near-shore fish assemblages along the coast of Victoria (Colton & Swearer 2012), for detecting habitat preferences of pelagic fish (Kirby et al. 2003, Hobday & Campbell 2009), and determining the habitat for key species such as the West Australian dhufish, *Gloucosoma hebraicum*, (Hesp et al. 2002) and the blackspot jewfish, *Protonibea diacanthus*, in northern Australian waters (Phelan et al. 2008, Semmens et al. 2010). While much information on habitats where fisheries species are caught is available from fisheries data and the knowledge of fishers, there is generally much less information on habitats used for particular purposes such as spawning (see section 4 below) and nursery grounds (see sections 5-7 below), which are perhaps the most critical parts of fish life-cycles, and sparse information on non-target taxa, such as forage species.

Scientific Studies:

Scientific studies of fish-habitat relationships around Australia have generally focussed on local comparisons among contrasting habitat types. These include studies of fish utilisation of seagrass or other vegetated habitats versus unvegetated habitats (Edgar & Shaw 1995, Jenkins et al. 1997, Travers & Potter 2002, Burfeind et al. 2009, Gray et al. 2011) , salt marshes (Thomas & Connolly 2001), rocky reefs of different geology, depth and bottom relief (Harman et al. 2003, Shepherd & Brook 2007), different mangrove zones versus nearby channel habitats (Hindell & Jenkins 2005, Smith & Hindell 2005), and estuarine snags versus clear banks, unvegetated banks and channels (Sheaves 1996). One common feature of most of these studies is a focus on shallow water (often intertidal) habitats, and reflects relatively little study of deeper estuarine and coastal habitats. The few studies of shallow coastal versus deeper waters showed depth related faunal change (e.g. Staunton-Smith et al. 1999, Shepherd & Brook 2007), often within one habitat type (Shepherd & Brook 2007), indicating modification of habitat use with depth. A second feature of many habitat studies is a focus on vegetated areas, despite the fact that mud and sand are often dominant features of estuaries and coastal waters, and may dominate the habitat available to fish (Morrison et al. 2002). In addition to their areal extent their value may be underrated. For example, in European coastal waters the proportion of mudflats has been shown to correlate positively with fish density

(Nicolas et al. 2010). This suggests a need for greater concentration on the value and fish-habitat relationships of unvegetated habitats.

Variation in Fish-Habitat Relationships: Fish-habitat relationships are both species-specific (Hyndes et al. 1996), and spatially and temporally dynamic (Miller & Skilleter 2006), changing with a range of variables such as depth (Hyndes et al. 1999, Shepherd & Brook 2007) and plant type (York et al. 2006), and influenced by factors such as food, predation risk (Heithaus 2005) and physical environment – variables like dissolved oxygen (Morton 1992, Nicholson et al. 2008). These spatio-temporal factors need to be incorporated into studies because they can have a substantial influence on fish-habitat relationships. For instance, although few fish-habitat studies have been conducted at night those that have report substantial changes in fish assemblage structure and fish distribution (Gray et al. 1998, Griffiths 2001, Travers & Potter 2002). In addition, variations in life-histories over spatial scales as small as 10s of kms (Jackson et al. 2010), as well as multiple biogeographic breaks in nearshore fish assemblages along even short sections of Australia's coastline (Colton & Swearer 2012), present the possibility of complex changes in fish habitat relationships. Additional complexity stems from the use of multiple habitats by species like coral trout (Samoilys 1997a) and because events in adjacent habitats can affect composition (Ayvazian & Hyndes 1995). For example, harvesting large predators in one habitat can impact lower trophic levels leading to trophic cascades impacting other nearby habitats (Eriksson et al. 2011). This extensive variation makes it is difficult to confidently extrapolate information from one area to another meaning that, where possible, it is important to gain habitat utilisation specific to the area of interest.

In addition, fish-habitat understanding needs to account for the scale at which fish use habitats; so while understanding habitats at the scale of sand versus seagrass is appropriate for small benthic species like whiting (Hyndes et al. 1996), it may be irrelevant to sharks that use large areas of pelagic habitat (Cartamil et al. 2010) or range widely across the habitats of a coastal bay (Simpfendorfer & Milward 1993). Fish-habitat understanding also needs to be set in the context of the scales at which habitats are defined, and the scales at which habitats are conceptualised. Fish-habitat relationships have been discussed from the scale of "regions" (Sakabe & Lyle 2010) (these often relate more to physical variability than to habitat structure) to individual structures, like snags (Sheaves 1996) or rocky reefs (Shepherd & Brook 2007) for benthic associate species, or identifiable hydrodynamic features for pelagic fish (Hobday & Campbell 2009).

Tools for fish-habitat identification: Habitat identification can be difficult due to differences in sampling efficiency among habitat types (Hyndes et al. 1996, Cui et al. 2001) and because of the need to use different techniques to sample different habitats (Blaber et al. 1989, Pollard 1994). These problems are exacerbated by the limited scale into which most research projects are constrained, with spatial studies able to relate fish to specific habitat units or even specific habitat types (e.g. garfish to seagrass (Fowler et al. 2008)) but are rarely spatially extensive enough to provide a comprehensive identification at any more than local scales. It is this more extensive understanding that is needed to allow the integration of habitat patterns with ecological outcomes (Connell & Irving 2008).

Developing acoustic and video techniques provide the tools to address many of these problems. For instance, understanding of habitat utilisation of black jewfish, *Protonibea diacanthus*, in northern Australian waters has been greatly advanced through acoustic tagging programs (Semmens et al.

2010) at seasonal aggregations. Acoustic tagging has also been used to detect a variety of other habitat interactions, such as habitat changes of juvenile snapper, *Pagrus auratus,* moving into shallow water at night (Hartill et al. 2003), defining home ranges of reef fish (Lowry & Suthers 1998), and patterns of residency of sharks (Heupel et al. 2006, Knip et al. 2012a, b). As well as tracking using implanted acoustic tags, the vocalisations of fish can also be detected using acoustic techniques to provide information on locations of aggregations (Parsons et al. 2009). Sonar echograms of various types (side-scan, multibeam etc.) are key techniques for benthic habitat identification and mapping (Freeman et al. 2004), and can provide good habitat discrimination when backed up by limited ground truthing (Bax et al. 1999). When supplemented with data from underwater visual surveys (Morton & Gladstone 2011) or underwater video (Harvey et al. 2007, Harvey et al. 2012) these techniques can provide substantial detail on fish-habitat relationships.

The potential to formalise fisher and fisheries knowledge also has the potential to allow large advances in fish habitat understanding. Not only are many of the gaps in scientific understanding of fish-habitat relationships well understood by fishers, but fisheries catches (Hobday et al. 2011) and bycatch (Stobutzki et al. 2003) provide a rich source of habitat use information. This is particularly the case for many species of fish that form much of the bycatch of prawn trawlers (Heales et al. 2000, Madrid-Vera et al. 2007). The formalising of fisher knowledge and fisheries information into fish-habitat understanding would greatly advance understanding of fish-habitat relationships, provide important information for management, and provide a vital input into fish-habitat mapping.

These methods, together with a suite of other potentially useful techniques, provide a toolbox of approaches that can be combined in many different ways to address many of the outstanding questions about fish-habitat relationships. This information can then be combined with habitat classification schemes (e.g. Valesini et al. 2003, Valesini et al. 2010) to produce detailed habitat maps, that are the key components needed to underpin modelling of habitat value at a scale appropriate to management (Oliver et al. 2012). These maps should not only provide information on habitat types and the species and life-cycle stages that use them, but should include layers indicating the resources provided by different habitat units and key connectivities among them.

Habitat resource utilisation: Although simple occupancy of habitats by fish provides crucial information, management of habitats requires knowledge of the resources fish utilise in the habitats they occupy. Resource dynamics are not always obvious or predictable from local habitat components. For instance, nutrition supporting food webs may be derived from outside the habitat (Connolly et al. 2005, Melville & Connolly 2005, Abrantes & Sheaves 2008), while resource utilisation can vary among fish species (MacArthur & Hyndes 2007) and habitat patches (White et al. 2011), and be modified by other factors such as the presence of con-specifics (Hunt et al. 2011) and specific habitat patch attributes (Smith et al. 2008, Murphy et al. 2010). Not only can habitat be a major influence on diet (Schafer et al. 2002) secondary production specific to a habitat can provide a sensitive measure of changes in ecosystem function (Valentine-Rose et al. 2011). In fact, effective habitat-based management needs to go beyond the target species to consider all trophic levels and ecosystem outcomes (Fulton & Smith 2004). Knowledge of habitat resource utilisation is particularly important in determining the key habitat units and resources in need of protection and the extent to which artificial habitats can act as valuable fisheries habitats.

3. The Critical Roles of the Coastal Zone in Life-Histories of Inshore Fish Species

Coastal ecosystems (estuaries, tidal wetlands and shallow coastal waters) provide spawning, feeding and nursery grounds to fisheries, with their critical spawning and nursery roles recognised as vital contributors to healthy fish stocks around the world. The quality of spawning habitats is vital to support reproductive output, while nursery habitats provide juveniles with refuges from predation, rich feeding areas and areas where hydrodynamic structures provide energetic advantages.

Coastal ecosystems, such as estuaries, tidal wetlands and shallow coastal waters, support the lives of fish using them in three general ways; as feeding grounds, as spawning grounds, and as nursery grounds.

Feeding Grounds: Their location at the interface between land and sea provides coastal ecosystems with diverse inputs of nutrients, making them among the most nutrient-rich of marine environments. They provide a diversity of highly available, widely distributed foods of high nutritional quality to the organisms utilising them, supporting high population sizes and rapid growth. Prey quantity and quality affect growth (Sogard 1992, Scharf et al. 2006) because of substantial differences in prey energetic value (Ball et al. 2007). As a consequence, the availability and quality of food resources is a major contributor to the value of coastal ecosystems to fish and fisheries, supporting both local populations and fish moving in from outside.

Fish have many different ways of utilising the food resources available in estuaries and coastal ecosystems (Elliott et al. 2007), and many of these feeding patterns link coastal and offshore ecosystems in a nutritional sense (Fig. 1). They are important feeding areas for juveniles (Deegan et al. 2000, Sheaves & Molony 2000) that use coastal nursery grounds as critical growth and development areas (Fig. 1a)(Section 7 below), with many of these juveniles becoming prey components in trophic relays (Le Quesne 2000, Nemerson & Able 2004) that move coastal nutrients to offshore waters (Fig. 1b). They are also feeding areas for predators from offshore ecosystems that make inshore migrations (Fig. 1c) to access the rich prey resources available there (Deegan 1993, Begg & Hopper 1997, Heupel & Simpfendorfer 2008). At smaller spatial scales, access to appropriate food involves a variety of feeding patterns such as migrations into intertidal areas (Potthoff & Allen 2003, Dorenbosch et al. 2004, Unsworth et al. 2009), and regular feeding forays matching with upstream tidal flow (Naesje et al. 2012) or time of day (Heupel et al. 2010, Espinoza et al. 2011).

The habitats used by fisheries species as part of their day to day lives are well known to fishers. Although this information is not centralised and fully documented there is a wealth of information available far beyond what could be collected in scientific surveys (Fisher et al. 2012, Heyman & Granados-Dieseldorff 2012, Mireles et al. 2012, Rockmann et al. 2012). Consequently, this information needs to be formalised to provide an accessible knowledge base, and to allow evaluation of change. However, although much information on the feeding habitats used by the exploited component of fisheries stocks can be accessed through fisher knowledge or by dietary analysis of fisheries catches, resource dynamics that support feeding can be much more complex (see above). Thus, scientific studies that go beyond direct feeding relationships are needed to define the resources that support fish habitat utilisation. This is particularly the case for early-life history stages where many of the trophic relationships supporting nursery value are poorly understood (see Section 9).

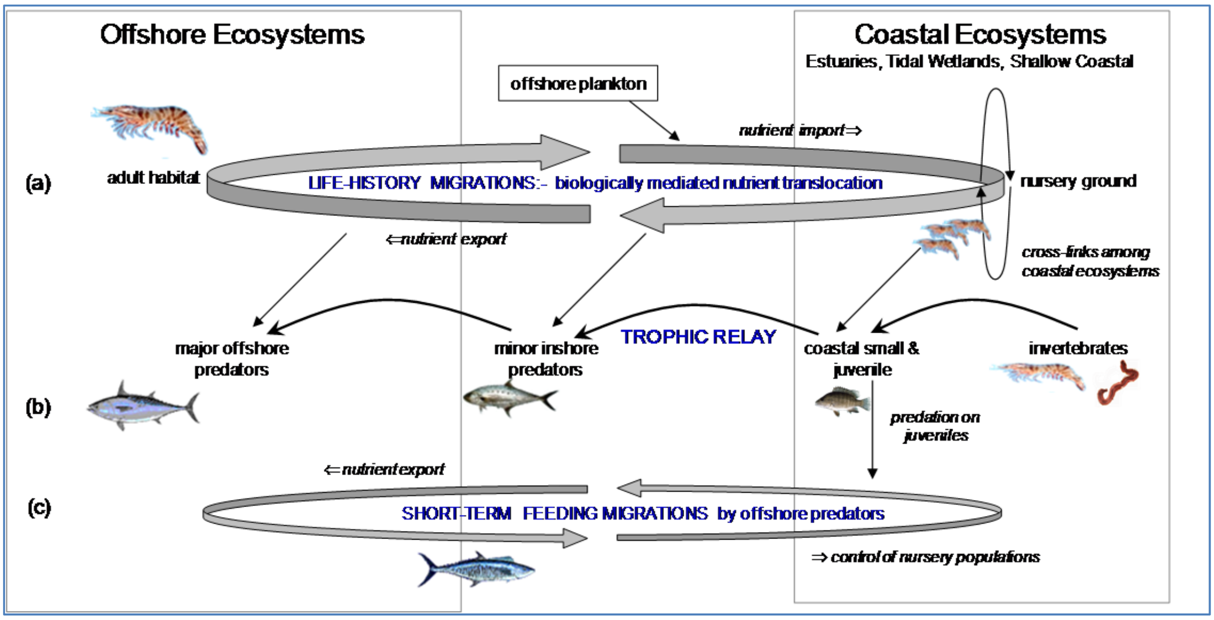

Figure 1: Some of the complex connections between coastal and adjacent ecosystems. (a) Life-history migrations that supply sub-adults to offshore fish stocks and in doing so provide extensive biologically-mediated translocation of nutrients, (b) Trophic relays where juveniles incorporate nutrients into their bodies that pass to other habitats through a series of feeding relationships, (c) Short-term feeding migrations by predators control nursery populations and translocate nutrients incorporated by nursery juveniles to other habitats.

Spawning Grounds: Coastal waters provide crucial spawning/larval development habitats for a large number of Australia's fish species, for example ichthyofauna representing 143 taxa from 93 Families have been recorded from shelf waters off southeastern Australia (Keane & Neira 2008) and 173 taxa from 119 Families were reported from the Sydney shelf (Gray & Miskiewicz 2000), while estuaries in tropical Australia are among the most species rich in the world (Robertson & Duke 1990a, Robertson & Blaber 1992, Sheaves 2012). A majority of species that use estuaries during their life history either migrate offshore or to the mouths of estuaries to spawn (Davis 1986, Griffin et al. 1987, Ward et al. 2003, Blaber et al. 2008) and in many cases time spawning to coincide with ebb tides (Sheaves & Molony 2012), to maximise passive movements of gametes into the coastal boundary layer (Wolanski 1992, Zaker et al. 2007). Others species, such as *Pagrus auratus*, migrate to estuaries and coastal embayments to spawn (Wakefield 2010, Wakefield et al. 2010) before returning to coastal waters.

While fisher information can provide much detail on the day to day habitat use by fisheries species, information on spawning habitats is more difficult to obtain. Some is certainly available through fisher knowledge but for many species this information will not be comprehensive because the spawning habitats of many species are cryptic (Richardson & Cowen 2004, Richardson 2008), and spawning locations are often small scale and very specific areas (Zeller 1998, Sheaves et al. 1999) and often used for only short periods of time (e.g. Samoilys 1997b, Fulton et al. 1999, Bloomfield & Gillanders 2005). As a result, some of the more critical knowledge gaps relate to spawning habitats (Milton et al. 1997, Humphries et al. 1999, Collins et al. 2000) (see Section 4).

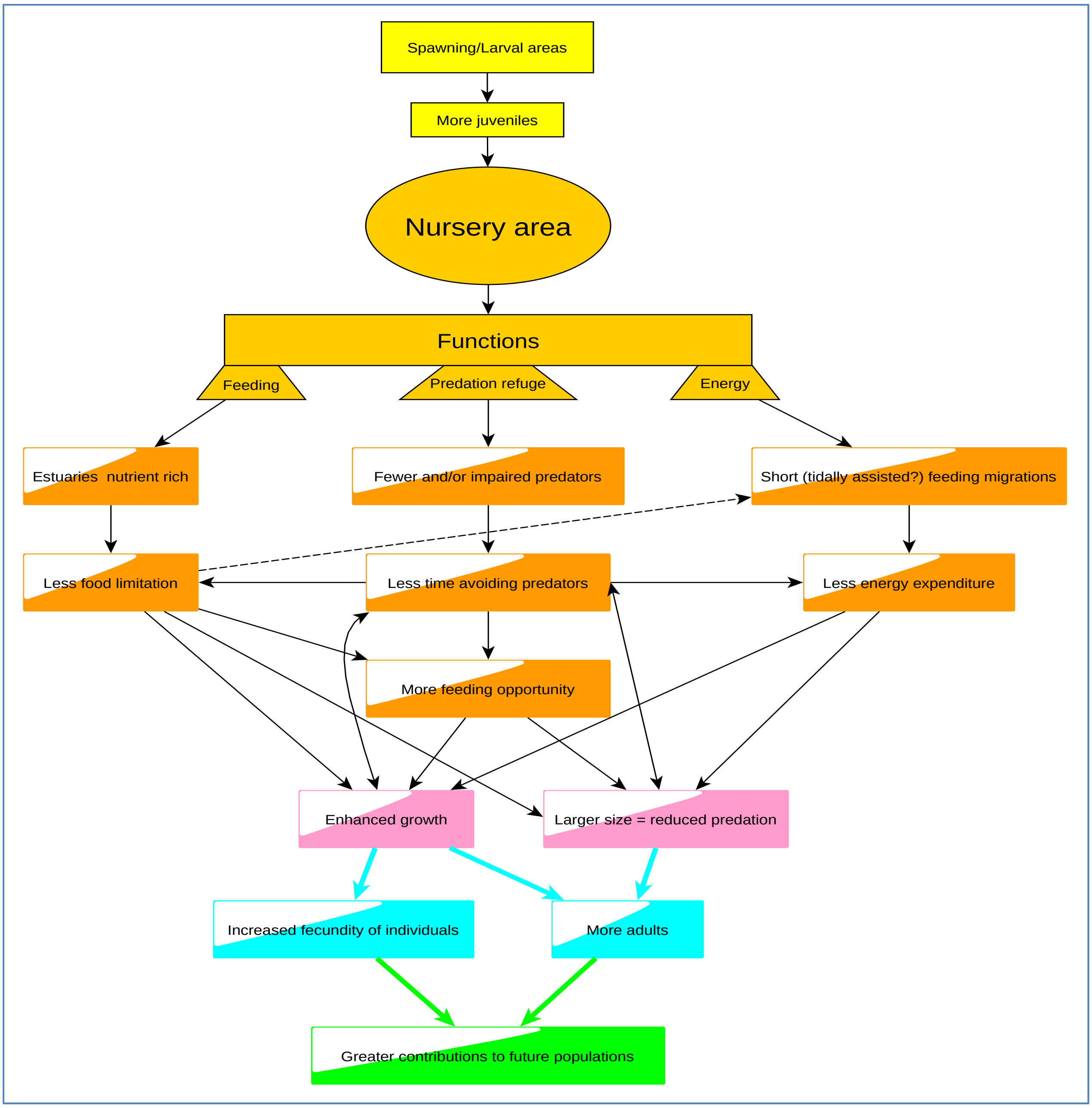

Figure 2 : The complexity of nursery provision by coastal ecosystems.

Nursery Grounds: Coastal ecosystems around the world are recognised as vital nurseries for a large range of fisheries species (e.g. Beck et al. 2001, Able 2005, Dahlgren et al. 2006) (Fig. 2). They are highly productive environments (Alongi 1990, 1996) with their fertile waters providing the nutrient rich conditions needed to support the juvenile phase when demands for food are at their greatest (Yanez-Arancibia et al. 1994). Rapid growth confers many advantages. For instance, rapid growth leads to more fecund adults that have a greater input to adult populations (Gray et al. 2012) and also provides "size refuge from predation" (Ellis & Gibson 1995, Kloskowski 2011, Nakamura et al. 2012), with juveniles passing rapidly through early stages where predation is greatest.

Coastal ecosystems also contain larger areas of shallow water and a variety of structurally complex habitats (see Sections 5 and 8), both of which provide important refuge habitats (Sheaves 2009, Nagelkerken et al. in press). Reduced predation leads to lower mortality and greater output of juveniles (Beck et al. 2001) and allows juveniles more feeding time (less time hiding/avoiding predators) also promoting enhanced growth. Occupation of coastal ecosystems also provides energetic advantages. Shallow waters, eddies behind complex structure and areas of reduced current flow provide fish with hydrodynamic advantages (less need to expend energy to remain in habitat)(McIvor & Odum 1988), which further enhance the potential for rapid growth.

Identification of nursery habitats is problematic because of factors such as their short duration of use (e.g. initial juvenile settlement habitats) or because the individuals involved are difficult to find and sample using traditional methods (various nursery stages). As a result, there are large number of critical knowledge gaps relating to nursery habitats (Beck et al. 2001, Able 2005, Dahlgren et al. 2006) (see Sections 5,6 and 7).

4. Spawning habitats

While there is a general understanding of the spawning areas of many species, specific spawning habitats are much less well known. Even when specific spawning habitats are known, often only a few of many potential spawning habitats have been investigated. More detailed research into spawning habitats and their values is necessary given the importance of spawning to the maintenance of fish stocks.

Spawning habitats need particular protection (Fulton et al. 1999) because fishery targeting of spawning aggregations can impose high mortality on reproductive components of the stock (Pears et al. 2007, Semmens et al. 2010), impairing reproductive output and leading to local stock depletion (Zeller 1998, Semmens et al. 2010). Spawning locations can be small scale and very specific areas (Zeller 1998, Sheaves et al. 1999), so considerable habitat detail is required to ensure protection (Fulton et al. 1999). However, specific spawning habitats can be hard to detect because their utilisation is often brief (Samoilys 1997b, Fulton et al. 1999, Bloomfield & Gillanders 2005, Sheaves & Molony 2013), and in the case of pelagic species, because spawning may be focussed on a combination of bathymetric and hydrographic factors (Neira & Keane 2008) that may change over time.

Spawning patterns are known for many benthic (Coulson et al. 2005, Hughes et al. 2008, Kendall & Gray 2009), reef (Kritzer 2004, Evans et al. 2008) and pelagic species (Mackie et al. 2005, Hughes & Stewart 2006, Dimmlich et al. 2009), but only in a relatively few cases (Samoilys 1997b, Hyndes et al. 1998, Kanandjembo et al. 2001) are exact spawning habitats known. Not only is spawning a short term event (Samoilys 1997b, Fulton et al. 1999, Sheaves & Molony 2013) but some species may become difficult to catch during spawning (Sheaves & Molony 2013), making spawning habitats even more difficult to detect. In addition, reproductive studies often focus on reproduction at a scale not conducive to spawning habitat identification (e.g. Evans et al. 2008, Ewing & Lyle 2009) or at a scale able to detect spawning regions but not specific spawning habitats (Miskiewicz et al. 1996, Fairclough et al. 2000b, a, Fowler et al. 2000). Also many sampling approaches used (e.g. hook and line (Jackson et al. 2012)) are targeted at specific locations and not representatively spread, as is needed to identify the full extent of spawning habitats used. In other cases studies involve inference from data, such as larval distributions (Lenanton et al. 1996) or egg collections (Ward & Staunton-Smith 2002), that are unsuitable for specific spawning habitat identification. So, although spawning locations are unknown in a general sense for many important fisheries species (Lenanton et al. 1996), detailed identification of spawning habitat is often limited to only one or a few locations over a species range (Sheaves et al. 1999, Parsons et al. 2009).

We have a good understanding about spawning migrations and timing for a few well studied estuary species such as *Lates calcarifer* (Griffin et al. 1987, Blaber et al. 2008), *Pomatomus saltatrix*, (Pollock 1985b, Zeller et al. 1996, Ward et al. 2003), *Acanthopagrus pacificus* (Sheaves 1996, Tobin et al. 1997), *A. australis* (Pollock 1982a, b, 1985a), *A. butcheri* (Sarre & Potter 1999), *Pagrus auratus* (Wakefield 2010, Wakefield et al. 2010), and a small number of other species. All of these species have a coastal larval phase, or in the case of *P. auratus* a coastal post-settlement stage. Although we have little clear knowledge about a majority of species, including important commercial and recreational species, there is substantial genetic evidence to support coastal dispersal phases for many species (Roberts et al. 2011, Shaddick et al. 2011). This includes species that were thought to be exclusively estuarine, i.e. only found in estuaries, such as *Ambassis marianus* and *A. jacksoniensis* (Mills et al. 2008). The implication of this is that coastal waters, and in particular the coastal boundary layer, should not be seen as an independent entity but as one of the many components that contributes to productive estuarine nursery areas.

5. Identification of Nursery Grounds for Australia's Coastal Fish

Nursery grounds have been identified in detail for very few Australian inshore fisheries species resulting in very incomplete understanding of the nursery habitat needs for even common Australian fisheries species. Most studies have only reported where juveniles have been found, which reflects where studies have been done not nursery value, so there is no comprehensive information about the range of habitats occupied or their relative importance. Critically, there is almost no information about the first habitats used by very small juveniles, even though the availability and quality of these habitats has been identified as a critical bottleneck determining nursery ground success.

The diversity of physical environments, coastal ecosystems and seascape mosaics around Australia's coastline are reflected in changes in biological community structure and trophic organisation, leading to different types and levels of nursery function and provisioning. These changes reflect differences in the distribution and availability of habitats and the range and types of primary producers in each habitat. For example, in tropical north Queensland and the Northern Territory, a large number of estuaries and extensive wetlands including seagrass beds, mudflats, sandflats, mangrove forests and floodplain forests occur, along with coastal lagoons and swamps. Large expanses of floodplain are seasonally flooded connecting billabongs and creeks, and fish such as barramundi, mangrove jacks and tarpon can move between the different habitats to feed (Davis et al. 2012). In contrast, high limestone cliffs dominate the coastline of the high energy coastline bordering the arid Nullarbor Plain on the Great Australian Bight, and there are almost no estuaries or coastal wetlands for ~1000 km. These contrasting geologies and environments generate completely different contexts for the development of food webs supporting nursery function.

Around the world the identification of nursery grounds has proved challenging, among other things because of the difficulty of censusing all the habitats that juveniles might occupy (Beck et al. 2001, Gillanders et al. 2003, Dahlgren et al. 2006, Ford et al. 2010). This has resulted in very incomplete understanding of the nursery habitat needs for even common Australian fisheries species (Table 1; Appendix Table 1). Very few studies (e.g. Laegdsgaard & Johnson 1995) have compared nursery utilisation by species among habitats, and only then at one location. Most studies have only reported where juveniles have been found (essentially all the information in Table 1), in actual fact only indicating where sampling was targeted and/or where it was possible to deploy the sampling gear used, and very little about the range of habitats occupied or their relative importance. A number of other studies include compiled lists of nursery habitats; however in most cases nursery occupation seem to be based on a combination of reported occurrences and reviewer knowledge. While there is little doubt that these assessments are usually correct, they do not represent hard evidence on nursery identification or value.

The available information is also very incomplete; a cursory glance at the compilations (Table 1; Appendix 1) by anyone conversant with the species would indicate that many habitats where juveniles of these species can be observed are absent from the lists. Additionally, there is no way of knowing if the occurrences that are listed indicate habitats with core nursery values or if the reports just indicate incidental occurrences or occurrences in habitats with little nursery value. There is the final critical issue that few studies differentiate the habitats used by juvenile at different life-history stages. There is a particular lack of information on habitats used by juveniles immediately post-settlement. This is particularly worrying because the availability and quality of these habitats is often a critical bottleneck determining nursery ground success (Almany 2004, Webster 2004).

Nursery ground identity is clearly the most fundamental need for effective management as it underpins all other nursery understanding and decision making. Clearly, this information is very deficient for Australia's coastal fishes, with definitive information available on the full range of nurseries used or their relative values. Consequently, this represents a critical knowledge gap.

Table 1: Summary of nursery habitats identified for important Australian Coastal finfish (see Appendix Table 1 for details)

(a) Species with habitat-level identification

Habitat	Species	
mangroves	*Acanthopagrus pacificus* *Caranx ignoblis* *Caranx sexfasciatus* *Girella tricuspidata* *Gnathanodon speciosus* *Lutjanus argentimaculatus* *Lutjanus russelli* *Platycephalus endrachtensis* *Platycephalus fuscus* *Platycephalus indicus*	*Pomadasys argenteus* *Pomatomus saltatrix* *Rhabdosargus sarba* *Scomberoides commersonnianus* *Sillago analis* *Sillago ciliata* *Sillago maculata* *Sillago sihama* *Sphyraena barracuda*
mangrove channels	*Acanthopagrus australis* *Acanthopagrus pacificus* *Gnathanodon speciosus* *Liza vaigiensis* *Lutjanus argentimaculatus* *Lutjanus russelli* *Mugil cephalus* *Platycephalus endrachtensis*	*Platycephalus fuscus* *Platycephalus indicus* *Pomadasys argenteus* *Rhabdosargus sarba* *Scomberoides commersonnianus* *Scomberomorus commerson* *Scomberomorus semifasciatus* *Sillago sihama*
seagrass	*Acanthopagrus australis* *Girella tricuspidata* *Lutjanus sebae* *Mugil cephalus*	*Platycephalus fuscus* *Rhabdosargus sarba* *Sillaginodes punctatus*
algae	*Sillaginodes punctatus*	
sand	*Acanthopagrus australis* *Girella tricuspidata* *Lethrinus nebulosus* *Lutjanus erythropterus* *Lutjanus malabaricus* *Lutjanus sebae* *Pagrus auratus*	*Rhabdosargus sarba* *Scomberoides commersonnianus* *Sillaginodes punctatus* *Sillago analis* *Sillago ciliata* *Sillago robusta* *Sillago sihama*
mud	*Acanthopagrus australis* *Lutjanus erythropterus* *Lutjanus malabaricus* *Lutjanus sebae* *Mugil cephalus* *Rhabdosargus sarba*	*Scomberoides commersonnianus* *Sillago analis* *Sillago ciliata* *Sillago maculata* *Sillago robusta* *Sillago sihama*
rubble	*Lutjanus erythropterus*	*Lutjanus malabaricus*
tide/saltmarsh pools	*Lates calcarifer* *Liza vaigiensis* *Lutjanus argentimaculatus*	*Lutjanus russelli* *Sillago maculata*
rock walls	*Argyrosomus japonicus*	
submerged dead timber	*Epinephelus coioides* *Epinephelus malabaricus* *Lates calcarifer*	*Lutjanus argentimaculatus* *Lutjanus russelli*
deep water open shores	*Scomberomorus commerson* *Scomberomorus queenslandicus*	*Scomberomorus semifasciatus*

(b) Species with only general habitat identifications

estuary	*Acanthopagrus butcheri* *Caranx papuensis* *Polydactylus macrochir*	*Pomadasys kaakan* *Scomberoides tala*
nearshore waters	*Protonibea diacanthus*	*Sillago burrus*
brackish/fresh water	*Lates calcarifer*	*Macquaria novemaculeata*
pelagic	*Seriola dumerili*	*Seriola lalandi*

Table 1(a) summarises information on the habitats used by juveniles of Australian inshore fisheries species. Occurrences have been recorded in one or more habitats for most species, although for some the only information is at an ecosystem level (Table 1b), so is not habitat specific. It is notable that for some species, like *Lutjanus johnii* and *Lethrinus miniatus,* there are no records of habitats used by juveniles (Appendix table 1).

Mangroves and Mangrove Channels:

Mangroves occur in low energy environments around Australia's northern and eastern coasts. They are ubiquitous in the tropics and extend down the east coast to Corner Inlet in southern Victoria, where the most southerly mangroves in the world occur (Duke 2006). Mangroves are absent from Western Australia's temperate coasts except for a relic stand at Bunbury in the far southeast. Juveniles of many species are recorded as occurring in mangroves, and subtidal channels associated with them (Table 1a) reflecting a view widely held around the world that mangroves are key nursery grounds for many species (e.g. Blaber 1980, Dorenbosch 2006, Nagelkerken et al. 2007). Mangroves also provide nurseries for important crustaceans, in particular banana prawns (*Penaeus merguiensis*) (Vance et al. 1990) and mud crabs (*Scylla serrata*) (Hill 1976).

While many juvenile fish clearly do occur in mangroves caution is needed in interpreting the bias of nursery occupancy implied by Table 1. Firstly, mangroves have been the target of many studies focussed on juveniles precisely because of the paradigm that they are nurseries. Secondly, because Australia's mangroves are tidal they are relatively easy to sample using nets (e.g. fykes) that capture fish as they leave the mangroves, while other nearby habitats (e.g. structurally complex subtidal habitats) are very difficult to sample (Sheaves 1992). Thirdly, in many of the studies the word mangroves really refers to a "mangroves system", and so really relates to a unit at a scale akin to an "estuary" rather than directly relating specifically to use of mangrove habitats. Finally, because Australia's mangroves are tidal most species can only use them for part of the time and so require the use of non-mangrove habitats when access to mangrove is not possible (Sheaves 2009).

Seagrass:

Major seagrass areas occur around Australia, especially along low energy coastlines. Seagrass distribution is patchy along the high-energy southern coast, where it is generally restricted to estuaries, protected bays and coastal lagoons. High diversities and abundances of invertebrates and fish have been reported from all Australian states [Queensland: (Blaber & Blaber 1980, Vanderklift & Jacoby 2003, Burfeind et al. 2009); Western Australia: (Travers & Potter 2002); New South Wales: (Ferrell & Bell 1991, Gray et al. 1996, West & King 1996); South Australia: (Connolly 1994); Victoria: (Jenkins et al. 1997, Jenkins & Wheatley 1998)], and is generally considered to be a critical nursery habitat for a variety of fish species.

Juveniles of a many species of fish are found in Australia's seagrass (Table 1a) as are a variety of important invertebrates, including prawns (mostly *Penaeus* spp. and *Metapenaeus* spp.) and rock lobsters (*Jasus* spp. and *Panulirus* spp.) (Burchmore et al. 1984, Jenkins & Hamer 2001, Longmore 2002). Seagrass probably provides nursery value as part of a seascape mosaic including other habitats such as mangroves (Jelbart et al. 2007), as has been demonstrated in other parts of the world (e.g. Dorenbosch 2006, Nagelkerken et al. 2007).

Open Sand/Mud Habitats:

Open sandy and muddy habitats occupy a large proportion of Australia's coastal zone (Short 2006), and include intertidal habitats, like beaches and unvegetated sand and mud banks, as well as subtidal areas of consolidated and mobile sands and muds. Beaches can provide alternative nursery habitats for species generally associated with estuaries (Lenanton 1982, Robertson & Lenanton 1984, Lenanton & Potter 1987, Ayvazian & Hyndes 1995) but provide little habitat complexity (Robertson & Lenanton 1984) and so are unsuitable for many species. Although Table 1 records juveniles of many species associated with sandy or muddy habitats the exact relationship is unclear because many juveniles pass through open sandy or muddy habitats when moving among more structurally complex refuges (Sheaves 2009).

Saltmarsh, Wetland Pools and Tide Pools:

Although they have not been researched extensively, flooded saltmarshes are used by a range of invertebrates and fish including many juveniles (Table 1). Most research that is available relates to temperate regions, especially of southeast Queensland (Morton et al. 1987, Morton et al. 1988, Thomas & Connolly 2001, Connolly 2005), with some studies also from South Australia (Connolly et al. 1997, Bloomfield & Gillanders 2005), Victoria (Crinall & Hindell 2004) and New South Wales (Mazumder et al. 2006, Saintilan et al. 2007).

Work in the tropics has concentrated on permanent (Sheaves et al. 2007, Sheaves & Johnston 2008, Davis et al. 2012) and temporary (Russell & Garrett 1983) wetland pools. Juveniles of a number of species use both types of pools and, together with freshwater wetlands, are usually considered important juvenile habitats for barramundi. However, there are relatively few reports of the occurrence of very small juveniles, so it seems that this key habitat is yet to be identified definitively.

Structurally complex habitats:

Structurally complex habitats include dead timber [snags or large woody debris (LWD)], reef, rocky rubble and human imposed artificial structures. Although the importance of structural complexity is well documented for coral reefs (e.g. Almany 2004, Webster 2004), there have been relatively few studies of the fish assemblages of complex structures in estuary or nearshore ecosystems, and work understanding the values of artificial structures has only recently begun to develop (see Section 6). Consequently, the relative low occurrence of juveniles in these habitats (Table 1a) is likely to be a substantial underestimate.

6. Relative Values of Coastal of Nursery Grounds

Despite advances in understanding of nursery grounds greater clarity in their definition is required. A recent key advance is the recognition that nursery grounds comprise mosaics of interacting habitats, so can't be simply evaluated on a case-by-case basis. Evaluating nursery value based simply on occupation fails to account for the complexity of nursery ground contributions. Measuring outputs (proportional contribution) is a substantial advance but fails to account for non-numeric factors like differential fitness or include understanding of processes that contribute to nursery value. Effective management needs to be based on an understanding of all these factors because it is the processes that support nursery function that need to be managed if nursery function is to be maintained in the face of impacts and change.

Coastal ecosystems around the world have long been considered critically important for sustaining fisheries; functioning as nurseries for a great diversity of species (Boesch & Turner 1984). Juvenile nurseries are often spatially separate from the areas or ecosystems occupied by other life stages of the population (Deegan et al. 2000), but despite this spatial separation processes regulating growth and survival in the nursery may have profound influences on adult stock size and population viability (Levin & Stunz 2005). Recent recognition of the importance of protecting nurseries as a key part of fishery management is reflected in management policy and laws around the globe, for example, the US Sustainable Fisheries Act of 1996 requiring the identification and protection of 'Essential Fish Habitat' in US waters, and the Fish Habitat Area network implemented by the State Fisheries Department in Qld (McKinnon et al. 2003). With increasing coastal development and other impacts to coastal nurseries (Edgar et al. 2000), there is an urgent need to identify, manage, and protect the nursery grounds that support our fishery species if they are to continue to be sustainable into the future (Nagelkerken et al. in review).

The concept of nursery value is a relatively recent idea however it has been implied for much longer under another guise, that of relative value of different habitat types (Dahlgren et al. 2006). This highlights one of the key problems with evaluating nursery value; the concepts of nursery grounds (areas occupied during juvenile stages) and the component habitats that confer nursery ground value are often conflated, leading to ill-defined theories, confused conceptualisation and ambiguity in nursery valuation. This lack of clarity in conceptualisation hampers management because it leads to confusion about the exact focus that management should take (e.g. individual habitats or ecosystems such as estuaries) and the specific scale(s) at which action should be targeted (Azovsky 2000). This ambiguity is further complicated by recently developed understanding that few habitats act alone to support juveniles but rather interact as components of habitat mosaics (Patterson et al. 2005, Sheaves 2009), each providing particular values, but acting together to confer nursery value (Dorenbosch 2006, Nagelkerken et al. in review). Unfortunately, almost all the past literature has focussed on valuing individual habitats so, by necessity; this review has a mainly habitat-by-habitat focus. However, it is important to remember that habitats don't act alone, that nursery values are not conferred by any one habitat type, and that the nursery value of a habitat will often depend on the seascape context in which it occurs (Nagelkerken et al. in review).

Valuing nursery grounds: the need to understand function

Traditionally, the value of different habitats as nurseries has usually been implied based on occupation; the relative densities or abundances of juveniles among habitats (Minello 1999, Minello et al. 2003, Nagelkerken 2007), with the focus of many studies confined to comparisons among a small number of habitat types (Heck et al. 2003). However, in the context of supporting fisheries and sustaining populations, the density of individuals in juvenile habitats may not reflect the relative nursery ground value of each habitat (Beck et al. 2001) since individuals must survive to successfully migrate to join adult populations (Gillanders et al. 2003), and ultimately reproduce (Sheaves et al 2006) to sustain the species. Simply measuring occupation also fails to account for spatial relationships between habitats (Berkstrom et al. 2012) and small-scale temporal movements to alternative feeding or protective (Sheaves 2005a, Verweij et al. 2008) habitats, and may miss crucial habitats where occupation may be very short-term (Dahlgren & Eggleston 2000, Grol et al. 2011) but which may provide critical contributions to nursery value. Consequently measuring occupation at individual habitat scales fails to account for the complexity of interactions, biotic and abiotic, thus rendering the approach less informative than understanding how synergies among habitats function to secure species persistence (Sheaves et al. in press).

Recently there has been increasing recognition that nursery value of a habitat, or of a mosaic of habitats that constitute a nursery area, can best be assessed by outputs rather than simply by occupation (Dahlgren et al. 2006). Shifting focus from occupation to outputs provides a much more holistic and logical way of assessing nursery area value because it considers end-results and so accounts for contribution to the production of succeeding generations (Sheaves et al. 2006), not only an important fisheries goal but key to sustainability of aquatic ecosystems in general.

Beck et al. (2001) and Dahlgren et al. (2006) suggest that nursery value can be assessed on the basis that the habitat with the greatest proportional contribution of individuals to adult stocks consequently has the highest nursery value. However, this approach also has limitations. Firstly, methods of tracing contributions from nursery habitats to subsequent generations are only beginning to be developed (McMahon et al. 2011a, McMahon et al. 2011b) and are not readily available, so for most parts of the world there is insufficient knowledge to allow contributions to be defined (Able 2005). Secondly, methods based on proportional contribution assume that nursery function has no effect on fecundity. This is an unreasonable assumption because nursery function directly affects size and growth and subsequent lifetime fecundity of individuals (Chigbu & Sibley 1994, Sedinger et al. 1995). In effect, proportional contribution to adult stocks doesn’t guarantee high contribution to future generations and is an oversimplification of the complexity that needs to be addressed. Thirdly, even where such ranking is achievable, a proportional contribution approach does not help elucidate the processes underpinning nursery ground function (Sheaves et al 2006), so it provides little help to managers charged with maintaining ecosystem function in the face of specific impacts in particular locations. Ultimately, in order to value and protect nursery grounds for fishery species, we need to protect nursery function, and hence, we need to understand how nurseries function (Sheaves et al 2006), not just define them based on above-average relative contributions to adult stocks (Beck et al. 2001, Dahlgren et al. 2006).

There is also an inherent danger in the valuation approach. Placing relative values on particular nursery areas or habitats implies that lower value nurseries are less important even though they still contribute to future populations. Classification as more valuable implies higher priority for conservation (Dahlgren et al. 2006), possibly at the expense of lower value areas (Sheaves et al. 2006). Because of our lack of a complete understanding of the overall complexity within and among systems (interactions between different ecosystems, their associated habitats and organisms, and physical processes) there is a real danger that prioritisation of conservation effort will allow lower value habitats to degrade because of a focus on perceived "key" high value areas. Allowing degradation of any habitat is problematic because we have little idea of the consequences of such an action (Sheaves et al. 2006). Understanding of nursery area value for fish needs to be developed far beyond simple fish-habitat associations to encompass environmental requirements of organisms that support fish populations. Preservation of high value fish nurseries would be pointless if environmental conditions for supporting organisms were allowed to degrade because they we not recognised as key contributors to the nursery function for fish.

For management purposes, what we really need to know is how nurseries function, what are the processes that support that function, and how do we maintain nursery function in the face of impacts to habitats, seascapes and functions that support nursery value. Often, managers will be faced with specific impacts at particular locations, and aim to protect nursery and other ecological functions (Nagelkerken et al in review), rather than prioritising locations for protection (Beck et al. 2001, Dahlgren et al. 2006). At the core of all understanding of nursery function, regardless of the approach to identifying and valuing them, is a need to know which habitats are used throughout each of the life stages, how these habitats are connected in space and time, and what resources and processes support the species in those habitats (Beck et al. 2001, Gillanders et al. 2003, Able 2005).

Current state of knowledge.

Estuaries as nurseries: There is very little research into the relative value of different nurseries for fish in Australia (Gillanders & Kingsford 1996), or anywhere in the world (Beck 2001). Indeed, the most widely quoted nurseries value is for "estuaries" in general, even though studies from coastal ecosystems in the Caribbean (Nagelkerken 2009) and Africa (Dorenbosch 2006) have clearly demonstrated that nursery values are conferred by particular ensembles of interacting habitats rather than catch-all units like estuaries (Nagelkerken et al. in review). One of the difficulties is that the concepts underpinning nursery value are still developing. For instance, the concept of estuarine dependence, one of the pillars of nursery ground value, remains a key area of research globally, with the extent that many species considered to rely on estuaries also occupy alternate habitats and ecosystems still not established (Able 2005). So even the most widely regarded important nurseries may not be the exclusive, or even most important nursery habitats occupied by a great diversity of species (Able 2005).

The primary driver of this knowledge gap is the lack of even basic surveys of all potential nursery habitats. For example, salt marshes have long been recognised as critical nurseries for a range of important fishery species in North America (Turner 1977). Penaeid shrimps are found in the highest densities along the vegetated fringe of the marsh (Minello & Rozas 2002), with the marsh-edge habitat estimated to provide the greatest production of shrimp (Minello et al. 2008). However open water habitats may also be important foraging areas for juvenile shrimp (Fry 2008). Despite evidence that very small juvenile shrimp may also occupy open bay waters (Fry 2008, Minello et al. 2008) previously considered as sub-adult habitat (Lindner & Cook 1970), such open water habitats away from the marsh complex have essentially never been surveyed with gears that can quantify small juvenile shrimp density (Minello et al. 2008). The salt marsh systems of the Gulf and Atlantic coasts of the USA are perhaps the best studied coastal nurseries on the planet (Blaber 2002), yet even for the most valuable fishery species in that region, the full range of habitats used by each life stage remain uncertain. Despite significant advances in many aspects of nursery ground ecology (e.g. Gillanders 2005), for the rest of the world, the general state of knowledge lags even further behind the USA (Adams et al. 2006a). Much research has focused on the values of specific habitats within estuarine and other coastal systems as nurseries. These include seagrass (Heck et al. 2003), salt marshes (Minello et al. 2003), and mangroves (Faunce & Serafy 2006), and integrated seascapes comprising these and other habitats (Adams et al. 2006a).

Within Australia, the fishery species for which the most information about juvenile habitat and nursery function exists, tend to be those that occupy the shallow-water habitats most regularly sampled with gears suitable for collecting small juveniles (e.g. whiting (*Sillago* spp) in southern Australia (Jenkins & May 1994, Kruck et al 2009), or those supporting highly valuable commercial fisheries (e.g. banana prawns *Penaeus merguiensis* in northern Australia (Staples & Vance 1987, Vance et al 1990). However, even in well studied situations there are substantial knowledge gaps. For instance, despite substantial research the exact importance of mangrove habitats for juvenile banana prawns remains unclear (Lee 2004, Sheaves et al. 2012). For a few species the range of habitats occupied by all life stages is relatively well known paving the way for investigations into the functioning and values of each in support of populations (Nagelkerken et al in review). For the majority however, the full range of habitats used by each life stage, and in many cases, the location of entire life stages, remains unknown.

Critical settlement habitats: While habitats occupied by later stage juveniles are sometimes reasonably well known (e.g. barramundi appear in wetlands at about 60mm+ (Russell & Garrett 1983, Davis 1986, Russell & Garrett 1988)), the initial settlement habitats for the majority of fishery species in Australia are unknown. This is a serious knowledge deficit because these habitats represent potentially critical life-cycle bottlenecks. For instance, on coral reefs, early post-settlement mortality, within 48 hours of settlement, can have long-lasting impacts on cohort strength and community structure (Almany 2004, Webster 2004). The availability of suitable settlement habitats and the survival of early life stages of estuarine species can similarly be a critical regulating force on population viability (Brown et al. 2005, Levin & Stunz 2005). Hence, the availability and condition of these initial settlement habitats, and the processes affecting successful occupancy of them, are likely to be critically important in regulating fish stocks.

The scale of settlement habitats and their position within the seascape is also critical. For example, while seagrass meadows are recognised as important settlement habitats for a range of fishery species (Jenkins et al. 1997, Jenkins & Wheatley 1998), not all seagrass is equivalent. Ford et al. (2010b) found seagrass settlement hotspots related to the location and isolation of the meadow; with beds adjacent to high volume tidal channels and isolated from other nearby seagrass beds being preferred settlement habitats. Similarly, (Loneragan et al. 1994) found that seagrass beds in shallow (<2m) water contained the highest densities of juvenile tiger prawns, despite the occurrence of high density seagrass beds in slightly deeper water nearby. Consequently, a particular patch of settlement habitat may be particularly important, even though there are other areas of the same habitat located elsewhere in the system. This has significant implications for management of impacts such as dredging along entrance channels (Tupper 2007) when it might adversely impact important adjacent nursery habitats. Moreover, offsets, whereby an area of 'equivalent' habitat is created to replace a degraded or destroyed habitat, must be considered in the context that the area of replacement habitat needs to be of equivalent value to the habitat it replaces. This also has implications for the transferability of findings about the importance of habitats in one region to those in another region (Sheaves 2012), since the habitat location within the seascape can strongly regulate its value, even if all other features of the habitat are similar to other alternative habitat units.

7. Connectivities Supporting Life-History Functions

Recent advances in understanding that nursery ground value is provided by complexes of interacting habitats has highlighted the importance of understanding the diverse connectivities that support nursery value. In fact the health and integrity of connectivities is critical to almost all aspects of fish life-histories but, because of its importance has only recently become clear, our understanding of connectivity is not extensive.

Connectivity has many meanings but here we restrict it to *linkages between spatial units (habitats, ecosystems, patches, micro-habitats, areas) that support life-history functions of fisheries species* (Secor & Rooker 2005). Connectivity occurs over all spatial and temporal scales, and acts to enable events in one spatial unit to influence outcomes in another unit. For example, connectivity is necessary to link coastal populations with spawning aggregations (Barbour & Adams 2012). The critical need for fisheries species to access multiple habitats is becoming increasingly clear (Yanez-Arancibia et al. 1993, Able 2005b, Dorenbosch et al. 2005, Sheaves 2005, Dahlgren et al. 2006, Sheaves 2009), and this requirement implies a crucial role for connectivity. In fact, without connectivity the multistage life-cycle, that is a feature of most fisheries species (Doherty & Williams 1988), could not occur.

Support for nursery ground function is one of the many important roles of connectivity, because the juvenile stages of fisheries species have the most critical demand for resources (Yanez-Arancibia et al. 1994), and because connectivity influences the importance of a range of vital rates that influence growth and persistence of populations (Lopez-Duarte et al. 2012). Utilisation of coastal and estuarine nursery grounds involves connectivities across a spectrum of scales, but these can be grouped into four broad categories (Fig. 3): (a) life-history connectivity, including recruitment to nursery grounds and eventual migration to adult habitats, (b) ontogenetic progression within nursery ground, (c), short-term seascape connectivities to access resources, and (d) connectivities supporting long-term changes in location among nursery habitats or nursery units.

At the largest life-history scale (Fig. 3(a)) nurseries can only fulfil their function if the individuals are able to migrate to them as larvae (Reyns et al. 2007) then move to adult habitats at the end of their juvenile period (Secor & Rooker 2005). At the largest scale are the connectivities that support ontogenetic migrations manifested as progressive movements through different ecosystems or habitats during growth and development (Dahlgren & Eggleston 2000, Rochard et al. 2001). These include sequential movement along salinity gradients (McBride et al. 2001, Rochard et al. 2001), or progression through a sequence of habitats (Dorenbosch et al. 2005, Nagelkerken 2007) that often corresponds to progressive movements to deeper habitats (Mumby et al. 2004, Aburto-Oropeza et al. 2009). Connectivities within nursery grounds are also critical to facilitate the diverse processes that support nursery ground functioning (Nagelkerken et al. in review). In fact, a considerable component of ontogenetic progression (e.g. movement along salinity gradients or progression through different habitats) occurs within nursery grounds (Fig. 3(b)). These are critical connectivities that allow juveniles to use areas that provide specific habitats or environmental conditions critical to their developmental stage (Dahlgren & Eggleston 2000, Adams et al. 2006b, Dorenbosch 2006, Nagelkerken 2009). Seascape connectivities (Fig. 3(c)) allow juveniles at each life history stage to move among habitat types that supply particular resources; allowing them access to specific feeding grounds (Heupel et al. 2006, Farrugia et al. 2011), to make tidally related feeding forays (Potthoff & Allen 2003, Heupel et al. 2010, Naesje et al. 2012), to migrate to intertidal areas at high tide (Dorenbosch et al. 2004, Jelbart et al. 2007), and to access low mortality habitats (Chittaro et al. 2005, Hammerschlag et al. 2010, Grol et al. 2011). These connectivities are crucial to the functioning of the complexly interacting habitat mosaics that comprise coastal nurseries (Sheaves 2009, Nagelkerken et al. in review), and result in the well-recognised seascape configuration effects (Dorenbosch et al. 2007, Olds et al. 2012) that lead to enhanced occupation of units of habitat that fulfil specific requirements when they are well connected to other habitat types (Jelbart et al. 2007, Unsworth et al. 2008, Olds et al. 2012). Connectivity also allows movements between different patches of a habitat type (Fig. 3(d)). This may simply be to facilitate the utilisation of resources across a large number of patches or feeding sites, but at a larger scale can allow juveniles to escape adverse environmental conditions (Childs et al. 2008, Knip et al. 2011). Each scale of connectivity combines both spatial and temporal aspects (Fig. 3(e)). The temporal component is obvious in migrations into intertidal areas for food and refuge (Potthoff & Allen 2003, Dorenbosch et al. 2004, Unsworth et al. 2009), regular feeding forays matching with upstream tidal flow (Naesje et al. 2012) or time of day (Heupel et al. 2010, Espinoza et al. 2011), migrations to accommodate seasonal change (Dantas et al. 2012) or utilise seasonally available habitats (Davis et al. 2012), or migrations allowing recolonisation of depopulated habitats (Sheaves & Johnston 2008).

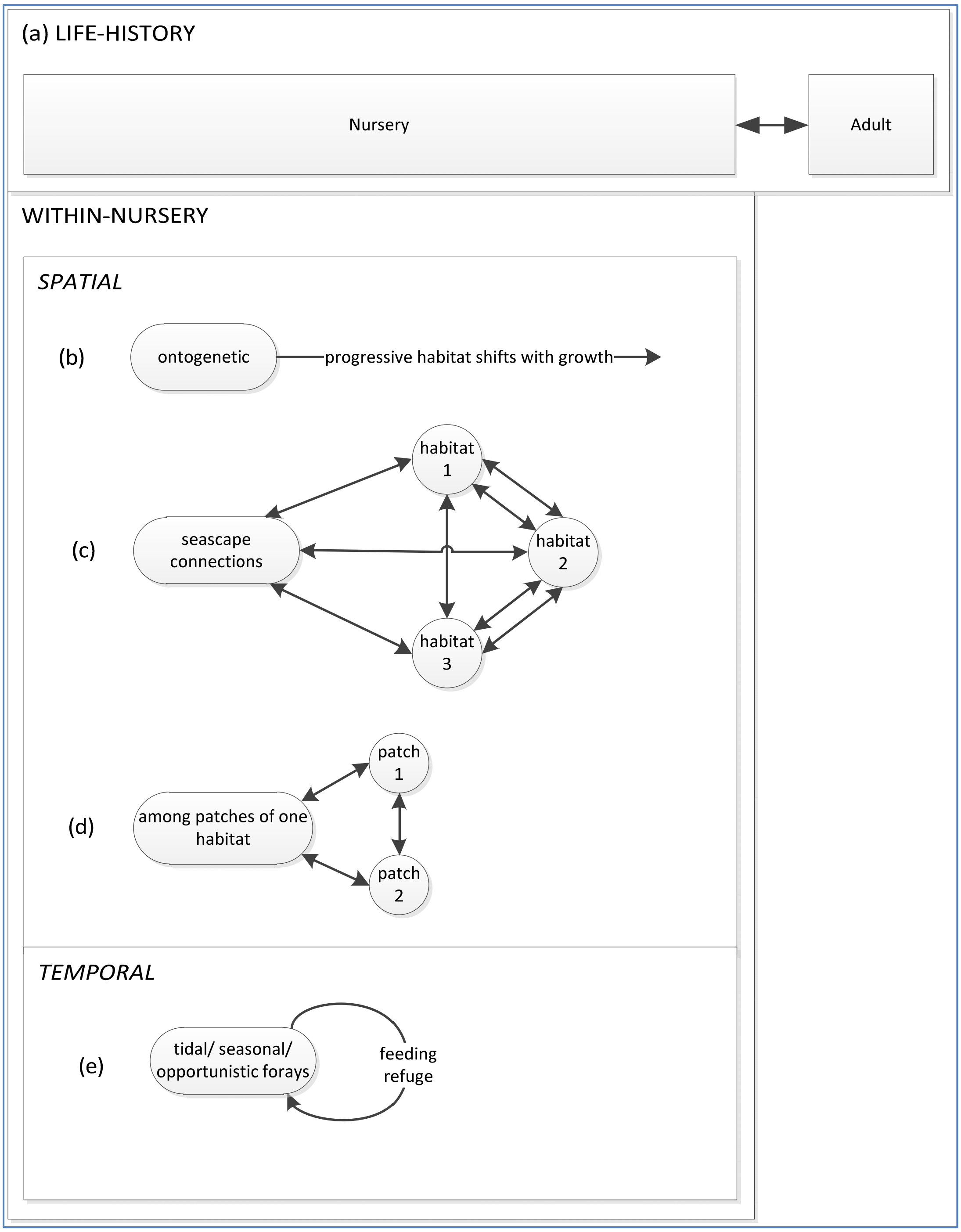

Figure 3: Scales of Connectivity

Our knowledge of the juvenile habitat requirements of even the iconic and highly valuable barramundi, *Lates calcarifer*, remains insufficient to base strong management actions for the protection of connectivity across the coastal landscape. Barramundi appear as larvae in estuaries, and as small juveniles in adjacent swamps, which may be either fresh or salt water (Russell & Garrett 1983, 1985). The general pattern of movement into ephemeral swamps appears consistent, yet the significance of marine-freshwater connectivity in sustaining barramundi populations remains unclear. The challenges of sampling small recruits during wet season flooding in the sort of habitats barramundi appear to recruit to probably accounts for the generally low numbers that have been recorded, however the location of the bulk of new recruits remains uncertain. Many such habitats subsequently dry up, and some may simply act as sinks if juveniles do not migrate to alternate habitats before disconnection (Russell & Garrett 1985). Subsequent movements may be into either fresh or salt water, and once again, the relative importance of the two is unclear, however recent studies indicate flexibility in life history occupation of fresh and salt water habitats, with components of the population remaining in one or the other for extended periods (McCulloch et al. 2005, Milton et al. 2008). The importance of marine-freshwater connectivity for other species with similar distributions such as mangrove jack is less well understood but beginning to be investigated (Russell & McDougall 2005). For the majority of fishery species in tropical Australia, the location of all juvenile habitats, and the critically important settlement habitats remains unknown. Understanding the functioning and relative value of different nurseries clearly cannot be complete until all such habitats are identified.

Roles, Consequences and Implications of Connectivity

The presence and extent of connectivity is critical in nursery ground functioning. Most obviously, it links juvenile and adult populations (Secor & Rooker 2005), supports ontogenetic migrations (McBride et al. 2001), allows utilisation of nursery resources (Dorenbosch 2006), and underpins the key nursery values of access to stage-specific food resources and reduced predation (Nagelkerken et al. in review). Connectivities are not equal because moving from a safe refuge to access resources in another area exposes juveniles to increased risk of predation (Caddy 2008), while good connectivity enhances feeding on prey resources (Micheli & Peterson 1999) and enhances colonisation of habitat patches by prey organisms (Darcy & Eggleston 2005) , so quality connectivities enhance nursery utilisation and nursery value.

At a more detailed level connectivity facilitates the functioning of spatially structured food webs (see Section 7), underpins resilience and persistence, and allows recolonisation after extinction. Not only is connectivity important in resilience of species to harvesting pressure (Cuveliers et al. 2010) by linking exploited stocks to multiple nursery grounds, it is vital for the resilience of the ecosystems fisheries species rely on. For example, reef fish populations are often limited by the extent of connectivity to juvenile habitats (Schmitt & Holbrook 2000, Mumby et al. 2004, Jelbart et al. 2007, Unsworth et al. 2008, Olds et al. 2012), and at a more specific level, the presence of highly connected mangrove nurseries determines the occurrence of parrot fish critical for control of algae (Mumby & Hastings 2008, Adam et al. 2011). Connectivity is also a critical factor in population persistence in fragmented landscapes (Matsuzaki et al. 2011), with restricted connectivity limiting species occurrence and abundance (Sheaves et al. 2010). In fact, reinstating connectivity can rehabilitate both fisheries populations and fisheries outcomes (Boys et al. 2012), and is a necessary ingredient in allowing recolonisation after extinction (Thorrold et al. 2001, Cowen et al. 2007, Sheaves & Johnston 2008).

Understanding and protecting connectivity is clearly critical to effective fisheries management and the efficient design of protected area networks; the habitat mosaics that nursery function relies on can’t function without it and it is central to facilitating recolonisation and maintaining resilience. In particular, it is critical to understand both small scale and large scale connectivities, and to identify and protect connectivity pathways and corridors (Lipcius et al. 2001, Reyns et al. 2007).

8. The Role of Natural and Artificial Structurally Complex Habitats

Structurally complex habitats, such as fallen trees and rocky reefs, provide key refuge habitats in coastal nurseries. Structures built by humans in the marine environment have the potential to provide valuable structural complexity that can provide refuge, feeding, spawning and nursery habitats, if they are engineered appropriately. There is a considerable need for detailed research to determine how the ecological value of artificial structures can be optimised.

Structurally complex habitats are critically important components of coastal and estuarine nurseries (Webb & Kneib 2002, Caddy 2008, Bostrom et al. 2011, Franca et al. 2012), providing refuge (Allouche 2002) and feeding areas for juvenile fish and mobile invertebrates (Sheaves 1996, Webb & Kneib 2002, Nagelkerken 2009) , and acting as critical initial settlement habitats (Dahlgren & Eggleston 2000, Dauble et al. 2012). Complex structures are also critical in providing spawning and feeding areas for adults (Zeller 1998).

The role of the complexity provided by living structures such as seagrass (Verweij et al. 2006), *Spartina* tidal marshes (Webb & Kneib 2002), mangroves (Thayer et al. 1987), and oyster reefs (Coen et al. 2000) is recognised around the world. In contrast, the roles of dead timber (snags or woody debris (LWD)) (Simenstad et al. 2003) and rocky structures are poorly understood. Most study of LWD has occurred in freshwater, where its importance is well established (e.g. Downs & Simon 2001, Erskine & Webb 2003), while most reef studies focus on areas well away from the shore (e.g. Hannah & Blume 2012). Understanding the ecological and fisheries roles of these types of natural habitat in coastal and estuarine ecosystems is important in its own right, and it is becoming more important because these are the habitats most closely mimicked by human infrastructure imposed in coastal and estuarine environments, and recent work has emphasised the real habitat benefits that can flow from coastal infrastructure as long as it is designed appropriately (e.g. Cheney et al. 1994).

Natural LWD has been shown to be one of the most critical contributors to structural complexity (Erskine & Webb 2003), providing nursery, shelter, refuge, spawning and feeding areas for a wide variety of fishes in rivers (e.g. Daugherty & Sutton 2005) and lakes (e.g. Sass et al. 2006). In consequence, many programs have been implemented to replace LWD removed during desnagging (Gerhard & Reich 2000) or no longer supplied naturally because riparian clearing has greatly diminished snag generating potential (Boyer 2003). Even though LWD is often the dominant subtidal complex structure in estuaries (Everett & Ruiz 1993), a paucity of definitive studies of its role and importance in estuaries means that little specific knowledge exists, so most understanding is extrapolated from freshwater systems, with little evaluation of its applicability to estuaries (Simenstad et al. 2003). The few studies of LWD in estuaries suggest it has similar ecological values in estuarine situations, and is particularly important in conferring nursery ground value. It provides critical nursery habitats for important tropical (Sheaves 1992, 1996a) and temperate (Hindell 2007) fisheries species, including the juveniles of offshore fisheries species (Sheaves & Molony 2000). Its high nursery value stems from its structural complexity that provides fauna with refuge from predation (Everett & Ruiz 1993), and its surface that provides substrate for the growth of epifauna (Caddy 2008) preyed on by juvenile fish (Sheaves et al. in press). LWD also provides habitat for burrowing organisms (Leonel et al. 2002, Davidson et al. 2008) and produces local areas of elevated topography in salt marshes that provide platforms for the development of key wetland vegetation

(Hood 2007). Limited studies of natural rocky reefs have shown rich coverings of epifauna (Connell & Glasby 1999, Clynick 2006) and diverse fish fauna (Ghanbarifardi & Malek 2009), again with the potential to contribute substantial nursery ground value.

In contrast to the paucity of studies of natural LWD in estuaries, there has been a recent upsurge in studies related to the ecology of artificial structures such as breakwaters (Cenci et al. 2011), pilings (Atilla et al. 2003, Andersson et al. 2009), marinas (Cheney et al. 1994), swimming enclosures (Clynick et al. 2008), oil production platforms (Westmeyer et al. 2007), and jetties (Condini et al. 2011). This asymmetry is a problem because there is little understanding against which to evaluate the value of artificial structures (Connell & Glasby 1999) or to use as models for appropriate outcomes of artificial design. However, this upsurge in activity has begun to build the body of understanding needed to evaluate the nursery value of artificial habitat and identify ways in which artificial structures can be engineered to maximise nursery and other environmental values.

Artificial habitats often support rich fish (Feary et al. 2011) and invertebrate (Glasby 2000) assemblages, often with similar species as found in natural systems (Bulleri et al. 2005, Clynick et al. 2008), and can provide important habitats for endangered species (Condini et al. 2011), and in some cases can provide effective replacements for lost habitats (Cheney et al. 1994). In some instances the benefits of artificial structures seem obvious; artificial LWD (digger logs) can have similar values to natural snags (Floyd et al. 2009) and can be effective in the restoration of degraded fish habitats (MacInnis et al. 2008), while pilings can increase epibenthic abundance and diversity (Clynick et al. 2007, Andersson et al. 2009) leading to enhanced fish abundance (Coleman & Connell 2001, Clynick et al. 2007). However, assemblage structure on artificial structures usually differs from natural habitats (Danna et al. 1994, Chapman 2003, Clynick et al. 2008, Bulleri & Chapman 2010) and, although artificial structures may increase the abundance and diversity of subtidal epibiota and the fish fauna they support (Clynick et al. 2007), the assemblages often differ in identity, diversity and abundance to those occurring on natural surfaces (Connell & Glasby 1999).

Many structures are available for habitat enhancement. For instance, in ports, habitat enhancement can stem from careful design of basic port infrastructure (Browne & Chapman 2011, Feary et al. 2011), to specially designed habitat enhancement structures (Chapman & Blockley 2009, Paalvast et al. 2012). There is considerable scope for infrastructure design to support specific values such as nursery provision (Chapman & Underwood 2011). For instance, exposed versus sheltered sides of breakwaters in northwest Italy have different fauna (Bulleri & Chapman 2004), with those on exposed sides having fauna similar to adjacent rocky reefs while quite different fauna develop on the sheltered side (Clynick 2006). Similarly, the type (Glasby 2000, Burt et al. 2009, Green et al. 2012) and orientation of substrate (Glasby & Connell 2001, Chapman 2006) influences faunal type and abundance, as do the patterns of patchiness and connectivity (Goodsell et al. 2007) . These effects mean careful design focussed on specific aims is required to maximise the value of artificial habitats (Browne & Chapman 2011). For example, different design choices are likely to be necessary to mimic natural assemblages compared to those required to optimise fisheries values, to maximise fish abundance, maximise biodiversity or support particular ecological processes (Jackson et al. 2008, Ivesa et al. 2010). Opportunities exist to use artificial habitats to gain specific nursery advantages. For instance, the sheltered habitats produced by Italian breakwaters provide recruitment habitats for important fisheries species (Clynick 2006).

Although the opportunities for artificial habitats to enhance ecological and fisheries values, any development needs to be coupled with detailed understanding of the full range of consequences (Browne & Chapman 2011). Indeed, it is becoming clear that shoreline modifications, such as seawalls, riprap and overwater structures, have complex impacts on fish assemblages (Blockley & Chapman 2006, Toft et al. 2007). For instance, many artificial structures are detrimental to the environment and fisheries, with shading by large platform dock structures (>20,000 m^2) leading to greatly reduced numbers of fish (Able et al. 1998, Duffy-Anderson et al. 2003, Sanger et al. 2004)and impaired juvenile growth rates (Able et al. 1999). Other concerns include the possibility that high abundances of fish on some artificial reefs may simply reflect attraction away from nearby natural habitats (Fujita et al. 1996), and that other human activities associated with infrastructure (e.g. dredging) can have on-going effects on water and habitat quality(Able et al. 1998), seriously eroding benefits from careful infrastructure design. Up until now most work on the role and impact of artificial structures has focussed on the flora and fauna growing on the structures. While this supplies useful knowledge much more work directed to specific fisheries questions is needed to gain a detailed understanding of the ways artificial structures can be engineered to enhance nursery ground and other fisheries values.

9. Habitat-Specific Food Webs and Trophic Interactions supporting Life-Cycles

Because access to rich feeding environments is one of the key contributors to nursery ground value improved understandings of food webs and how they vary over space and time is critical to supporting nursery ground value. This need for detailed food web understanding extends to other life-cycle stages because it is a key component of the values conferred by habitats at different life-history stages.

The biomass of any cohort of a species is greatest during nursery residence (Yanez-Arancibia et al. 1994) so the nursery phase needs to occur in nutritionally rich ecosystems. This means that understanding food webs and feeding relationships is crucial to understanding nursery ground value. This need for detailed food web understanding extends to other life-cycle stages because it is a key component of the values conferred by habitats at different life-history stages.

There are many issues around food and feeding; as well as requiring particular prey at particular life stages (Robertson & Duke 1990b), juveniles need to acquire their prey in the face of varying predation risk. This forces trade-offs that can profoundly affect nursery ground value, and the quantity and quality of sub-adults migrating to adult habitats (Sogard 1992, Burrows 1994, Alofs & Polivka 2004). Consequently, habitats where high quality and appropriate nutrients are available are critical to support juveniles during this vital growth phase (Sogard 1992, Harter & Heck 2006).

While information on habitat-related distribution of fish is lacking, detailed food web studies are even more incomplete and irregularly distributed. In part this reflects the sheer length and diversity of Australia's coastline and the sparse distribution of urban centres and research institutions. Together the incomplete coverage of habitat studies and paucity of food web studies mean a that there is only scattered information on habitat-specific food webs supporting the different life-history stages of fishery species that use coastal habitats as nurseries. Even then, available studies are mostly descriptive (e.g. What does a species eat? Where is it found?), and do not focus on fundamental issues and processes, such as nutrient sources and energy flow, which are ultimately the critical factors that support nursery function. This is partly because available trophic studies rarely cover a size range that accounts for ontogenetic variations in diet (Wilson & Sheaves 2001), and rarely provide information on the habitat-specific diets of small (<5 cm) juveniles. Perhaps more importantly, in the past most studies have been based on the analyses of stomach contents (Salini et al. 1998). Although stomach content data gives important information on the taxonomic composition of diets, it does not identify the sources of nutrition at the base of the food web or the most important producers and habitats for fishery species. Recent developments in biochemical tracers, such as stable isotope and fatty acid analysis, has begun to allow identification of the ultimate sources of nutrition and the specific habitats used for feeding (Loneragan et al. 1997, Connolly et al. 2005a). Although far from comprehensive, the combination of stomach content analysis and new biochemical techniques are beginning to provide habitat-specific dietary information.

Estuaries and Bays (including mangroves and saltmarshes): Mangrove and saltmarshes have received much attention in trophic studies around Australia. However, most studies are limited to comparisons of fish communities between these habitats and adjacent seagrass beds or unvegetated habitats (Robertson & Duke 1987, Laegdsgaard & Johnson 1995), and there is still much debate on the energetic links between these wetlands and aquatic food webs. Mangroves are particularly abundant in northern Australia, especially in the Northern Territory and Queensland, where mangrove forests are highly productive (Bunt et al. 1979, Clough 1998) and contribute a large proportion of the organic carbon available for aquatic consumers (Alongi et al. 1998). For example, in the Hinchinbrook Channel in North Queensland, up to 56% of the total organic carbon is of mangrove origin (Alongi et al. 1998).

Although mangrove material is of poor nutritional quality (Alongi et al. 1989), mangrove carbon enters estuarine food webs through direct grazing by herbivorous invertebrates such as sesarmid crabs and mangrove snails (Robertson & Daniel 1989, Micheli 1993, Oakes et al. 2010), and through the detrital pathways (Abrantes & Sheaves 2008, 2009b, Oakes et al. 2010). However, despite the large expanses of mangrove forests and high availability of mangrove-derived carbon, the importance of this source for fishery species is limited, and food webs in mangrove areas are mostly based on a combination of more easily assimilated aquatic sources (Loneragan et al. 1997, Abrantes & Sheaves 2008, 2009b, Oakes et al. 2010). A notable exception are groupers *Epinephelus* spp. and snappers *Lutjanus* spp. in North Queensland, which feed extensively on sesarmid crabs, as part of a very short food chain from mangroves to large predatory fish (Sheaves & Molony 2000).

In temperate eastern Australia (Victoria, South Australia, New South Wales), mangroves are confined to sheltered shores such as estuaries, embayments and inlets, while in Western Australia mangroves are mostly distributed through the northern and western shores, and are abundant only in the northern regions of the Kimberley and Pilbara. The few studies for these areas indicate that mangroves are not important contributors to consumer nutrition (Boon et al. 1997, Hadwen et al. 2007, Heithaus et al. 2011).

Extensive saltmarsh meadows occur in all States, but are most abundant in Queensland, the Northern Territory and Western Australia (Bucher & Saenger 1991). In tropical regions, saltmashes generally occur landward of mangrove forests, while in the temperate southern regions vast expanses of saltmarsh occur adjacent to waterways. Saltmarsh habitats are traditionally considered to export organic matter to adjacent subtidal habitats, supporting aquatic foodwebs (Teal 1962, Odum 1968). However, this paradigm was based on information from the USA, where the flooding patterns are very different to Australia. Since, unlike those in the Northern Hemisphere, many saltmarsh habitats in northern Australia occur high in the intertidal and are only submerged during the highest spring tides for relatively short periods of time, their nursery function is likely to be very different to that in the Northern Hemisphere (Connolly 2009). Flooded saltmarshes are used by a range of invertebrates and fish, which then feed on saltmarsh detritus and/or invertebrates such as insects, crab zoea and amphipods, transporting saltmarsh carbon into the aquatic food web. Recent stable isotope studies have confirmed the incorporation of saltmarsh material by invertebrates such as crabs, penaeid prawns and gastropods (Guest & Connolly 2004, Guest & Connolly 2006, Guest et al. 2006, Abrantes & Sheaves 2008, 2009b), meaning that despite the low frequency of inundation, saltmarsh carbon can be important for fishery species.

For both saltmarsh and mangrove habitats, very few studies provide quantitative information on the incorporation of saltmarsh/mangrove material by fishery species, and those that do indicate that wetland producers have limited importance for estuarine consumers in tropical (Boon et al. 1997, Abrantes & Sheaves 2008, 2009b), subtropical (Melville & Connolly 2003, Connolly et al. 2006) and temperate regions (Boon et al. 1997, Svensson et al. 2007), and food webs supporting adjacent fisheries rely mostly on a range of sources, mostly aquatic. However, because this importance depends on the assemblage and availability of different sources (Svensson et al. 2007), different systems are likely to have different patterns of importance meaning results from one area are unlikely to be transferable. For example, riparian vegetation might have a greater importance for consumers in intermittently open estuaries due to increased residency time in these areas when compared to open estuaries (Hadwen et al. 2007).

Seagrass Meadows: Despite the occurrence of substantial seagrass beds around Australia and their high values as nurseries (Howard 1984, Jenkins et al. 1997, Jenkins & Wheatley 1998, Hindell 2006), there is little quantitative information from anywhere in Australia of the relative contributions to food webs from direct consumption of seagrass by herbivores versus indirect consumption by detritivores. There is a little more information on the relative contribution of seagrass compared to other sources of nutrition, but this is still very localised in extent. As a consequence, the trophic contribution of seagrass to different coastal fisheries is unclear. However, importance appears to vary greatly between regions, depending on availability and productivity of different producers. For example, in Torres Strait and Shark Bay some of the largest seagrass areas in Australia (Kirkman 1997), shallow and relatively clear waters mean that food webs rely mostly on benthic producers such as benthic microalgae and seagrass (Fry et al. 1983, Belicka et al. 2012, Speed et al. 2012). In systems like the relatively turbid Hinchinbrook Channel, however, seagrass productivity is limited by turbidity, so the importance of seagrass is relative less and consumers rely on a combination of sources, including plankton, microphytobenthos, seagrass and mangroves (Abrantes & Sheaves 2009).

In northern Australia important fisheries for tiger (*Penaeus esculentus* and *P. semisulcatus*) and endeavour (*Metapenaeus endeavouri*) prawns (Staples et al. 1985, Haywood et al. 1995) relies on seagrass beds as nurseries, however, to date only one study investigated the importance of seagrass carbon for penaeid prawn nutrition in seagrass beds in Australia (Loneragan et al. 1997). That study, conducted in the Embley River, Cape York Peninsula, indicates that juveniles rely on different sources, depending on their position in the estuary: animals from seagrass habitats depend mostly on seagrass and epiphytes, while those in macroalgal beds in mangrove creeks depend mostly on macroalgae and seston (Loneragan et al. 1997). Since penaeid prawns are a major prey for many fishery species (Robertson 1988, Salini et al. 1990), the energetic flow from seagrass to those fish in seagrass areas must also be important. However, because penaeid prawns undergo important ontogenetic variations in diet (Abrantes & Sheaves 2009), and can rely on different sources depending on habitat (Loneragan et al. 1997, Abrantes & Sheaves 2009, Alongi 2009), much research is still needed to determine the sources of nutrition for penaeid juveniles while in the different nursery grounds around Australia. Other important crustaceans, such as blue swimmer crabs *Portunus pelagicus* and rock lobsters *Panulirus cygnus*, use seagrass nurseries in south western Australia. Juveniles of these species forage on invertebrates and plant material in seagrass beds, but macroalgae rather than seagrass is their ultimate source of their nutrition (Joll & Phillips 1984, Jernakoff 1987, de Lestang et al. 2000, MacArthur et al. 2011). However, different size juveniles forage in different habitats and there can be variations in diet between sites and seasons (Joll & Phillips 1984), so there are still considerable gaps in our knowledge about the ultimate sources of nutrition for different size juveniles.

Beside garfish, *Hyporamphus* spp. (Carseldine & Tibbetts 2005, Noell 2005, Tibbetts & Carseldine 2005), no other commercial finfish species is known to feed directly on seagrass. However, seagrass is directly or indirectly consumed by a range of macroinvertebrates, which are prey for carnivorous fish such as flathead and whiting, entering coastal food webs (Howard 1984, Robertson 1984, Hindell 2006). *S*table isotope and fatty acid studies indicate that seagrass carbon is important for a range of fishery species including flathead in Victoria (Klumpp & Nichols 1983, Nichols et al. 1986), whiting (Connolly et al. 2005b, Connolly et al. 2006), queenfish and trevallies (Abrantes & Sheaves 2009) in Queensland. However, most of those studies do not provide quantitative estimates of seagrass contribution, and due to the frequent similarity in stable isotope and/or fatty acid composition between seagrass and other producers, it is often impossible to separate the importance of seagrass from other sources. Techniques such as stable isotope labelling (Oakes et al. 2010), sulphur stable isotope analysis ($\delta^{34}S$) (Connolly et al. 2004) or compound-specific stable isotope analyses (McMahon et al. 2011a) have considerable potential for more precise estimates, but these techniques are still novel and expensive, so rarely used .

Beaches: Unvegetated habitats that dominate beach environments provide little structural complexity (Robertson & Lenanton 1984), and food webs depend mostly on inputs from offshore, from land and/or from other coastal habitats (McLachlan & Brown 2006). Detached macrophytes (seagrass and macroalgae) are often transported from distant habitats and accumulate in surf zones, forming beach wrack. These accumulations are particularly abundant along the temperate Australian coast, especially in Victoria, Tasmania (e.g. Cheshire and Hallam 1988), South Australia (Duong & Fairweather 2011) and southern Western Australia (e.g. Hansen 1984). Bacteria break down wrack and are responsible for most of secondary production of those beaches (Hansen 1984, McLachlan 1985). This macrophyte subsidy increases productivity in these otherwise nutrient poor and unproductive environments (Kirkman & Kendrick 1997), providing important food and habitat for macroinvertebrates (Hanson 1984, Robertson and Lucas 1983, Crawley and Hyndes 2007, Ince et al. 2007, Poore and Gallagher *in press*) and fish (Lenanton 1982, Robertson & Lenanton 1984, Crawley et al. 2006).

Some work has focused on the importance of beach wrack for aquatic consumers. Most have been conducted in south western Australia (Lenanton et al. 1982, Robertson and Lucas 1983, Lenanton and Caputi 1989, Crawley et al. 2006), with limited studies in New South Wales (Poore and Gallagher in press; Rossi and Underwood 2002) and South Australia (Duong 2008). These studies indicate that benthic macrofauna is more abundant on high-wrack beaches and is generally dominated by large populations of amphipods, with isopods and insects also present (McLachlan 1985, Ince et al. 2007). These invertebrates are in turn important prey for fish, including fishery species such as mullet, whiting, herring, cobbler and catfish (Lenanton et al. 1982, Robertson and Lucas 1983, Lenanton and Caputi 1989, Robertson and Lenanton 1984, Crawley et al. 2006), forming a short and simple food web from macrophyte detritus to colonising microbes, detritivorous invertebrates and fish.

Because algae are generally more easily assimilated than seagrass (Klumpp 1989), the algal component of wrack is often preferred by detritivores (Robertson and Lucas 1983; Crawley and Hyndes 2007, Doropoulos et al. 2009, Poore and Gallagher *in press*). Although seagrass dominates the wrack biomass in south-western Australia brown algae, particularly the kelp *Ecklonia radiata*, contributes disproportionately to surf-zone food webs (Crawley et al. 2006). Similarly, in New South Wales amphipods feed preferentially on *Sargassum* spp. even though they use both *Sargassum* spp. and the seagrass *Zostera capricorni* habitats extensively (Poore and Gallagher *in press*). However, there are still no estimates of the relative importance of the different wrack components, and other sources such as marine plankton, to fishery species that use these habitats. This importance is likely to vary both spatially and seasonally, depending on factors such as wrack availability and species abundance and composition, as well as the assemblage of primary consumer invertebrates. There is also no information on the importance of wrack in tropical regions, or on how much how much detritus and nutrients broken down by microbes in beach wrack subsidizes offshore production around Australia.

Energetic Subsidies and Trophic Links: Subsidies from vegetation transported into a habitat can support food webs on productive habitats such as mangrove forests, algal beds or mudflats (Heck et al. 2008) as well as on unproductive beaches. For example, the coastal habitats of the western coast of south western Australia are characterized by limestone reefs dominated by macroalgae, with patches of macroalgae interspersed with unvegetated sand and seagrass meadows. There, detached reef algae are transported into adjacent seagrass beds where they are incorporated by seagrass-associated fauna, forming an important link between these habitats (Wernberg et al. 2006, Hyndes et al. 2012). Macroalgae from offshore also subsidizes food webs in less productive inshore reefs (Vanderklift & Wernberg 2008). In other regions, seagrass subsidies can support food webs in adjacent mudflats, as in the Gulf St Vincent, South Australia (Connolly et al. 2005b) and in Port Curtis, South Queensland (Connolly et al. 2006). Despite the importance of the different subsidies for receiving habitats, few studies have attempted to quantify these exchanges and the functional roles of the different habitats in supporting fishery species are still not well understood for most Australian coastal seascapes.

Trophic links between distant habitats also occur as a result of animal movement (Polis et al. 1997). For example, the recruitment of penaeid prawns, portunid crabs, and fish such as eels, tarwhine and jacks from offshore or adjacent coastal/reef areas into estuaries (Dall et al. 1990, Smith & Suthers 2000) can constitute an important subsidy of marine carbon to coastal estuaries. However, studies are yet to estimate the contribution of these marine subsidies to coastal nursery food webs. Also, fish and invertebrates often move between habitats to feed on different sources (Linke et al. 2001, Gillanders 2006, Saintilan et al. 2007), linking spatially separated food chains, but studies generally overlook the importance of this connectivity for fishery species.

Coastal food webs can also receive subsidies from the terrestrial environment. Freshwater flow allows the delivery of sediments and organic matter from river catchments to the coastal zone. For example, in North Queensland, the Herbert River is estimated to contribute 27% of the total organic carbon input for the Hinchinbrook Channel, a contribution much higher than that of aquatic sources, which together have estimated contribution of only ~17% (Alongi et al. 1998, Alongi 2009). Seasonal floods affect coastal food webs (Connolly et al. 2009, Schlacher et al. 2009) increasing fishery production in adjacent coastal habitats (Loneragan and Bunn 1999, Meynecke et al. 2006, Connolly et al. 2009, Gillson et al. 2009), meaning that the ecology of river catchments can affect downstream estuarine food webs. Floods also allow the connectivity between habitats (e.g. freshwater and estuarine reaches and floodplain wetlands), providing an opportunity for juveniles of species such as snappers and barramundi to have access to different sources. Despite this importance, no studies have quantified the importance of terrestrial subsidies to coastal fishery species. This is a very important gap in our knowledge, especially given the ever increasing transformation of the natural landscapes in river catchments.

10. Critical Knowledge Gaps

There are a variety of critical knowledge gaps relating to fish habitats that need to be filled before coastal and estuarine fisheries can be managed effectively. This is particularly the case for crucial spawning and nursery habitat functions, and detailed habitat mapping. There is also an important need to incorporate fisher knowledge into formal fish-habitat understanding.

Overall, knowledge of most issues relating to habitat utilisation over fish life-histories is incomplete. This is particularly the case for crucial spawning and nursery habitat functions, where understanding is incomplete or completely lacking for many important species, and extends to a lack of detailed habitat mapping, as well as a need to incorporate fisher knowledge into formal fish habitat understanding. These deficits need to be addressed urgently because the coastal locations of these spawning and nursery habitats mean they are exposed to direct effects of sea level rise and changing rainfall patterns (Poloczanska et al., 2007, Koehn et al, 2011), and are often situated close to the locations where intense coastal development is occurring (Edgar et al 2000, Corn & Copeland 2010). The most critical knowledge gaps include:

General Issues

1. Mapping, baselines and monitoring

Knowledge of habitats and fish habitat relationships needs to be organised to allow its integration into management. The three key components of this are habitat mapping, establishing robust and comprehensive baselines, and subsequent monitoring of change in habitats and fish-habitat utilisation. To provide their full value, mapping, baseline studies and monitoring need to be conducted at scales appropriate to management and relevant to ecosystem processes. Mapping should not only provide information on habitat types, and the species and life-cycle stages that use them, but should include layers indicating the resources provided by different habitat units and key connectivities among them.

2. Formalising fisher knowledge on fish habitat utilisation

Fishers have a wealth of knowledge on the habitats used by fisheries species as part of their day to day lives. This information needs to be fully documented and compiled into a formalised knowledge base because it has the potential to provide much more extensive detail than possible from scientific surveys. The formalising of fisher knowledge and fisheries information into fish-habitat understanding would greatly advance understanding of fish-habitat relationships, provide important information for management, and provide a vital input into fish-habitat mapping.

3. Connectivities supporting life-history functions

Because nursery utilisation, spawning and day to day activities of fish depend on access to a diversity of habitats and resources, almost all aspects of fish life-histories require appropriate connections between habitat units and resources. Accordingly, detailed understanding of connectivity is integral to ensuring effective management, and needs to incorporate both scale specific and life-history specific elements.

4. Environmental conditions that facilitate or impair connectivity

Habitat utilisation and connectivity are both greatly influenced by environmental conditions that facilitate or impair successful utilisation. However, this knowledge is lacking for many species. As a result more extensive knowledge is needed on the biotic, abiotic, and anthropogenic factors that affect habitat utilisation.

5. How the habitat value of artificial structures can be maximized

The ever-increasing impacts of humans on coastal ecosystems mean that it is critical to understand how human-imposed structures can be engineered to optimise fisheries outcomes, such as enhancing nursery value and feeding opportunities, and providing appropriate spawning habitats. Up until now most work has focussed on the flora and fauna growing on anthropogenic structures, so more work, focused on fisheries species, is needed to gain a detailed understanding of the ways in which fisheries values can be optimised.

6. Information on non-target species

Habitat utilisation information is lacking on species that are not usually targeted by fisheries. These species are important because they play critical ecosystem roles, and are often key forage species supporting exploited fish stocks. Opportunities exist to extract part of this information from studies of fisheries bycatch but for many species additional studies will be required to access habitats not accessible to gears used by fishers.

7. Habitat values of deeper and unvegetated habitats

Most habitat studies have concentrated on shallow water areas, and often on vegetated habitats or reefs. Despite deeper and unvegetated habitats representing the majority of areas available to fish, and undergoing substantial modification due to trawling, relatively few studies have evaluated their habitat values.

8. Habitat resource utilisation

Knowledge of habitat resource utilisation is particularly important in supporting management decisions, such as determining the key habitat units supporting life-history processes, the specific resources in need of protection and the extent to which artificial habitats can act as valuable fisheries habitats. Consequently, there needs to be a concerted effort to ensure that fish-habitat studies go beyond identification of fish-habitat relationships to include investigation of resource utilisation in those habitats.

Spawning-Specific Issues

9. Detailed identification of spawning habitats

Spawning habitats need particular protection because reproduction is a critical bottleneck in life-histories and because spawning aggregations often provide sites of over-exploitation. However, specific spawning habitats can be hard to detect so additional effort needs to go into their identification.

10. The exact settlement process

With a few notable exceptions, we lack knowledge on the settlement and recruitment processes that deliver juveniles from spawning grounds to nursery grounds. This gap means that it is difficult to evaluate the extent to which particular spawning habitats contribute to future fish stocks or determine if a habitat's nursery value is a function of factors intrinsic to the nursery or simply a function of limitation of the supply of juveniles.

Nursery-Specific Issues

11. The range of nursery habitats utilised

Nursery grounds have been identified in detail for very few Australian inshore fisheries species resulting in very incomplete understanding of the nursery habitat needs for even common Australian fisheries species. This is a crucial knowledge gap because understanding of the nursery habitats required by different species is the fundamental basis for all other elements of nursery understanding and vital for underpinning effective management. As with most of the succeeding gaps, understanding needs to be developed in the context of relevant spatial and temporal scales.

12. The habitats utilised at different stages of nursery residence

There is no understanding of the habitat requirements of juveniles at different stages of nursery residence. This is vital information because the availability and quality of habitats used by particular life stages has been identified as primary determinants of nursery ground success.

13. Synergies among habitats that support nursery function

The realisation that few species rely on a single habitat for their nursery requirements means that understanding of nursery habitats needs to include synergies among the elements of the habitat mosaics that support nursery function.

14. Non-habitat nursery resources requirements

Because much of the value of nurseries is derived from non-habitat resources (such as food) a more precise understanding of these non-habitat factors is required.

15. Stage-specific habitat and non-habitat resource requirements

It is now understood that successful nursery ground utilisation relies on utilisation of a succession of specific habitat and non-habitat resources. Consequently, understanding of both habitat and non-habitat resource requirements needs to be stage-specific. This is particularly important because focus on nursery use in general is likely to lead to vital stage-specific resources (e.g. initial recruitment habitats) being overlooked, even though these are often the critical bottlenecks determining successful nursery occupation.

16. Geographic variation in nursery ground value

Most nursery understanding is very limited in its spatial coverage, often limited to a single site. Consequently, the transferability of understanding to other areas is unknown. Understanding of geographic variation in key components of nursery ground provision and value would greatly improve the situation and allow more confident application of knowledge to other areas.

17. Relative contributions to adult stocks from different nursery habitats

Understanding the relative contributions of different nurseries to fisheries stocks is one of the key pieces of information needed by managers. However, assessment of relative values has rarely been achieved for any fishery in the world. New chemical methods provide real opportunities to improve the situation but they need to become more accessible and widely used. However, these new methods can only be applied once the range of possible nurseries has been identified (Gap 1), and require substantial specific additional knowledge (Gaps 2-6, and 8-12) before information on relative value can be converted into management actions.

18. Processes regulating growth and survival of juveniles in nursery grounds

Relative nursery contribution is not simply a function of the number of individuals contributed by different nurseries but depends on the health and condition of juveniles entering adult habitats. As a result, knowledge of processes regulating growth and survival is an important need.

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References

Able KW (2005) A re-examination of fish estuarine dependence: Evidence for connectivity between estuarine and ocean habitats. Estuarine Coastal and Shelf Science 64:5-17

Able KW, Manderson JP, Studholme AL (1998) The distribution of shallow water juvenile fishes in an urban estuary: The effects of manmade structures in the lower Hudson river. Estuaries 21:731-744

Able KW, Manderson JP, Studholme AL (1999) Habitat quality for shallow water fishes in an urban estuary: the effects of man-made structures on growth. Marine Ecology-Progress Series 187:227-235

Abrantes K, Sheaves M (2008) Incorporation of terrestrial wetland material into aquatic food webs in a tropical estuarine wetland. Estuar Coast Shelf Sci 80:401–412

Abrantes K, Sheaves M (2009a) Food web structure in a near-pristine mangrove area of the Australian Wet Tropics. Estuar Coast Shelf Sci 82:597–607

Abrantes K, Sheaves M (2009b) Sources of nutrition supporting juvenile penaeid prawns in an Australian dry tropics estuary. Mar Freshwat Res 60:949-959

Aburto-Oropeza O, Dominguez-Guerrero I, Cota-Nieto J, Plomozo-Lugo T (2009) Recruitment and ontogenetic habitat shifts of the yellow snapper (Lutjanus argentiventris) in the Gulf of California. Marine Biology 156:2461-2472

Adam TC, Schmitt RJ, Holbrook SJ, Brooks AJ, Edmunds PJ, Carpenter RC, Bernardi G (2011) Herbivory, Connectivity, and Ecosystem Resilience: Response of a Coral Reef to a Large-Scale Perturbation. Plos One 6

Adams AJ, Dahlgren CP, Kellison GT, Kendall MS, Layman CA, Ley JA, Nagelkerken I, Serafy JE (2006a) Nursery function of tropical back-reef systems. Marine Ecology-Progress Series 318:287-301

Adams AJ, Wolfe RK, Kellison GT, Victor BC (2006b) Patterns of juvenile habitat use and seasonality of settlement by permit, Trachinotus falcatus. Environmental Biology of Fishes 75:209-217

Allouche S (2002) Nature and functions of cover for riverine fish. Bulletin francais de la peche et de la pisciculture [Bull Fr Peche Piscic] no

Almany GR (2004) Does increased habitat complexity reduce predation and competition in coral reef fish assemblages? OIKOS 106:275-284

Alongi DM (1990) Effect of mangrove detrital outwelling on nutrient regeneration and oxygen fluxes in coastal sediments of the central Great Barrier Reef lagoon. Estuar Coast Shelf Sci 31:581-598

Alongi DM (1996) The dynamic of benthic nutrient pools and fluxes in tropical mangrove forests. J Mar Res 54:123-148

Alongi DM (2009) The Energetics of Mangrove Forests. Springer, Dordrecht, 216 pp. In:

Alongi DM, Ayukai T, Brunskill GJ, Clough BF, Wolanski E (1998) Sources, sinks, and export of organic carbon through a tropical, semi-enclosed delta (Hinchinbrook Channel, Australia). Mangroves and Salt Marshes 2:237–242

Alongi DM, Boto KG, Tirendi F (1989) Effect of exported mangrove litter on bacterial productivity and dissolved organic carbon fluxes in adjacent tropical nearshore sediments. Mar Ecol Prog Ser 56:133-144

Andersson MH, Berggren M, Wilhelmsson D, Ohman MC (2009) Epibenthic colonization of concrete and steel pilings in a cold-temperate embayment: a field experiment. Helgoland Marine Research 63:249-260

Atilla N, Wetzel MA, Fleeger JW (2003) Abundance and colonization potential of artificial hard substrate-associated meiofauna. Journal of Experimental Marine Biology and Ecology 287:273-287

Ayvazian SG, Hyndes GA (1995) Surf-zone fish assemblages in south-western Australia: do adjacent nearshore habitats and the warm Leeuwin Current influence the characteristics of the fish fauna? Mar Biol 122:527-536

Azovsky A (2000) Concept of scale in marine ecology: linking the words or the worlds? Web Ecology 1:28-34

Ball B, Linnane A, Munday B, Davies R, McDonnell J (2003) The rollerball net: A new approach to environmentally friendly ottertrawl design. Archive of Fishery and Marine Research 50:193-203

Ball JR, Esler D, Schmutz JA (2007) Proximate composition, energetic value, and relative abundance of prey fish from the inshore eastern Bering Sea: implications for piscivorous predators. Polar Biology 30:699-708

Barbour AB, Adams AJ (2012) Biologging to examine multiple life stages of an estuarine-dependent fish. Marine Ecology-Progress Series 457:241-250

Bax N, Kloser R, Williams A, Gowlett-Holmes K, Ryan T (1999) Seafloor habitat definition for spatial management in fisheries: a case study on the continental shelf of southeast Australia. Oceanologica Acta 22:705-720

Beck M, Heck K, Able K, Childers D, Eggleston D, Gillandes B, Halpern B, Hays C, Hoshino K, Minello T, Orth R, Sheridan P, Weinstein M (2001) The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51:633-641

Begg GA, Hopper GA (1997) Feeding patterns of school mackerel (Scomberomorus queenslandicus) and spotted mackerel (S-munroi) in Queensland east-coast waters. Marine and Freshwater Research 48:565-571

Belicka LL, Burkholder DA, Fourqurean JW, Heithaus MR, Macko SA, Jaffe R (2012) Stable isotope and fatty acid biomarkers of seagrass, epiphytic, and algal organic matter of consumers in a nearly pristine seagrass ecosystem. Mar Freshwat Res 63:1085–1097

Berkstrom C, Gullstrom M, Lindborg R, Mwandya AW, Yahya SAS, Kautsky N, Nystrom M (2012) Exploring 'knowns' and 'unknowns' in tropical seascape connectivity with insights from East African coral reefs. Estuarine, Coastal and Shelf Science 107:1-21

Bianchi TS, Allison MA (2009) Large-river delta-front estuaries as natural "recorders'' of global environmental change. Proceedings of the National Academy of Sciences of the United States of America 106:8085-8092

Blaber SJM (2002) Fishes in Estuaries. Fish and Fisheries 3:360-361

Blaber SJM, Blaber TG (1980) Factors affecting the distribution of juvenile estuarine and inshore fish. J Fish Biol 17:143–162

Blaber SJM, Brewer DT, Salini JP (1989) Species composition and biomasses of fishes in different habitats of a tropical northern Australian estuary: Their occurrence in the adjoining sea and estuarine dependence. Estuar Coast Shelf Sci 29:509-531

Blaber SJM, Milton DA, Salini JP (2008) The Biology of Barramundi (Lates calcarifer) in the Fly River System. Developments in Earth and Environmental Sciences 9:411-426

Blockley DJ, Chapman MG (2006) Recruitment determines differences between assemblages on shaded or unshaded seawalls. Marine Ecology-Progress Series 327:27-36

Bloomfield AL, Gillanders BM (2005) Fish and invertebrate assemblages in seagrass, mangrove, saltmarsh, and nonvegetated habitats. Estuaries 28:63-77

Boesch DF, Turner RE (1984) Dependence of fishery species on salt marshes: the role of food and refuge. Estuaries 7:460-468

Bond NR, Lake PS (2003) Characterizing fish-habitat associations in streams as the first step in ecological restoration. Austral Ecology 28:611-621

Boon PI, Bird FL, Bunn SE (1997) Diet of the intertidal callianassid shrimps *Biffarius arenosus* and *Trypea australiensis* (Decapoda:Thalassinidea) in Western Port (southern Australia), determined with multiple stable-isotope analyses. Mar Freshwat Res 48:503-511

Bostrom C, Pittman SJ, Simenstad C, Kneib RT (2011) Seascape ecology of coastal biogenic habitats: advances, gaps, and challenges. Marine Ecology-Progress Series 427:191-217

Boyer K (2003) Riparian mangement for wood in rivers. American Fisheries Society Symposium 37:407-420

Boys CA, Kroon FJ, Glasby TM, Wilkinson K (2012) Improved fish and crustacean passage in tidal creeks following floodgate remediation. Journal of Applied Ecology 49:223-233

Brostoff W, Clarke D (1993) Monitoring marsh development on an island constructed of dredged material in South Carolina's Winyah Bay. WETLANDS RES PROG BULL 3:7-9

Brown CA, Jackson GA, Holt SA, Holt GJ (2005) Spatial and temporal patterns in modeled particle transport to estuarine habitat with comparisons to larval fish settlement patterns. Estuar Coast Shelf Sci 64:33-46

Browne MA, Chapman MG (2011) Ecologically Informed Engineering Reduces Loss of Intertidal Biodiversity on Artificial Shorelines. Environmental Science & Technology 45:8204-8207

Bucher DJ, Saenger P (1991) An inventory of Australian estuaries and enclosed marine waters: an overview of results. Aust Geog Stud 29:370-381

Bulleri F, Chapman MG (2004) Intertidal assemblages on artificial and natural habitats in marinas on the north-west coast of Italy. Marine Biology 145:381-391

Bulleri F, Chapman MG (2010) The introduction of coastal infrastructure as a driver of change in marine environments. Journal of Applied Ecology 47:26-35

Bulleri F, Chapman MG, Underwood AJ (2005) Intertidal assemblages on seawalls and vertical rocky shores in Sydney Harbour, Australia. Austral Ecology 30:655-667

Bunt JS, Boto KG, Boto G (1979) A survey method for estimating potential levels of mangrove forest primary production. Marine Biology 52:123-128

Burchmore JJ, Pollard DA, Bell JD (1984) Community structure and trophic relationships of the fish fauna of an estuarine *Posidonia australis* seagrass habitat in Port. Hacking, New South Wales. Aquatic Botany 18:71--87

Burfeind DD, Tibbetts IR, Udy JW (2009) Habitat preference of three common fishes for seagrass, *Caulerpa taxifolia*, and unvegetated substrate in Moreton Bay, Australia. Environ Biol Fish 84:317–322

Burt J, Bartholomew A, Bauman A, Saif A, Sale PF (2009) Coral recruitment and early benthic community development on several materials used in the construction of artificial reefs and breakwaters. Journal of Experimental Marine Biology and Ecology 373:72-78

Caddy JF (2008) The importance of "Cover" in the life histories of demersal and benthic marine resources: A neglected issue in fisheries assessment and management. Bulletin of Marine Science 83:7

Cappo, M., Alongi, D., Williams, D. and Duke, N. (1998) A review and synthesis of Australian fisheries habitat research: Major threats, issues and gaps in knowledge of coastal and marine fisheries habitats - A prospectus of opportunities for the FRDC Ecosystem Protection Program. Volume 3: Bibliography and information sources Cape Ferguson, Qld., Australia: Australian Institute of Marine Science

Carseldine L, Tibbetts IR (2005) Dietary analysis of the herbivorous hemiramphid *Hyporhamphus regularis ardelio*: an isotopic approach. J Fish Biol 66:1589-1600

Cartamil D, Wegner NC, Kacev D, Ben-Aderet N, Kohin S, Graham JB (2010) Movement patterns and nursery habitat of juvenile thresher sharks Alopias vulpinus in the Southern California Bight. Marine Ecology Progress Series 404:249-258

Cenci E, Pizzolon M, Chimento N, Mazzoldi C (2011) The influence of a new artificial structure on fish assemblages of adjacent hard substrata. Estuarine Coastal and Shelf Science 91:133-149

Chapman MG (2003) Paucity of mobile species on constructed seawalls: effects of urbanization on biodiversity. Marine Ecology-Progress Series 264:21-29

Chapman MG (2006) Intertidal seawalls as habitats for molluscs. Journal of Molluscan Studies 72:247-257

Chapman MG, Blockley DJ (2009) Engineering novel habitats on urban infrastructure to increase intertidal biodiversity. Oecologia 161:625-635

Chapman MG, Underwood AJ (2011) Evaluation of ecological engineering of "armoured" shorelines to improve their value as habitat. Journal of Experimental Marine Biology and Ecology 400:302-313

Cheney D, Oestman R, Volkhardt G, Getz J (1994) Creation of rocky intertidal and shallow subtidal habitats to mitigate for the construction of a large marina in Puget-Sound, Washington. Bulletin of Marine Science 55:772-782

Cheshire AC, Hallam ND (1988) Biomass and density of native stands of Durvillaea potatorum (southern bull-kelp) in south eastern Australia. Mar Ecol Prog Ser 48:277-283

Chigbu P, Sibley T (1994) Relationship between abundance, growth, egg size and fecundity in a landlocked population of longfin smelt, Spirinchus thaleichthys. Journal of Fish Biology 45:1-15

Childs AR, Cowley PD, Naesje TF, Booth AJ, Potts WM, Thorstad EB, Okland F (2008) Do environmental factors influence the movement of estuarine fish? A case study using acoustic telemetry. Estuarine Coastal and Shelf Science 78:227-236

Chittaro PM, Usseglio P, Sale P (2005) Variation in fish density, assemblage composition and relative rates of predation among mangrove, seagrass and coral reef habitats. Environmental Biology of Fishes 72:175-187

Clough B (1998) Mangrove forest productivity and biomass accumulation in Hinchinbrook Channel, Australia. Mangroves and Salt Marshes 2:191–198

Clynick BG (2006) Assemblages of fish associated with coastal marinas in north-western Italy. Journal of the Marine Biological Association of the United Kingdom 86:847-852

Clynick BG, Chapman MG, Underwood AJ (2007) Effects of epibiota on assemblages of fish associated with urban structures. Marine Ecology-Progress Series 332:201-210

Clynick BG, Chapman MG, Underwood AJ (2008) Fish assemblages associated with urban structures and natural reefs in Sydney, Australia. Austral Ecology 33:140-150

Coen LD, Luckenbach MW, Breitburg D (2000) Oyster reefs as essential fish habitat for finfish and decapod crustaceans: A comparison from natural and developing reefs. Journal of Shellfish Research [J Shellfish Res] 19

Coleman MA, Connell SD (2001) Weak effects of epibiota on the abundances of fishes associated with pier pilings in Sydney Harbour. Environ Biol Fish 61:231-239

Collins MR, Rogers SG, Smith TIJ, Moser ML Primary factors affecting sturgeon populations in the southeastern United States: Fishing mortality and degradation of essential habitats. In. Rosenstiel School of Marine and Atmospheric Science

Condini MV, Seyboth E, Vieira JP, Garcia AM (2011) Diet and feeding strategy of the dusky grouper Mycteroperca marginata (Actinopterygii: Epinephelidae) in a man-made rocky habitat in southern Brazil. Neotropical Ichthyology 9:161-168

Connell SD, Glasby TM (1999) Do urban structures influence local abundance and diversity of subtidal epibiota? A case study from Sydney Harbour, Australia. Marine Environmental Research 47:373-387

Connell SD, Irving AD (2008) Integrating ecology with biogeography using landscape characteristics: a case study of subtidal habitat across continental Australia. Journal of Biogeography 35:1608-1621

Connolly R (2005) Modification of saltmarsh for mosquito control in Australia alters habitat use by nekton. Wetlands Ecology and Management 13:149–161

Connolly RM (1994) A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australian estuary. Aust J Mar Freshwat Res 45:1033-1044

Connolly RM (2009) Fish on Australian saltmarshes. In: Saintilan N (ed) Australian Saltmarsh Ecology. CSIRO Publishing, Collingwood

Connolly RM, Currie DR, Danaher KF, Dunning M, Melzer A, Platten JR, Shearer D, Stratford PJ, Teasdale PR, Vandergragt M (2006) Intertidal wetlands of Port Curtis: Ecological patterns and processes and their implications. Technical Report No. 43, CRC for Coastal Zone, Estuary and Waterway Management, Brisbane. In:

Connolly RM, Dalton A, Bass DA (1997) Fish use of an inundated saltmarsh flat in a temperate Australian estuary. Australian Journal of Ecology 22:222-226

Connolly RM, Gorman D, Guest MA (2005a) Movement of carbon among estuarine habitats and its assimilation by invertebrates. Oecologia 144:684-691

Connolly RM, Guest MA, Melville AJ, Oakes JM (2004) Sulfur stable isotopes separate producers in marine food-web analysis. Oecologia 138:161-167

Connolly RM, Hindell JS, Gorman D (2005b) Seagrass and epiphytic algae support nutrition of a fisheries species, *Sillago schomburgkii*, in adjacent intertidal habitats. Mar Ecol Prog Ser 286:69-79

Connolly RM, Schlacher TA, Gaston TF (2009) Stable isotope evidence for trophic subsidy of coastal benthic fisheries by river discharge plumes off small estuaries. Marine Biology Research 5:164–171

Corn L, Copeland C (2010) The Deepwater Horizon oil spill: coastal wetlands and wildlife impacts and response. In: CRS Report for Congress. Congressional Researech Service, Washington, USA

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R, Paruelo J, Raskin R, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387:253-260

Coulson PG, Hesp SA, Potter IC, Hall NG (2005) Comparisons between the biology of two co-occurring species of whiting (Sillaginidae) in a large marine embayment. Environmental Biology of Fishes 73:125-139

Cowen RK, Gawarkiewicz G, Pineda J, Thorrold SR, Werner F (2007) Populaion connectivity in marine sysems: an overview. Oceanography 20:14-21

Crawley KR, Hyndes GA (2007) The role of different types of detached macrophytes in the food and habitat choice of a surf-zone inhabiting amphipod. Mar Biol 151:1433–1443

Crawley KR, Hyndes GA, Ayvazian SG (2006) Influence of different volumes and types of detached macrophytes on fish community structure in surf zones of sandy beaches. Mar Ecol Prog Ser 307:233–246

Crinall SM, Hindell JS (2004) Assessing the Use of Saltmarsh Flats by Fish in a Temperate Australian Embayment. Estuaries 27:728-739

Cui GR, Bax NJ, Punt AE, Knuckey IA (2001) Estimating gill-net selectivity for five species caught in the South East Fishery, Australia. Marine and Freshwater Research 52:691-699

Cuveliers EL, Geffen AJ, Guelinckx J, Raeymaekers JAM, Skadal J, Volckaert FAM, Maes GE (2010) Microchemical variation in juvenile Solea solea otoliths as a powerful tool for studying connectivity in the North Sea. Marine Ecology-Progress Series 401:211-220

Dahlgren C, Eggleston D (2000) Ecological processes underlying ontogenetic habitat shifts in a coral reef fish. Ecology 81:2227-2240

Dahlgren CP, Kellison G, Adams AJ, Gillanders BM, Kendall MS, Layman CA, Ley JA, Nagelkerken I, Serafy JE (2006) Marine nurseries and effective juvenile habitats: concepts and applications. Marine Ecology Progress Series 312:291-295

Dall W, Hill B, Rothlisberg P, Staples D (1990) The biology of the penaeidae. In: Blaxter JHS, Southward AJ (eds) Adv Mar Biol, Book 27

Danna G, Badalamenti F, Gristina M, Pipitone C (1994) Influence of artificial reefs on coastal nekton assemblages of the Gulf of Castellammare (Northwest Sicily). Bulletin of Marine Science 55:418-433

Dantas DV, Barletta M, Lima ARA, Ramos JDA, da Costa MF, Saint-Paul U (2012) Nursery Habitat Shifts in an Estuarine Ecosystem: Patterns of Use by Sympatric Catfish Species. Estuaries Coasts 35:587-602

Darcy MC, Eggleston DB (2005) Do habitat corridors influence animal dispersal and colonization in estuarine systems? Landscape Ecology 20:841-855

Dauble AD, Heppell SA, Johansson ML (2012) Settlement patterns of young-of-the-year rockfish among six Oregon estuaries experiencing different levels of human development. Marine Ecology-Progress Series 448:143-154

Daugherty DJ, Sutton TM (2005) Seasonal Movement Patterns, Habitat Use, and Home Range of Flathead Catfish in the Lower St. Joseph River, Michigan. North American Journal of Fisheries Management 25:256-269

Davidson TM, Rumrill SS, Shanks AL (2008) Colonization and substratum preference of an introduced burrowing crustacean in a temperate estuary. Journal of Experimental Marine Biology and Ecology 354:144-149

Davis B, Johnston R, Baker R, Sheaves M (2012) Fish utilisation of wetland nurseries with complex hydrological connectivity. PLoS ONE 7:e49107

Davis TLO (1986b) Migration patterns in barramundi, Lates calcarifer (Bloch), in Van Diemen Gulf, Australia, with estimates of fishing mortality in specific areas. Fisheries Research (Amsterdam) 4(3-4) 1986:243-258

de Lestang S, Platell ME, Potter IC (2000) Dietary composition of the blue swimmer crab *Portunus pelagicus* L. Does it vary with body size and shell state and between estuaries? J Exp Mar Biol Ecol 246:241-257

Deegan L (1993) Nutrient and energy transport between estuaries and coastal marine ecosystems by fish migrations. Can J Fish Aquat Sci 50:74-79

Deegan L, Hughes J, Rountree R (2000) Salt marsh ecosystem support of marine transient species. In: Weinstein M (ed) Concepts and controversies in tidal marsh ecology. Kluwer academic publishers, London

Dimmlich WF, Ward TM, Breed WG (2009) Spawning dynamics and biomass estimates of an anchovy Engraulis australis population in contrasting gulf and shelf environments. Journal of Fish Biology 75:1560-1576

Doherty P, Williams D (1988) The replenishment of coral reef fish populations. Oceanography and Marine Biology:487-551

Dorenbosch M (2006) Connectivity between fish assemblages o seagrass beds, mangroves and coral reefs. PhD, Raboud University Nijmegen, Nijmegen

Dorenbosch M, Grol MGG, Christianen MJA, Nagelkerken I, van der Velde G (2005) Indo-Pacific seagrass beds and mangroves contribute to fish density coral and diversity on adjacent reefs. Marine Ecology-Progress Series 302:63-76

Dorenbosch M, Verberk W, Nagelkerken I, van der Velde G (2007) Influence of habitat configuration on connectivity between fish assemblages of Caribbean seagrass beds, mangroves and coral reefs. Marine Ecology-Progress Series 334:103-116

Dorenbosch M, Verweij MC, Nagelkerken I, Jiddawi N, van der Velde G (2004) Homing and daytime tidal movements of juvenile snappers (Lutjanidae) between shallow-water nursery habitats in Zanzibar, western Indian Ocean. Environmental Biology of Fishes 70:203-209

Doropoulos C, Hyndes GA, Lavery PS, Tuya F (2009) Dietary preferences of two seagrass inhabiting gastropods: Allochthonous vs autochthonous resources. Estuarine Coastal and Shelf Science 83:13–18

Downs S, Simon A (2001) Fluvial geomorphological analysis of the recruitment of large woody debris in the Yalobusha River network, Central Mississippi, USA Geomorphology 37:65-91

Duarte CM (2002) The future of seagrass meadows. Environmental Conservation 29:192-206

Duffy-Anderson JT, Manderson JP, Able KW (2003) A characterization of juvenile fish assemblages around man-made structures in the New York New Jersey Harbor Estuary, USA. Bulletin of Marine Science 72:877-889

Duke N (2006) Australia's Mangroves. University of Queensland press. Brisbane.

Duke NC, Meynecke JO, Dittmann S, Ellison AM, Anger K, Berger U, Cannicci S, Diele K, Ewel KC, Field CD, Koedam N, Lee SY, Marchand C, Nordhaus I, Dahdouh-Guebas F (2007) A world without mangroves? Science 317:41-42

Duong HLS, Fairweather PG (2011) Effects of sandy beach cusps on wrack accumulation, sediment characteristics and macrofaunal assemblages. Austral Ecology 36:733-744

Duong S (2008) Investigating the ecological implications of wrack removal on South Australian sandy beaches.

Edgar GJ, Barrett NS, Graddon DJ, Last PR (2000) The conservation significance of estuaries: a classification of Tasmanian estuaries using ecological, physical and demographic attributes as a case study. Biol Conserv 92:383-397

Edgar GJ, Barrett NS, Graddon DJ, Last PR (2000) The conservation significance of estuaries: a classification of Tasmanian estuaries using ecological, physical and demographic attributes as a case study. Biological Conservation 92:383-397

Edgar GJ, Shaw C (1995) The production and trophic ecology of shallow-water fish assemblages in southern Australia .1. Species richness, size-structure and production of fishes in Western Port, Victoria. Journal of Experimental Marine Biology and Ecology 194:53-81

Elliott M, Whitfield AK, Potter IC, Blaber SJM, Cyrus DP, Nordlie FG, Harrison TD (2007) The guild approach to categorizing estuarine fish assemblages: a global review. Fish and Fisheries 8(3), September 2007: 241-268

Ellis T, Gibson RN (1995) Size-selective predation of 0-group flatfishes in a Scottish coastal nursery ground. Mar Ecol Prog Ser 127:27-37

Eriksson BK, Sieben K, Eklof J, Ljunggren L, Olsson J, Casini M, Bergstrom U (2011) Effects of Altered Offshore Food Webs on Coastal Ecosystems Emphasize the Need for Cross-Ecosystem Management. Ambio 40:786-797

Erskine WD, Webb AA (2003) Desnagging to resnagging: new directions in river rehabilitation in southeastern Australia. River Res Appl 19:233-249

Espinoza M, Farrugia TJ, Lowe CG (2011) Habitat use, movements and site fidelity of the gray smooth-hound shark (Mustelus californicus Gill 1863) in a newly restored southern California estuary. Journal of Experimental Marine Biology and Ecology 401:63-74

Evans RD, Russ GR, Kritzer JP (2008) Batch fecundity of Lutjanus carponotatus (Lutjanidae) and implications of no-take marine reserves on the Great Barrier Reef, Australia. Coral Reefs 27:179-189

Everett RA, Ruiz GM (1993) Coarse woody debris as a refuge from predation in aquatic communities - an experimental test. Oecologia 93:475-486

Ewing GP, Lyle JM (2009) Reproductive dynamics of redbait, Emmelichthys nitidus (Emmelichthyidae), from south-eastern Australia. Fisheries Research 97:206-215

Fairclough DV, Dimmlich WF, Potter IC (2000a) Length and age compositions and growth rates of the Australian herring Arripis georgiana in different regions. Marine and Freshwater Research 51:631-640

Fairclough DV, Dimmlich WF, Potter IC (2000b) Reproductive biology of the Australian herring Arripis georgiana. Marine and Freshwater Research 51:619-630

Farrugia TJ, Espinoza M, Lowe CG (2011) Abundance, habitat use and movement patterns of the shovelnose guitarfish (Rhinobatos productus) in a restored southern California estuary. Marine and Freshwater Research 62:648-657

Faunce CH, Serafy JE (2006) Mangroves as fish habitat: 50 years of field studies. Mar Ecol Prog Ser 318:1-18

Feary DA, Burt JA, Bartholomew A (2011) Artificial marine habitats in the Arabian Gulf: Review of current use, benefits and management implications. Ocean & Coastal Management 54:742-749

Ferrell DJ, Bell JD (1991) Differences among assemblages of fish associated with *Zostera capricorni* and bare sand over a large spatial scale. Mar Ecol Prog Ser 72:15-24

Feyrer F, Nobriga ML, Sommer TR (2007) Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Sciences 64:723-734

Fisher R, O'Leary RA, Low-Choy S, Mengersen K, Caley M (2012) A software tool for elicitation of expert knowledge about species richness or similar counts. Environmental Modelling & Software 30:1-14

Floyd TA, MacInnis C, Taylor BR (2009) Effects of artificial woody structures on Atlantic salmon habitat and populations in a Nova Scotia stream. River Res Appl 25:272-282

Foden J, Rogers SI, Jones AP (2009) Recovery rates of UK seabed habitats after cessation of aggregate extraction. Marine Ecology Progress Series 390:15-26

Ford JR, Williams RJ, Fowler AM, Cox DR, Suthers IM (2010) Identifying critical estuarine seagrass habitat for settlement of coastally spawned fish. Mar Ecol Prog Ser 408:181-193

Fowler AJ, McLeay L, Short DA (2000) Spatial variation in size and age structures and reproductive characteristics of the King George whiting (Percoidei : Sillaginidae) in South Australian waters. Marine and Freshwater Research 51:11-22

Fowler AJ, Steer MA, Jackson WB, Lloyd MT (2008) Population characteristics of southern sea garfish (Hyporhamphus melanochir, Hemiramphidae) in South Australia. Marine and Freshwater Research 59:429-443

Franca S, Vasconcelos RP, Fonseca VF, Tanner SE, Reis-Santos P, Costa MJ, Cabral HN (2012) Predicting fish community properties within estuaries: Influence of habitat type and other environmental features. Estuarine Coastal and Shelf Science 107:22-31

Freeman S, Mackinson S, Flatt R (2004) Diel patterns in the habitat utilisation of sandeels revealed using integrated acoustic surveys. Journal of Experimental Marine Biology and Ecology 305:141-154

Freese L, Auster PJ, Heifetz J, Wing BL (1999) Effects of trawling on seafloor habitat and associated invertebrate taxa in the Gulf of Alaska. Marine Ecology Progress Series 182:119-126

Fry B (2008) Open bays as nurseries for Louisiana brown shrimp. Estuaries Coasts 31:776-789

Fry B, Scalan RS, Parker PL (1983) $^{13}C/^{12}C$ ratios in marine food webs of the Torres Strait, Queensland. Mar Freshwat Res 34:707-715

Fujita T, Kitagawa D, Okuyama Y, Jin Y, Ishito Y, Inada T (1996) Comparison of fish assemblages among an artificial reef, a natural reef and a sandy-mud bottom site on the shelf off Iwate, northern Japan. Environ Biol Fish 46:351-364

Fulton E, Kault D, Mapstone B, Sheaves M (1999) Spawning season influences on commercial catch rates: computer simulations and Plectropomus leopardus, a case in point. Canadian Journal of Fisheries and Aquatic Sciences 56:1096-1108

Fulton EA, Smith ADM (2004) Lessons learnt from a comparison of three ecosystem models for Port Phillip Bay, Australia. African Journal of Marine Science 26:219-243

Gage JD, Roberts JM, Hartley JR, Humphery JD (2005) Potential impacts of deep-sea trawling on the benthic ecosystem along the Northern European continental margin: A review. In: Barnes BW, Thomas JP (eds) Benthic Habitats and the Effects of Fishing, Book 41

Gaspar MB, Leitao F, Santos MN, Chicharo L, Dias MD, Chicharo A, Monteiro CC (2003) A comparison of direct macrofaunal mortality using three types of clam dredges. ICES Journal of Marine Science 60:733-742

Gerhard M, Reich M (2000) Restoration of streams with large wood: Effects of accumulated and built-in wood on channel morphology, habitat diversity and aquatic fauna. Int Rev Hydrobiol 85:123-137

Ghanbarifardi M, Malek M (2009) Distribution, diversity, and abundance of rocky intertidal fishes in the Persian Gulf and Gulf of Oman, Iran. Marine Biology Research 5:496-502

Gillanders BM (2005) Using elemental chemistry of fish otoliths to determine connectivity between estuarine and coastal habitats. Estuar Coast Shelf Sci 64:47-57

Gillanders BM (2006) Seagrasses, Fish, and Fisheries. In: Larkum AWD, Orth RJ, Duarte CM (eds) Seagrasses: biology, ecology and conservation. Springer, Dordrecht

Gillanders BM, Able KW, Brown JA, Eggleston DB, Sheridan PF (2003) Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: An important component of nurseries. Marine ecology progress series 247:281-295

Gillanders BM, Kingsford MJ (1996) Elements in otoliths may elucidate the contribution of estuarine recruitment to sustaining coastal reef populations of a temperate reef fish. Mar Ecol Prog Ser 141:13-20

Gillson J, Scandol J, Suthers I (2009) Estuarine gillnet fishery catch rates decline during drought in eastern Australia. Fish Res 99:26–37

Glasby TM (2000) Surface composition and orientation interact to affect subtidal epibiota. Journal of Experimental Marine Biology and Ecology 248:177-190

Glasby TM, Connell SD (2001) Orientation and position of substrata have large effects on epibiotic assemblages. Marine Ecology-Progress Series 214:127-135

Goodsell PJ, Chapman MG, Underwood AJ (2007) Differences between biota in anthropogenically fragmented habitats and in naturally patchy habitats. Marine Ecology-Progress Series 351:15-23

Gray CA, Chick RC, McElligott DJ (1998) Diel changes in assemblages of fishes associated with shallow seagrass and bare sand. Estuarine Coastal and Shelf Science 46:849-859

Gray CA, McElligott DJ, Chick RC (1996) Intra- and Inter-estuary Differences in Assemblages of Fishes Associated with Shallow Seagrass and Bare Sand. Mar Freshwat Res 47:723-735

Gray CA, Miskiewicz AG (2000) Larval fish assemblages in south–east Australian coastal waters: seasonal and spatial structure. Estuarine, Coastal and Shelf Science 50:549-570

Gray CA, Rotherham D, Johnson DD (2011) Consistency of temporal and habitat-related differences among assemblages of fish in coastal lagoons. Estuarine Coastal and Shelf Science 95:401-414

Green DS, Chapman MG, Blockley DJ (2012) Ecological consequences of the type of rock used in the construction of artificial boulder-fields. Ecological Engineering 46:1-10

Griffin RK, Dadswell MJ, Klauda RJ, Moffitt CM, Saunders RL, Rulifson RA, Cooper JE (1987) Life history, distribution, and seasonal migration of barramundi in the Daly River, Northern Territory, Australia, Vol

Griffiths SP (2001) Diel variation in the seagrass ichthyofaunas of three intermittently open estuaries in south-eastern Australia: implications for improving fish diversity assessments. Fisheries Management and Ecology 8:123-140

Grol MGG, Nagelkerken I, Rypel AL, Layman CA (2011) Simple ecological trade-offs give rise to emergent cross-ecosystem distributions of a coral reef fish. Oecologia 165:79-88

Guest M, Connolly R (2006) Movement of carbon among estuarine habitats: the influence of saltmarsh patch size. Mar Ecol Prog Ser 310:15-24

Guest M, Connolly RM, Lee SY, Loneragan NR, Breitfuss MJ (2006) Mechanism for the small-scale movement of carbon among estuarine habitats: organic matter transfer not crab movement. Oecologia 148:88-96

Guest MA, Connolly RM (2004) Fine-scale movement and assimilation of carbon in saltmarsh and mangrove habitat by resident animals. Aquat Ecol 38:599-609

Guyonnet B, Grall J, Vincent B (2008) Modified otter trawl legs to reduce damage and mortality of benthic organisms in North East Atlantic fisheries (Bay of Biscay). Journal of Marine Systems 72:2-16

Hadwen WL, Russell GL, Arthington AH (2007) Gut content- and stable isotope-derived diets of four commercially and recreationally important fish species in two intermittently open estuaries. Mar Freshwat Res 58:363–375

Hammerschlag N, Morgan AB, Serafy JE (2010) Relative predation risk for fishes along a subtropical mangrove-seagrass ecotone. Marine Ecology Progress Series 401:259-267

Hannah RW, Blume MTO (2012) Tests of an experimental unbaited video lander as a marine fish survey tool for high-relief deepwater rocky reefs. Journal of Experimental Marine Biology and Ecology 430:1-9

Hansen G (1984) Accumulations of macrophyte wrack along sandy beaches in Western Australia: biomass, decomposition rate and significance in supporting nearshore production. Ph.D. Thesis, University of Western Australia, 93 pp.

Harman N, Harvey ES, Kendrick GA (2003) Differences in fish assemblages from different reef habitats at Hamelin Bay, south-western Australia. Marine and Freshwater Research 54:177-184

Harvey ES, Butler JJ, McLean DL, Shand J (2012) Contrasting habitat use of diurnal and nocturnal fish assemblages in temperate Western Australia. Journal of Experimental Marine Biology and Ecology 426:78-86

Harvey ES, Cappo M, Butler JJ, Hall N, Kendrick GA (2007) Bait attraction affects the performance of remote underwater video stations in assessment of demersal fish community structure. Marine Ecology Progress Series 350:245-254

Haywood MDE, Vance DJ, Loneragan NR (1995) Seagrass and algal beds as nursery habitats for tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) in a tropical Australian estuary. Mar Biol 122:213 - 223

Heales DS, Brewer DT, Wang YG (2000) Subsampling multi-species trawl catches from tropical northern Australia: Does it matter which part of the catch is sampled? Fisheries Research 48:117-126

Heck KL, Carruthers TJB, Duarte CM, Hughes AR, Kendrick G, Orth RJ, Williams SW (2008) Trophic transfers from seagrass meadows subsidize diverse marine and terrestrial consumers Ecosystems 11:1198–1210

Heck KL, Hays C, Orth RJ (2003) A critical evaluation of the nursery role hypothesis for seagrass meadows. Marine ecology progress series 253:123-136

Heck KL, Hays G, Orth RJ (2003) Critical evaluation of the nursery role hypothesis for seagrass meadows. Marine Ecology-Progress Series 253:123-136

Heithaus ER, Heithaus PA, Heithaus MR, Burkholder D, Layman CA (2011) Trophic dynamics in a relatively pristine subtropical fringing mangrove community. Mar Ecol Prog Ser 428:49-61

Heithaus MR (2005) Habitat use and group size of pied cormorants (Phalacrocorax varius) in a seagrass ecosystem: possible effects of food abundance and predation risk. Marine Biology 147:27-35

Hesp SA, Potter IC, Hall NG (2002) Age and size composition, growth rate, reproductive biology, and habitats of the West Australian dhufish (Glaucosoma hebraicum) and their relevance to the management of this species. Fishery Bulletin 100:214-227

Heupel MR, Simpfendorfer CA (2008) Movement and distribution of young bull sharks Carcharhinus leucas in a variable estuarine environment. Aquatic Biology 1:277-289

Heupel MR, Simpfendorfer CA, Collins AB, Tyminski JP (2006) Residency and movement patterns of bonnethead sharks, Sphyrna tiburo, in a large Florida estuary. Environmental Biology of Fishes 76:47-67

Heupel MR, Yeiser BG, Collins AB, Ortega L, Simpfendorfer CA (2010) Long-term presence and movement patterns of juvenile bull sharks, Carcharhinus leucas, in an estuarine river system. Marine and Freshwater Research 61:1-10

Heyman WD, Granados-Dieseldorff P (2012) The voice of the fishermen of the Gulf of Honduras: Improving regional fisheries management through fisher participation. Fisheries Research (Amsterdam) 125-126:129-148

Hilborn R, Walters CJ, Ludwig D (1995) Sustainable exploitation of renewable resources. Annual Review of Ecology and Systematics 26:45-67

Hill BJ (1976) Natural food, foregut clearance-rate and activity of the crab Scylla serrat. Mar Biol 34:109-116

Hily C, Le Loc'h F, Grall J, Glemarec M (2008) Soft bottom macrobenthic communities of North Biscay revisited: Long-term evolution under fisheries-climate forcing. Estuarine Coastal and Shelf Science 78:413-425

Hindell JS (2006) Assessing the trophic link between seagrass habitats and piscivorous fishes. Mar Freshwat Res 57:121-131

Hindell JS (2007) Determining patterns of use by black bream Acanthopagrus butcheri (Munro, 1949) of re-established habitat in a south-eastern Australian estuary. J Fish Biol 71:1331-1346

Hindell JS, Jenkins GP (2005) Assessing patterns of fish zonation in temperate mangroves, with emphasis on evaluating sampling artefacts. Marine Ecology Progress Series 290:193-205

Hobday AJ, Campbell G (2009) Topographic preferences and habitat partitioning by pelagic fishes off southern Western Australia. Fisheries Research 95:332-340

Hobday AJ, Hartog JR, Spillman CM, Alves O (2011) Seasonal forecasting of tuna habitat for dynamic spatial management. Canadian Journal of Fisheries and Aquatic Sciences 68:898-911

Hood W (2007) Large Woody Debris influences Vegetation Zonation in an Oligohaline Tidal Marsh. Estuaries Coasts 30:441-450

Howard R (1984) The trophic ecology of caridean shrimps in an eelgrass community. Aquatic Botany 18:155-174

Hughes JM, Stewart J (2006) Reproductive biology of three commercially important Hemiramphid species in south-eastern Australia. Environmental Biology of Fishes 75:237-256

Hughes JM, Stewart J, Kendall BW, Gray CA (2008) Growth and reproductive biology of tarwhine Rhabdosargus sarba (Sparidae) in eastern Australia. Marine and Freshwater Research 59:1111-1123

Humphries P, King AJ, Koehn JD (1999) Fish, Flows and Flood Plains: Links between Freshwater Fishes and their Environment in the Murray-Darling River System, Australia. Environmental Biology of Fishes 56:129-151

Hunt TL, Ford JR, Swearer SE (2011) Ecological determinants of recruitment to populations of a temperate reef fish, Trachinops caudimaculatus (Plesiopidae). Marine and Freshwater Research 62:502-509

Hyndes G, Hanson C (2009) Ecological Interactions in Coastal Marine Ecosystems: Trophodynamics. Final report on the outcomes from a Strategic Research Fund for the Marine Environment (SRFME) collaborative project. Centre for Marine Ecosystems Research, Edith Cowan University, Joondalup, Western Australia. In:

Hyndes GA, Lavery PS, Doropoulos C (2012) Dual processes for cross-boundary subsidies: incorporation of nutrients from reef-derived kelp into a seagrass ecosystem. Mar Ecol Prog Ser 445:97–107

Hyndes GA, Platell ME, Potter IC, Lenanton RCJ (1998) Age composition, growth, reproductive biology, and recruitment of King George whiting, Sillaginodes punctata, in coastal waters of southwestern Australia. Fishery Bulletin 96:258-270

Hyndes GA, Platell ME, Potter IC, Lenanton RCJ (1999) Does the composition of the demersal fish assemblages in temperate coastal waters change with depth and undergo consistent seasonal changes? Marine Biology 134:335-352

Hyndes GA, Potter IC, Lenanton RCJ (1996) Habitat partitioning by whiting species (Sillaginidae) in coastal waters. Environmental Biology of Fishes 45:21-40

Ince R, Hyndes GA, Lavery PS, Vanderklift MA (2007) Marine macrophytes directly enhance abundances of sandy beach fauna through provision of food and habitat. Estuarine Coastal and Shelf Science 74:77-86

Ivesa L, Chapman MG, Underwood AJ, Murphy RJ (2010) Differential patterns of distribution of limpets on intertidal seawalls: experimental investigation of the roles of recruitment, survival and competition. Marine Ecology-Progress Series 407:55-69

Jackson AC, Chapman MG, Underwood AJ (2008) Ecological interactions in the provision of habitat by urban development: whelks and engineering by oysters on artificial seawalls. Austral Ecology 33:307-316

Jackson G, Cheng YW, Wakefield CB (2012) An evaluation of the daily egg production method to estimate spawning biomass of snapper (Pagrus auratus) in inner Shark Bay, Western Australia, following more than a decade of surveys 1997-2007. Fisheries Research 117:22-34

Jackson G, Norriss JV, Mackie MC, Hall NG (2010) Spatial variation in life history characteristics of snapper (Pagrus auratus) within Shark Bay, Western Australie. New Zealand Journal of Marine and Freshwater Research 44:1-15

Jelbart JE, Ross PM, Connolly RM (2007) Fish assemblages in seagrass beds are influenced by the proximity of mangrove forests. Marine Biology 150:993-1002

Jenkins GP (2004) The ecosystem effects of abalone fishing: a review. Marine and Freshwater Research 55:545-552

Jenkins GP, Hamer PA (2001) Spatial variation in the use of seagrass and unvegetated habitats by post-settlement King George whiting (Percoidei: Sillaginidae) in relation to meiofaunal distribution and macrophyte structure. Mar Ecol Prog Ser 224:219–229

Jenkins GP, May HMA (1994) Variation in settlement and larval duration of King George whiting, *Sillaginodes punctata* (Sillaglnidae], in Swan Bay, Victoria, Australia. Bulletin of Marine Science 54:281-296

Jenkins GP, May HMA, Wheatley MJ, Holloway MG (1997) Comparison of Fish Assemblages Associated with Seagrass and Adjacent Unvegetated Habitats of Port Phillip Bay and Corner Inlet, Victoria, Australia, with Emphasis on Commercial Species. Estuarine Coastal and Shelf Science 44:569–588

Jenkins GP, Wheatley MJ (1998) The influence of habitat structure on nearshore fish assemblages in a southern Australian embayment: Comparison of shallow seagrass, reef-algal and unvegetated sand habitats, with emphasis on their importance to recruitment. J Exp Mar Biol Ecol 221:147–172

Jenkins SR, Beukers-Stewart BD, Brand AR (2001) Impact of scallop dredging on benthic megafauna: a comparison of damage levels in captured and non-captured organisms. Marine Ecology Progress Series 215:297-301

Jernakoff P (1987) Foraging patterns of juvenile western rock lobsters *Panulirus cygnus* George. J Exp Mar Biol Ecol 113:125–144

Joll LM, Phillips BF (1984) Natural diet and growth of juvenile western rock lobsters *Panulirus cygnus* George. J Exp Mar Biol Ecol 75:145–169

Kaiser MJ, Spencer BE (1996) The effects of beam-trawl disturbance on infaunal communities in different habitats. Journal of Animal Ecology 65:348-358

Kanandjembo AN, Potter IC, Platell ME (2001) Abrupt shifts in the fish community of the hydrologically variable upper estuary of the Swan River. Hydrological Processes 15:2503-2517

Keane JP, Neira FJ (2008) Larval fish assemblages along the south-eastern Australian shelf: linking mesoscale non-depth-discriminate structure and water masses. Fisheries Oceanography 17:263-280

Kearney RE, Andrew NL, West RJ (1996) Some issues in the management of Australia's marine and coastal fisheries resources. Ocean & Coastal Management 33:133-146

Kelleway J, Williams RJ, Laegdsgaard P (2008) Mapping, assessment and monitoring of saltmarshes. In: Saintilan N (ed) Australian Saltmarsh Ecology. CSIRO Publishing, Collingwood

Kendall BW, Gray CA (2009) Reproduction, age and growth of Sillago maculata in south-eastern Australia. Journal of Applied Ichthyology 25:529-536

Kirby DS, Abraham ER, Uddstrom ER, Uddstrom MJ, Dean H (2003) Tuna schools/aggregations in surface longline data 1993-98. New Zealand Journal of Marine and Freshwater Research 37:633-644

Kirkman H (1997) Seagrasses of Australia. State of the Environment Technical Paper Series (Estuaries and the Sea). Department of the Environment, Canberra.

Kirkman H, Kendrick GA (1997) Ecological significance and commercial harvesting of drifting and beachcast macroalgae and seagrasses in Australia: a review. Journal of Applied Phycology 9:311–326

Kloskowski J (2011) Consequences of the size structure of fish populations for their effects on a generalist avian predator. Oecologia 166:517-530

Klumpp D, Nichols P (1983) A study of food chains in seagrass communities II. Food of the rock flathead, Platycephalus laevigatus Cuvier, a major predator in a Posidonia australis seagrass bed. Aust J Mar Freshwat Res 34: 745-754

Klumpp DW, Howard, R.K. & Pollard, D.A. (1989) Trophodynamics and nutritional ecology of seagrass communities. In: Larkum AWD, McComb AJ, Shepherd SA (eds) Biology of Seagrasses: A Treatise on the Biology of Seagrasses with Special Reference to the Australian Region. Elsevier, Amsterdam

Knip DM, Heupel MR, Simpfendorfer CA (2012a) Evaluating marine protected areas for the conservation of tropical coastal sharks. Biological Conservation 148:200-209

Knip DM, Heupel MR, Simpfendorfer CA (2012b) Habitat use and spatial segregation of adult spottail sharks Carcharhinus sorrah in tropical nearshore waters. Journal of Fish Biology 80:767-784

Knip DM, Heupel MR, Simpfendorfer CA, Tobin AJ, Moloney J (2011) Wet-season effects on the distribution of juvenile pigeye sharks, Carcharhinus amboinensis, in tropical nearshore waters. Marine and Freshwater Research 62:658-667

Koehn JD, Hobday AJ, Pratchett MS, Gillanders BM (2011) Climate change and Australian marine and freshwater environments, fishes and fisheries: synthesis and options for adaptation. Marine and Freshwater Research 62:1148-1164

Koenig CC, Coleman FC, Grimes CB, Fitzhugh GR, Scanlon KM, Gledhill CT, Grace M (2000) Protection of fish spawning habitat for the conservation of warm-temperate reef-fish fisheries of shelf-edge reefs of Florida. Bulletin of Marine Science 66:593-616

Kritzer JP (2004) Sex-specific growth and mortality, spawning season, and female maturation of the stripey bass (Lutjanus carponotatus) on the Great Barrier Reef. Fishery Bulletin 102:94-107

Kruck NC, Chargulaf CA, Saint-Paul U, Tibbetts IR (2009) Early post-settlement habitat and diet shifts and the nursery function of tidepools during *Sillago* spp. recruitment in Moreton Bay, Australia. Mar Ecol Prog Ser 384:207-219

Laegdsgaard P, Johnson CR (1995) Mangrove habitats as nurseries: unique assemblages of juvenile fish in subtropical mangroves in eastern Australia. Marine Ecology Progress Series 126:67-81

Last PR, White WT, Gledhill DC, Hobday AJ, Brown R, Edgar GJ, Pecl G (2011) Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Global Ecology and Biogeography 20:58-72

Le Quesne WJF (2000) Nekton utilisation of intertidal estuarine marshes in the Knysna Estuary. Transactions of the Royal Society of South Africa 55:205-214

Lee Long WJ, Mellors JE, Coles RG (1993) Seagrasses between Cape York and Hervey Bay, Queensland, Australia. Aust J Mar Freshwat Res 44:19-31

Lee SY (2004) Relationship between mangrove forests and prawn production: a re-evaluation. Marine Biology 145:943-949

Lenanton RC, Ayvazian SG, Pearce AF, Steckis RA, Young GC (1996) Tailor (Pomatomus saltatrix) off Western Australia: Where does it spawn and how are the larvae distributed? Marine and Freshwater Research 47:337-346

Lenanton RCJ (1982) Alternative non-estuarine nursery habitats for some commercially and recreationally important fish of south-western Australia. Aust J Mar Freshwat Res 33

Lenanton RCJ, Caputi N (1989) The roles of food supply and shelter in the relationship between fishes, in particular *Cnidoglanis macrocephalus* (Valenciennes), and detached macrophytes in the surf zone of sandy beaches. J Exp Mar Biol Ecol 128:165–176

Lenanton RCJ, Potter IC (1987) Contribution of Estuaries to Commercial Fisheries in Temperate Western Australia and the Concept of Estuarine Dependence. Estuaries 10:28-35

Lenanton RCJ, Robertson AI, Hansen JA (1982) Nearshore Accumulations of Detached Macrophytes as Nursery Areas for Fish. Mar Ecol Prog Ser 9:51-57

Leonel RMV, Lopes S, Aversari M (2002) Distribution of wood-boring bivalves in the Mamanguape River estuary, Paraiba, Brazil. Journal of the Marine Biological Association of the United Kingdom 82:1039-1040

Levin PS, Stunz GW (2005) Habitat triage for exploited fishes: Can we identify ‘‘Essential Fish Habitat?’’. Estuarine, Coastal and Shelf Science 64:70-78

Lindner MJ, Cook HL (1970) Synopsis of biological data on the white shrimp *Penaeus setiferus* (Linnaeus) 1767. FAO Fisheries Synopsis 101. FAO Fish. Rep. 4: 1439-1469.

Linke TE, Platell ME, Potter IC (2001) Factors influencing the partitioning of food resources among six fish species in a large embayment with juxtaposing bare sand and seagrass habitats. J Exp Mar Biol Ecol 266:193-217

Lipcius RN, Seitz RD, Goldsborough WJ, Montane MM, Stockhausen WT (2001) A deepwater dispersal corridor for adult female blue crabs in Chesapeake Bay, Vol 17

Loneragan NR, Bunn SE (1999) River flows and estuarine ecosystems: implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. Austral Ecology 24:431-440

Loneragan NR, Bunn SE, Kellaway DM (1997) Are mangroves and seagrasses sources of organic carbon for penaeid prawns in a tropical Australian estuary? A multiple stable-isotope study. Mar Biol 130:289-300

Loneragan NR, Kenyon RA, Haywood MDE, Staples DJ (1994) Population dynamics of juvenile tiger prawns (Penaeus esculentus and P. semisulcatus) in seagrass habitats of the western Gulf of Carpentaria, Australia. Marine Biology 119:133-143

Longmore A (2002) Identifying important food sources for fish in Western Port Bay.

Lopez-Duarte PC, Carson HS, Cook GS, Fodrie FJ, Becker BJ, DiBacco C, Levin LA (2012) What Controls Connectivity? An Empirical, Multi-Species Approach. Integrative and Comparative Biology 52:511-524

Lotze HK, Lenihan HS, Bourque BJ, Bradbury RH, Cooke RG, Kay MC, Kidwell SM, Kirby MX, Peterson CH, Jackson JBC (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312:1806-1809

Lowry MB, Suthers IM (1998) Home range, activity and distribution patterns of a temperate rocky-reef fish, Cheilodactylus fuscus. Marine Biology 132:569-578

MacArthur LD, Hyndes GA (2007) Varying foraging strategies of Labridae in seagrass habitats: Herbivory in temperate seagrass meadows? Journal of Experimental Marine Biology and Ecology 340:247-258

MacArthur LD, Phillips DL, Hyndes GA, Hanson CE, Vanderklift MA (2011) Habitat surrounding patch reefs influences the diet and nutrition of the western rock lobster. Mar Ecol Prog Ser 436:191–205

MacInnis C, Floyd TA, Taylor BR (2008) Large Woody Debris Structures and Their Influence on Atlantic Salmon Spawning in a Stream in Nova Scotia, Canada. North American Journal of Fisheries Management 28:781-791

Mackie MC, Lewis PD, Gaughan DJ, Newman SJ (2005) Variability in spawning frequency and reproductive development of the narrow-barred Spanish mackerel (Scomberomorus commerson) along the west coast of Australia. Fishery Bulletin 103:344-354

Madrid-Vera J, Amezcua F, Morales-Bojorquez E (2007) An assessment approach to estimate biomass of fish communities from bycatch data in a tropical shrimp-trawl fishery. Fisheries Research 83:81-89

Malecha PW, Stone RP (2009) Response of the sea whip Halipteris willemoesi to simulated trawl disturbance and its vulnerability to subsequent predation. Marine Ecology Progress Series 388:197-206

Matsuzaki SS, Terui A, Kodama K, Tada M, Yoshida T, Washitani I (2011) Influence of connectivity, habitat quality and invasive species on egg and larval distributions and local abundance of crucian carp in Japanese agricultural landscapes. Biological Conservation 144:2081-2087

Mazumder D, Saintilan N, Williams RJ (2006) Trophic relationships between itinerant fish and crab larvae in a temperate Australian saltmarsh. Mar Freshwat Res 57:193–199

McBride RS, MacDonald TC, Matheson RE, Jr., Rydene DA, Hood PB (2001) Nursery habitats for ladyfish, Elops saurus, along salinity gradients in two Florida estuaries. Fishery Bulletin [Fish Bull] 99:443-458

McCulloch M, Cappo M, Aumend J, Muller W (2005) Tracing the life history of individual barramundi using laser ablation MC_ICP_MS Sr-isotope and SR/Ba ratios in otoliths. Marine and Freshwater Research 56:637-644

McIvor CC, Odum WE (1988) Food, predation risk, and microhabitat selection in a marsh fish assemblage. Ecology 69:1341-1351

McKinnon S, Sheppard R, Beumer J (2003) Fish Habitat Area Selection and Assessment: Departmental Proceedures, Queensland Department of Primary Industries, Fish Habitat Management Operational Policy FHMOP 007. In. Queensland Department of Primary Industries, Brisbane

McLachlan A (1985) The biomass of macro- and interstitial fauna on clean and wrack-covered beaches in Western Australia. Estuarine Coastal and Shelf Science 21:587–599

McLachlan A, Brown AC (2006) Ecology of sandy shores. Elsevier, Amsterdam.

McMahon KW, Berumen ML, Mateo I, Elsdon TS, Thorrold SR (2011a) Carbon isotopes in otolith amino acids identify residency of juvenile snapper (Family: Lutjanidae) in coastal nurseries. Coral Reefs 30:1135-1145

McMahon KW, Fogel ML, Johnson BJ, Houghton LA, Thorrold SR (2011b) A new method to reconstruct fish diet and movement patterns from delta C-13 values in otolith amino acids. Can J Fish Aquat Sci 68:1330-1340

Melville AJ, Connolly RM (2003) Spatial analysis of stable isotope data to determine primary sources of nutrition for fish. Oecologia 136:499-507

Melville AJ, Connolly RM (2005) Food webs supporting fish over subtropical mudflats are based on transported organic matter not in situ microalgae. Marine Biology 148:363-371

Meynecke J-O, Lee SY, Duke NC, Warnken J (2006) Effect of rainfall as a component of climate change on estuarine fish production in Queensland, Australia. Estuarine Coastal and Shelf Science 69:491-504

Micheli F (1993) Feeding ecology of mangrove crabs in North Eastern Australia: mangrove litter consumption by *Sesarma messa* and *Sesarma smithii*. J Exp Mar Biol Ecol 171:165-186

Micheli F, Peterson CH (1999) Estuarine vegetated habitats as corridors for predator movements. Conservation Biology 13:869-881

Milbrandt EC, Bartleson RD, Coen LD, Rybak O, Thompson MA, DeAngelo JA, Stevens PW (2012) Local and regional effects of reopening a tidal inlet on estuarine water quality, seagrass habitat, and fish assemblages. Continental shelf research 41:1-16

Miller SJ, Skilleter GA (2006) Temporal variation in habitat use by nekton in a subtropical estuarine system. Journal of Experimental Marine Biology and Ecology 337:82-95

Mills CE, Hadwen WL, Hughes JM (2008) Looking through glassfish: marine genetic structure in an estuarine species. Marine & Freshwater Research 59:627-637

Milton D, Halliday I, Sellin M, Marsh R, Staunton-Smith J, Woodhead J (2008) The effect of habitat and environmental history on otolith chemistry of barramundi Lates calcarifer in estuarine populations of a regulated tropical river. Estuarine, Coastal and Shelf Science 78:301-315

Milton DA, Chenery, Farmer MJ, Blaber SJM (1997) Identifying the spawning estuaries of the tropical shad, terubok Tenualosa toli, using otolith microchemistry. Marine Ecology Progress Series 153:283-291

Minello T, Rozas L, Baker R (2012) Geographic Variability in Salt Marsh Flooding Patterns may Affect Nursery Value for Fishery Species. Estuaries and Coasts 35:501-514

Minello TJ (1999) Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat. In: Benaka LR (ed) Proceedings of the Sea Grant Symposium on Fish Habitat: Fish Habitat and Rehabilitation, Book 22. American Fisheries Society Symposium, Bethesda, Maryland

Minello TJ, Able KW, Weinstein MP, Hays C (2003) Salt marshes as nurseries for nekton: Testing hypotheses on density, growth and survival through meta-analysis. Marine ecology progress series 246:39-59

Minello TJ, Able KW, Weinstein MP, Hays CG (2003) Salt marshes as nurseries for nekton: testing hypotheses on density, growth and survival through meta-analysis. Marine Ecology-Progress Series 246:39-59

Minello TJ, Matthews GA, Caldwell PA (2008) Population and production estimates for decapod crustaceans in wetlands of Galveston Bay, Texas. Transactions of the American Fisheries Society 137:129-146

Minello TJ, Rozas LP (2002) Nekton populations in Gulf Coast wetlands: finescale spatial distributions, landscape patterns, and restoration implications. Ecological Applications 12:441-445

Mireles C, Nakamura R, Wendt DE (2012) A collaborative approach to investigate site fidelity, home range, and homing behavior of cabezon (Scorpaenichthys marmoratus). Fisheries Research (Amsterdam) 113:133-142

Miskiewicz AG, Bruce BD, Dixon P (1996) Distribution of tailor (Pomatomus saltatrix) larvae along the coast of New South Wales, Australia. Marine and Freshwater Research 47:331-336

Morrison MA, Francis MP, Hartill BW, Parkinson DM (2002) Diurnal and tidal variation in the abundance of the fish fauna of a temperate tidal mudflat. Estuarine Coastal and Shelf Science 54:793-807

Morton JK, Gladstone W (2011) Spatial, temporal and ontogenetic variation in the association of fishes (family Labridae) with rocky-reef habitats. Marine and Freshwater Research 62:870-884

Morton RM (1992) Fish assemblages in residential canal developments near the mouth of a subtropical Queensland estuary. Australian Journal of Marine and Freshwater Research 43:1359-1371

Morton RM, Beumer JP, Pollock BR (1988) Fishes of a subtropical Australian saltmarsh and their predation upon mosquitoes. Environ Biol Fish 21:185-194

Morton RM, Pollock BR, Beumer JP (1987) The occurrence and diet of fishes in a tidal inlet to a saltmarsh in southern Moreton Bay, Queensland. Australian Journal of Ecology 12:217–237

Mumby PJ, Edwards AJ, Arias-Gonzalez JE, Lindeman KC, Blackwell PG, Gall A, Gorczynska MI, Harborne AR, Pescod CL, Renken H, Wabnitz CCC, Llewellyn G (2004) Mangroves enhance the biomass of coral reef fish communities in the Caribbean. Nature 427:533-536

Mumby PJ, Hastings A (2008) The impact of ecosystem connectivity on coral reef resilience. J Appl Ecol 45:854-862

Murphy HM, Jenkins GP, Hindell JS, Connolly RM (2010) Response of fauna in seagrass to habitat edges, patch attributes and hydrodynamics. Austral Ecology 35:535-543

Naesje TF, Cowley PD, Diserud OH, Childs AR, Kerwath SE, Thorstad EB (2012) Riding the tide: estuarine movements of a sciaenid fish, Argyrosomus japonicus. Marine Ecology-Progress Series 460:221-232

Nagelkerken I (2007) Are non-estuarine mangroves connected to coral reefs through fish migration? Bulletin of Marine Science 80:595-607

Nagelkerken I (2009) Evaluation of nursery function of mangroves and seagrass beds for tropical decapods and reef fishes: patterns and underlying mechanisms. In: Nagelkerken I (ed) Ecological connectivity among tropical coastal ecosystems. Springer

Nagelkerken I, Sheaves M, Baker R, Connolly R (in review) The seascape nursery: a novel spatial approach to identify and manage nurseries for coastal marine fauna. Ecological Applications

Nakamura Y, Hirota K, Shibuno T, Watanabe Y (2012) Variability in nursery function of tropical seagrass beds during fish ontogeny: timing of ontogenetic habitat shift. Marine Biology 159:1305-1315

Neira FJ, Keane JP (2008) Ichthyoplankton-based spawning dynamics of blue mackerel (Scomber australasicus) in south-eastern Australia: links to the East Australian Current. Fisheries Oceanography 17:281-298

Nemerson DM, Able KW (2004) Spatial patterns in diet and distribution of juveniles of four fish species in Delaware Bay marsh creeks: factors influencing fish abundance. Marine Ecology-Progress Series 276:249-262

Nichols PD, Klumpp DW, Johns RB (1986) Lipid components and utilization in consumers of a seagrass community: An indication of carbon source. Comparative Biochemistry and Physiology Part B: Comparative Biochemistry 83:103–113

Nicholson G, Jenkins GP, Sherwood J, Longmore A (2008) Physical environmental conditions, spawning and early-life stages of an estuarine fish: climate change implications for recruitment in intermittently open estuaries. Marine and Freshwater Research 59:735-749

Nicolas D, Lobry J, Le Pape O, Boet P (2010) Functional diversity in European estuaries: Relating the composition of fish assemblages to the abiotic environment. Estuarine Coastal and Shelf Science 88:329-338

Noell CJ (2005) Early life stages of the southern sea garfish, *Hyporhamphus melanochir* (Valenciennes 1846), and their association with seagrass beds. PhD, University of Adelaide,

Oakes JM, Connolly RM, Revill AT (2010) Isotope enrichment in mangrove forests separates microphytobenthos and detritus as carbon sources for animals. Limnol Oceanogr 55:393-402

Odum EP (1968) A research challenge: Evaluating the productivity of coastal and estuarine water. In: Proceedings of the Second Sea Grant Conference, University of Rhode Island

Olds AD, Connolly RM, Pitt KA, Maxwell PS (2012) Primacy of seascape connectivity effects in structuring coral reef fish assemblages. Marine Ecology-Progress Series 462:191-203

Oliver TSN, Rogers K, Chafer CJ, Woodroffe CD (2012) Measuring, mapping and modelling: an integrated approach to the management of mangrove and saltmarsh in the Minnamurra River estuary, southeast Australia. Wetlands Ecology and Management 20:353-371

Paalvast P, van Wesenbeeck BK, van der Velde G, de Vries MB (2012) Pole and pontoon hulas: An effective way of ecological engineering to increase productivity and biodiversity in the hard-substrate environment of the port of Rotterdam. Ecological Engineering 44:199-209

Parsons MJ, McCauley RD, Mackie MC, Siwabessy P, Duncan AJ (2009) Localization of individual mulloway (Argyrosomus japonicus) within a spawning aggregation and their behaviour throughout a diel spawning period. ICES Journal of Marine Science 66:1007-1014

Patterson WF, Wilson CA, Bentley SJ, Cowan JH, Henwood T, Allen YC, Dufrene TA (2005) Delineating juvenile red snapper habitat on the northern Gulf of Mexico continental shelf. In: Barnes BW, Thomas JP (eds) Benthic Habitats and the Effects of Fishing, Book 41

Pears RJ, Choat JH, Mapstone BD, Begg GA (2007) Reproductive biology of a large, aggregation-spawning serranid, Epinephelus fuscoguttatus (Forsskal): management implications. Journal of Fish Biology 71:795-817

Phelan MJ, Gribble NA, Garrett RN (2008) Fishery biology and management of Protonibea diacanthus (Sciaenidae) aggregations in far Northern Cape York Peninsula waters. Continental shelf research 28:2143-2151

Pitcher CR, Burridge CY, Wassenberg TJ, Hill BJ, Poiner IR (2009) A large scale BACI experiment to test the effects of prawn trawling on seabed biota in a closed area of the Great Barrier Reef Marine Park, Australia. Fisheries Research 99:168-183

Polis GA, Anderson WB, Holt RD (1997) Towards an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs. Annu Rev Ecol Syst 28:289-316

Pollard DA (1994) A comparison of fish assemblages and fisheries in intermittently open and permanently open coastal lagoons on the south coast of New South Wales, south-eastern Australia. Estuaries 17:631-646

Pollock BR (1982a) Movements and migrations of yellowfin bream, Acanthopagrus australis (Guenther), in Moreton Bay, Queensland as determined by tag recoveries. Journal of Fish Biology 20:245-252

Pollock BR (1982b) Spawning period and growth of yellowfin bream, Acanthopagrus australis (Gunther), in Moreton Bay, Australia. Journal of Fish Biology 21:349-355

Pollock BR (1985a) The reproductive cycle of yellowfin bream, Acanthopagrus australis (Guenther), with particular reference to protandrous sex inversion. Journal of Fish Biology 26:301-311

Pollock BR (1985b) The tailor (Pomatomus saltatrix) fishery at Fraser Island and its relation to the life-history of the fish. Proceedings of the Royal Society of Queensland 95:23-28

Poloczanska ES, Babcock RC, Butler A, Hobday AJ, Milton DA, Okey TA, Richardson AJ (2007) Climate change and Australian marine life. Oceanography and Marine Biology 45:407-478

Poore AGB, Gallagher KM (in press) Strong consequences of diet choice in a talitrid amphipod consuming seagrass and algal wrack. Hydrobiologia

Potthoff MT, Allen DM (2003) Site fidelity, home range, and tidal migrations of juvenile pinfish, Lagodon rhomboides, in salt marsh creeks. Environmental Biology of Fishes 67:231-240

Ramsay K, Kaiser MJ, Hughes RN (1998) Responses of benthic scavengers to fishing disturbance by towed gears in different habitats. Journal of Experimental Marine Biology and Ecology 224:73-89

Reyns NB, Eggleston DB, Luettich RA (2007) Dispersal dynamics of post-larval blue crabs, Callinectes sapidus, within a wind-driven estuary. Fisheries Oceanography 16:257-272

Richardson, D. E. (2008). Physical and biological characteristics of billfish spawning habitat in the Straits of Florida. Open Access Dissertations. Paper 26.

Richardson DE, Cowen RK (2004) Diversity of leptocephalus larvae around the island of Barbados (West Indies): relevance to regional distributions. Marine Ecology Progress Series 282:271-284

Roberts DG, Gray CA, West RJ, Ayre DJ (2011) Temporal stability of a hybrid swarm between the migratory marine and estuarine fishes *Acanthopagrus australis* and *A. butcheri*. Marine Ecology Progress Series 421:199-204

Robertson A, Blaber S (1992) Plankton, epibenthos and fish communities. In: Robertson A, Blaber S (eds) Tropical Mangrove Ecosystems. Americal Geophysical Union, Washington

Robertson AI (1984) Trophic interactions between the fish fauna and macrobenthos of an eelgrass community in Western Port, Victoria. Aquatic Botany 18:135-153

Robertson AI (1988) Abundance, diet and predators of juvenile banana prawns, *Penaeus merguiensis*, in a tropical mangrove estuary. Aust J Mar Freshwat Res 39:467-478

Robertson AI, Daniel PA (1989) The influence of crabs on litter processing in high intertidal mangrove forests in tropical Australia. Oecologia 78:191-198

Robertson AI, Duke NC (1987) Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. Mar Biol 96:193-205

Robertson AI, Duke NC (1990a) Mangrove fish-communities in tropical Queensland, Australia: Spatial and temporal patterns in densities, biomass and community structure. Mar Biol 104:369-379

Robertson AI, Duke NC (1990b) Recruitment, growth and residence time of fishes in a tropical Australian mangrove system. Estuar Coast Shelf Sci 31:723-743

Robertson AI, Lenanton RCJ (1984) Fish community structure and food chain dynamics in the surf-zone of sandy beaches: the role of detached macrophyte detritus. J Exp Mar Biol Ecol 84:265-283

Robertson AI, Lucas JS (1983) Food choice, feeding rates, and the turnover of macrophyte biomass by a surf-zone inhabiting amphipod. J Exp Mar Biol Ecol 72:99–124

Rochard E, Lepage M, Dumont P, Tremblay S, Gazeau C (2001) Downstream migration of juvenile European sturgeon Acipenser sturio L. in the Gironde estuary. Estuaries 24:108-115

Rockmann C, Ulrich C, Dreyer M, Bell E, Borodzicz E, Haapasaari P, Hauge KH, Howell D, Maentyniemi S, Miller D, Tserpes G, Pastoors M (2012) The added value of participatory modelling in fisheries management - what has been learnt? Marine Policy 36:1072-1085

Rooper CN, Wilkins ME, Rose CS, Coon C (2011) Modeling the impacts of bottom trawling and the subsequent recovery rates of sponges and corals in the Aleutian Islands, Alaska. Continental shelf research 31:1827-1834

Rossi F, Underwood AJ (2002) Small-scale disturbance and increased nutrients as influences on intertidal macrobenthic assemblages: experimental burial of wrack in different intertidal environments. Mar Ecol Prog Ser 241:29–39

Russell DJ, Garrett RN (1983) Use by juvenile barramundi, Lates calcarifer (Bloch), and other fishes of temporary supralittoral habitats in a tropical estuary in northern Australia. Aust J Mar Freshwat Res 34:805-811

Russell DJ, Garrett RN (1985) Early life history of barramundi, Lates calcarifer (Bloch), in north-eastern Queensland. Aust J Mar Freshwat Res 36:191-201

Russell DJ, Garrett RN (1988) Movements of juvenile barramundi, *Lates calcarifer*, (Bloch) in north-eastern Queensland. Aust J Mar Freshwat Res 39:117-123

Russell DJ, McDougall AJ (2005) Movement and juvenile recruitment of mangrove jack, Lutjanus argentimaculatus (Forsskal), in northern Australia. Marine and Freshwater Research 56:465-475

Sainsbury KJ, Campbell RA, Lindholm R, Whitelaw AW (1997) Experimental management of an Australian multispecies fishery: Examining the possibility of trawl-induced habitat modification. In: Pikitch EK, Huppert DD, Sissenwine MP (eds) Global Trends: Fisheries Management, Book 20

Saintilan N, Hossain K, Mazumder D (2007) Linkages between seagrass, mangrove and saltmarsh as fish habitat in the Botany Bay estuary, New South Wales. Wetlands Ecology and Management 15:277–286

Sakabe R, Lyle JM (2010) The influence of tidal cycles and freshwater inflow on the distribution and movement of an estuarine resident fish Acanthopagrus butcheri. Journal of Fish Biology 77:643-660

Salini JP, Blaber SJM, Brewer DT (1990) Diets of piscivorous fishes in a tropical Australian estuary, with special reference to predation on penaeid prawns. Mar Biol 105:363-374

Salini JP, Brewer DT, Blaber SJM (1998) Dietary studies on the predatory fishes of the Norman River estuary, with particular reference to penaeid prawns. Estuar Coast Shelf Sci 46:837-847

Samoilys MA (1997a) Movement in a large predatory fish: coral trout, Plectropomus leopardus (Pisces: Serranidae), on Heron Reef, Australia. Coral Reefs 16:151-158

Samoilys MA (1997b) Periodicity of spawning aggregations of coral trout Plectropomus leopardus (Pisces : Serranidae) on the northern Great Barrier Reef. Marine Ecology Progress Series 160:149-159

Sanger DM, Holland AF, Hernandez DL (2004) Evaluation of the impacts of dock structures and land use on tidal creek ecosystems in South Carolina estuarine environments. Environmental Management 33:385-400

Sarre GA, Potter IC (1999) Comparisons between the reproductive biology of black bream Acanthopagrus butcheri (Teleostei: Sparidae) in four estuaries with widely differing characteristics. International Journal of Salt Lake Research 8:179-210

Sass GG, Gille CM, Hinke JT, Kitchell JF (2006) Whole-lake influences of littoral structural complexity and prey body morphology on fish predator-prey interactions. Ecology of Freshwater Fish 15(3), September 2006: 301-308

Schafer LN, Platell ME, Valesini FJ, Potter IC (2002) Comparisons between the influence of habitat type, season and body size on the dietary compositions of fish species in nearshore marine waters. Journal of Experimental Marine Biology and Ecology 278:67-92

Scharf FS, Buckel JA, Rose KA, Juanes F, Cowan JH, Jr. (2006) Effects of variable prey and cohort dynamics on growth of young-of-the-year estuarine bluefish: evidence for interactions between spring- and summer-spawned cohorts. Transactions of the American Fisheries Society 135(5), September 2006: 1266-1289

Schlacher TA, Connolly RM, Skillington AJ, Gaston TF (2009) Can export of organic matter from estuaries support zooplankton in nearshore, marine plumes? Aquat Ecol 43:383-393

Schmitt R, Holbrook S (2000) Habitat-limited recruitment of coral reef damselfish. Ecology 81:3479-3494

Secor H, Rooker JR (2005) Connectivity in the life histories of fishes that use estuaries. Estuarine, Coastal and Shelf Science 64:1-3

Sedinger J, Flint P, Lindberg M (1995) Environmental influence on life-history traits: growth, survival, and fecundity in black brant (Branta bernicla). Ecology 76:2404-2414

Semmens JM, Buxton CD, Forbes E, Phelan MJ (2010) Spatial and temporal use of spawning aggregation sites by the tropical sciaenid Protonibea diacanthus. Marine Ecology Progress Series 403:193-203

Shaddick K, Gilligan DM, Burridge CP, Jerry DR, Truong K, Beheregaray LB (2011) Historic divergence with contemporary connectivity in a catadromous fish, the estuary perch (Macquaria colonorum). Canadian Journal of Fisheries and Aquatic Sciences 68:304

Sheaves M (1992) Patterns of distribution and abundance of fishes in different habitats of a mangrove-lined tropical estuary, as determined by fish trapping. Aust J Mar Freshwat Res 43:1461-1479

Sheaves M (1996) Habitat-specific distributions of some fishes in a tropical estuary. Marine and Freshwater Research 47:827-830

Sheaves M (2005) Nature and consequences of biological connectivity in mangrove systems. Marine Ecology-Progress Series 302:293-305

Sheaves M (2009) Consequences of Ecological Connectivity: the Example of the Coastal Ecosystem Mosaic. Marine Ecology Progress Series 391:107-115

Sheaves M (2012) Ecosystem equivalence and the ability to generalise: insights from global consistencies in mangrove fish assemblages. Marine Ecology-Progress Series 461:137-149

Sheaves M, Abrantes K, Johnston R (2007) Nursery ground value of an endangered wetland to juvenile shrimps. Wetlands Ecology and Management. 15(4): 311-327

Sheaves M, Baker R, Johnston R (2006) Marine nurseries and effective juvenile habitats: an alternative view. Marine Ecology Progress Series 318:303-306

Sheaves M, Brodie J, Brooke B, Dale P, Lovelock C, Waycott M, Gehrke P, Johnston R, Baker R (2007) Chapter 19 Vulnerability of coastal and estuarine habitats in the GBR to climate change. In: Johnson J, Marshal P (eds) Climate Change and the Great Barrier Reef: A Vulnerability Assessment. GBRMPA, Townsville

Sheaves M, Johnston R (2008) Influence of marine and freshwater connectivity on the dynamics of subtropical estuarine wetland fish metapopulations. Marine Ecology-Progress Series 357:225-243

Sheaves M, Johnston R, Connolly R (2012) Fish assemblages as indicators of estuary ecosystem health. Wetlands Ecol Manage 20:477-490

Sheaves M, Johnston R, Connolly R, Baker R (in press) Importance of Estuarine Mangroves to Juvenile Banana Prawns. Estuarine, Coastal and Shelf Science 1114: 208-219

Sheaves M, Johnston R, Connolly RM (2010) Temporal dynamics of fish assemblages of natural and artificial tropical estuaries. Marine Ecology-Progress Series 410:143-U156

Sheaves M, Molony B (2000) Short-circuit in the mangrove food chain. Marine Ecology-Progress Series 199:97-109

Sheaves M, Molony B (2013) Reproductive periodicity of the sparid, *Acanthopagrus pacificus*, on a hierarchy of temporal scales. Journal of Fish Biology (In press)

Sheaves M, Molony B, Tobin A (1999) Spawning migrations and local movements of a tropical sparid fish. Marine Biology 133:123-128

Shepherd SA, Brook JB (2007) Distribution and ontogenetic shifts in habitat and abundance of the temperate western blue groper, Achoerodus gouldii (Richardson). Journal of Fish Biology 71:1457-1478

Short AD (2006) Australian Beach Systems-Nature and Distribution. Journal of Coastal Research 22:11-27

Simenstad CA, Wick A, Van De Wetering S, Bottom DL (2003) Dynamics and ecological functions of wood in estuarine and coastal marine ecosystems. In: Gregory SV, Boyer KL, Gurnell AM (eds) Ecology and Management of Wood in World Rivers, Book 37

Simpfendorfer CA, Milward NE (1993) Utilization of a tropical bay as a nursery area by sharks of the families Carcharhinidae and Sphyrnidae. Environmental Biology of Fishes 37:337-345

Smith KA, Suthers IM (2000) Consistent timing of juvenile fish recruitment to seagrass beds within two Sydney estuaries. Mar Freshwat Res 51:765–776

Smith TM, Hindell JS (2005) Assessing effects of diel period, gear selectivity and predation on patterns of microhabitat use by fish in a mangrove dominated system in SE Australia. Marine Ecology Progress Series 294:257-270

Smith TM, Hindell JS, Jenkins GP, Connolly RM (2008) Edge effects on fish associated with seagrass and sand patches. Marine Ecology Progress Series 359:203-213

Sogard SM (1992) Variability in growth rates of juvenile fishes in different estuarine habitats. Marine Ecology Progress Series 85:35-53

Speed CW, Meekan MG, Field IC, McMahon CR, Abrantes K, Bradshaw CJA (2012) Trophic ecology of reef sharks determined using stable isotopes and telemetry. Coral Reefs 31:357-367

Staples DJ, Vance DJ (1987) Comparative recruitment of the banana prawn, Penaeus merguiensis , in five estuaries of the south-eastern Gulf of Carpentaria, Australia. Aust J Mar Freshwat Res 38:29-45

Staples DJ, Vance DJ, Heales DS (1985) Habitat requirements of juvenile penaeid prawns and their offshore fisheries. In: Rothlisberg PC, Hill BJ, Staples DJ (eds) Second Australian National Prawn Seminar NPS2 CSIRO Cleveland Marine Laboratories, Cleveland, Queensland, pp 47-54

Staunton-Smith J, Blaber SJM, Greenwood JG (1999) Interspecific differences in the distribution of adult and juvenile ponyfish (Leiognathidae) in the Gulf of Carpentaria, Australia. Marine and Freshwater Research 50:643-653

Stobutzki I, Jones P, Miller M (2003) A comparison of fish bycatch communities between areas open and closed to prawn trawling in an Australian tropical fishery. ICES Journal of Marine Science 60:951-966

Stobutzki IC, Silvestre GT, Abu Talib A, Krongprom A, Supongpan M, Khemakorn P, Armada N, Garces LR (2006) Decline of demersal coastal fisheries resources in three developing Asian countries. Fisheries Research 78:130-142

Svensson CJ, Hyndes GA, Lavery PS (2007) Food web analysis in two permanently open temperate estuaries: consequences of saltmarsh loss? Marine Environmental Research 64:286–304

Tanner JE (2005) Three decades of habitat change in Gulf St Vincent, South Australia. Transactions of the Royal Society of South Australia 129:65-73

Teal JM (1962) Energy flow in the salt marsh ecosystem of Georgia. Ecology 43:614-624

Thayer GW, Colby DR, Hettler WF (1987) Utilization of the red mangrove prop root habitat by fishes in south Florida. Marine Ecology-Progress Series 35:25-38

Thomas BE, Connolly RM (2001) Fish use of subtropical saltmarshes in Queensland, Australia: relationships with vegetation, water depth and distance onto the marsh. Mar Ecol Prog Ser 209:175-288

Thorrold SR, Latkoczy C, Swart PK, Jones CM (2001) Natal homing in a marine fish metapopulation. Science 291:297-299

Tibbetts IR, Carseldine L (2005) Trophic shifts in three subtropical Australian halfbeaks (Teleostei : Hemiramphidae). Mar Freshwat Res 56:925-932

Tobin AJ, Sheaves MJ, Molony BW (1997) Evidence of protandrous hermaphroditism in the tropical sparid Acanthopagrus berda. Journal of Fish Biology 50:22-33

Toft JD, Cordell JR, Simenstad CA, Stamatiou LA (2007) Fish distribution, abundance, and behavior along city shoreline types in puget sound. North American Journal of Fisheries Management 27:465-480

Travers MJ, Potter IC (2002) Factors influencing the characteristics of fish assemblages in a large subtropical marine embayment. J Fish Biol 2002:764–784

Tupper M (2007) Identification of nursery habitats for commercially valuable humphead wrasse Cheilinus undulatus and large groupers (Pisces: Serranidae) in Palau. Mar Ecol Prog Ser 332:189-199

Turner RE (1977) Intertidal vegetation and commercial yields of penaeid shrimp. Transactions of the American Fisheries Society 106:411-416

Turner SJ, Thrush SF, Hewitt JE, Cummings VJ, Funnell G (1999) Fishing impacts and the degradation or loss of habitat structure. Fisheries Management and Ecology 6:401-420

Unsworth RKF, De Leon PS, Garrard SL, Jompa J, Smith DJ, Bell JJ (2008) High connectivity of Indo-Pacific seagrass fish assemblages with mangrove and coral reef habitats. Marine Ecology-Progress Series 353:213-224

Unsworth RKF, Garrard SL, De Leon PS, Cullen LC, Smith DJ, Sloman KA, Bell JJ (2009) Structuring of Indo-Pacific fish assemblages along the mangrove-seagrass continuum. Aquatic Biology 5:85-95

Valentine-Rose L, Rypel AL, Layman CA (2011) Community secondary production as a measure of ecosystem function: a case study with aquatic ecosystem fragmentation. Bulletin of Marine Science 87:913-937

Valesini FJ, Clarke KR, Eliot I, Potter IC (2003) A user-friendly quantitative approach to classifying nearshore marine habitats along a heterogeneous coast. Estuarine Coastal and Shelf Science 57:163-177

Valesini FJ, Hourston M, Wildsmith MD, Coen NJ, Potter IC (2010) New quantitative approaches for classifying and predicting local-scale habitats in estuaries. Estuarine Coastal and Shelf Science 86:645-664

Vance DJ, Haywood MDE, Staples DJ (1990) Use of a mangrove estuary as a nursery area by postlarval and juvenile banana prawns, Penaeus merguiensis de Man, in northern Australia. Estuar Coast Shelf Sci 31:689-701

Vanderklift MA, Jacoby CA (2003) Patterns in fish assemblages 25 years after major seagrass loss. Mar Ecol Prog Ser 247:225–235

Vanderklift MA, Wernberg T (2008) Detached kelps from distant sources are a food subsidy for sea urchins. Oecologia 157:327–335

Verweij M, Nagelkerken I, Wartenberg S, Pen I, Gerard vd (2006) Caribbean mangroves and seagrass beds as daytime feeding habitats ofr juvenile French grunts, *Haemulon flavolineatum*. Marine Biology 149:1291-1299

Verweij MC, Nagelkerken I, Hans I, Ruseler SM, Mason PRD (2008) Seagrass nurseries contribute to coral reef fish populations. Limnology and Oceanography 53:1540-1547

Wakefield CB (2010) Annual, lunar and diel reproductive periodicity of a spawning aggregation of snapper Pagrus auratus (Sparidae) in a marine embayment on the lower west coast of Australia. Journal of Fish Biology 77:1359-1378

Wakefield CB, Fairclough DV, Lenanton RCJ, Potter IC (2010) Spawning and nursery habitat partitioning and movement patterns of Pagrus auratus (Sparidae) on the lower west coast of Australia. Fisheries Research (Amsterdam) 109:243-251

Walters C, Martell S (2004) Fisheries ecology and management, Vol. Princeton University Press Princeton

Ward T, Staunton-Smith J (2002) Comparison of the spawning patterns and fisheries biology of the sardine, *Sardinops sagax*, in temperate South Australia and sub-tropical southern Queensland. Fisheries Research 56:37-49

Ward TM, Staunton-Smith J, Hoyle S, Halliday IA (2003) Spawning patterns of four species of predominantly temperate pelagic fishes in the sub-tropical waters of southern Queensland. Estuar Coast Shelf Sci 56:1125-1140

Webb SR, Kneib RT (2002) Abundance and distribution of juvenile white shrimp Litopenaeus setiferus within a tidal marsh landscape. Marine Ecology-Progress Series 232:213-223

Webster MS (2004) Density dependence via intercohort competition in a coral-reef fish. Ecology 85:986-994

Wernberg T, Vanderklift MA, How J, Lavery PS (2006) Export of detached macroalgae from reefs to adjacent seagrass beds. Oecologia 147:692-701

West RJ, King RJ (1996) Marine, Brackish, and Freshwater Fish Communities in the Vegetated and Bare Shallows of an Australian Coastal River. Estuaries 19:31-41

Westmeyer MP, Wilson CA, Nieland DL (2007) Fidelity of red snapper to petroleum platforms in the northern Gulf of Mexico. In: Patterson WF, Cowan JH, Fitzhugh GR, Nieland DL (eds) Red Snapper Ecology and Fisheries in the US Gulf of Mexico, Book 60

White KS, Westera MB, Kendrick GA (2011) Spatial patterns in fish herbivory in a temperate Australian seagrass meadow. Estuarine Coastal and Shelf Science 93:366-374

Wilson JP, Sheaves M (2001) Short-term temporal variations in taxonomic composition and trophic structure of a tropical estuarine fish assemblage. Marine Biology 139:787-796

Wolanski E (1992) Hydrodynamics of mangrove swamps and their coastal waters. Hydrobiologia 247:141-161

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R (2006) Impacts of biodiversity loss on ocean ecosystem services. Science 314:787-790

Yanez-Arancibia A, Lara Dominguez AL, Pauly D (1994) Coastal lagoons as fish habitats. Elsevier Oceanography Series 60:363-376

Yanez-Arancibia A, Lara-Dominguez L, Day J (1993) Interactions between mangroves and seagrass habitats mediated by estuarine nekton assemblages: coupling of primary and secondary productivity. Hydrobiologia 264:1-12

York PH, Booth DJ, Glasby TM, Pease BC (2006) Fish assemblages in habitats dominated by Caulerpa taxifolia and native seagrasses in south-eastern Australia. Marine Ecology Progress Series 312:223-234

Zaker NH, Imberger J, Pattiaratchi C (2007) Dynamics of the coastal boundary layer off Perth, Western Australia. Journal of Coastal Research 23:1112-1130

Zeller BM, Pollock BR, Williams LE (1996) Aspects of the life history and management of tailor (Pomatomus saltatrix) in Queensland. Marine & Freshwater Research 47

Zeller DC (1998) Spawning aggregations: patterns of movement of the coral trout Plectropomus leopardus (Serranidae) as determined by ultrasonic telemetry. Marine Ecology Progress Series 162:253-263

Appendix

Appendix table 2: Review of nursery habitat identification for common Australian finfish species.

Common Name	Species	Juvenile habitat	Comments	reference
flathead	*Platycephalus endrachtensis*	Juveniles found in the mangrove channel and intertidal mangrove habitat	Dampier Region, Northern QLD	(Blaber et al. 1985)
		Juveniles found on muddy/sandy substrate in mangrove forests	Gulf of Carpentaria	(Blaber et al. 1989)
	Platycephalus fuscus	Juveniles caught in drainage creek surrounded by *Avicennia marina*	Botany Bay, NSW	(Bell et al. 1984)
		Juveniles caught in *Zostera* seagrass meadows	Botany Bay, NSW	(Middleton et al. 1984)
		Juveniles caught in *Posidonia australis* seagrass meadow	Port Hacking, NSW	(Burchmore et al. 1984)
		Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Juveniles caught in *Rhizophora stylosa* mangrove forest	Tin Can Bay, QLD	(Halliday and Young 1996)
		Juveniles commonly caught in seagrass, pneumatophore fringe, and mangroves. Rare on mudflats.	Moreton Bay QLD	(Laegdsgaard and Johnson 1995)
	Platycephalus indicus	Juveniles caught in *Rhizophora stylosa* mangrove forest	Tin Can Bay, QLD	(Halliday and Young 1996)
		Juveniles were not present in seagrass, or mudflats, rare in pneumatophore fringe and common in mangroves.	Moreton Bay QLD	(Laegdsgaard and Johnson 1995)
		Juveniles found in the mangrove channel	Dampier Region, Northern QLD	(Blaber et al. 1985)
		Juveniles found on muddy/sandy substrate in mangrove forests	Gulf of Carpentaria	(Blaber et al. 1989)
	Platycephalus arenarius	No reports		
Yellowfin bream	*Acanthopagrus australis*	Juveniles caught in drainage creek surrounded by *Avicennia marina*	Botany Bay, NSW	(Bell et al. 1984)
		Juveniles found on seagrass and sand (newly settled <20mm TL)	Richmond & Wooli Wooli Rivers NSW	(Gray et al. 1998)
		Juveniles caught in *Zostera* seagrass meadows	Botany Bay, NSW	(Middleton et al. 1984)
		Juveniles caught in *Posidonia australis* seagrass meadow	Port Hacking, NSW	(Burchmore et al. 1984)
		Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Juveniles caught in *Rhizophora stylosa* mangrove forest	Tin Can Bay, QLD	(Halliday and Young 1996)
		Recruit into seagrass before moving into deeper habitat after 3-4 months	Review	(Saintilan 2004)
		Juveniles caught in seagrass, mudflats, pneumatophore fringe and mangroves	Moreton Bay QLD	(Laegdsgaard and Johnson 1995)
		Occurs over seagrasses while juvenile	Review	(Gray et al. 1996)
		Recruits found in *Zostera capricorni* beds	4 estuaries NSW	(McNeill et al. 1992)
		Juveniles collected on seagrass beds	Botany Bay NSW	(Worthington et al. 1992)

Common Name	Species	Juvenile habitat	Comments	reference
		Juveniles in muddy/sandy substrate in mangrove forests and seagrass areas		(Blaber and Blaber 1980)
		Juveniles on sandy/seagrass substrate		(Griffiths 2001)
		Juveniles in seagrass		(Hannan 1998)
Pikey bream	*Acanthopagrus pacificus* (formerly *berda*)	Less than 5% of juveniles came from habitats other than mangrove-lined estuaries	Alligator creek QLD	(Robertson and Duke 1990)
		Juveniles in estuaries	Northern Queensland	Sheaves (2006, 2009)
Bream	*Acanthopagrus butcheri*	Completes its life cycle within estuaries	Review	(Gavin and Potter 2000) (Potter & Hyndes 1994) (Sarre & Potter 2000)
Snapper	*Pagrus auratus*	Post-settlement and early juvenile phase within sheltered bays and estuaries	Review	(Hamer et al. 2003)
		Juveniles on sandy substrate		(Hannan 1998)
Tarwhine	*Rhabdosargus sarba*	Juveniles caught in drainage creek surrounded by *Avicennia marina*	Botany Bay, NSW	(Bell et al. 1984)
		Seagrass and sand (newly settled <20mm TL)	Richmond & Wooli Wooli Rivers NSW	(Gray et al. 1998)
		Juveniles caught in *Zostera* seagrass meadows	Botany Bay, NSW	(Middleton et al. 1984)
		Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Juveniles caught in *Rhizophora stylosa* mangrove forest	Tin Can Bay, QLD	(Halliday and Young 1996)
		Recruit into seagrass before moving into deeper habitat after 3-4 months	Review	(Saintilan 2004)
		Recruits found in *Zostera capricorni* beds	4 estuaries NSW	(McNeill et al. 1992)
		Juveniles collected on seagrass beds	Botany Bay NSW	(Worthington et al. 1992)
		Seagrass and sandy substratum		(Hannan 1998)
		Juveniles in muddy/sandy substrate in mangrove forests and seagrass areas		(Blaber and Blaber 1980)
whiting	*Sillaginodes punctatus*	Early juvenile stage prefers seagrass. Post-settlement habitats are more variable. Newly settled more abundant in seagrass (Barker Inlet SA, Western Port VIC, Port Phillip Bay VIC) or unvegetated habitats (Swan Bay). Correlates with small crustacean abundances.	Port Phillip Bay, VIC/Review	(Jenkins and Hamer 2001)
		Young 0+ age group fish were found to inhabit heavily grassed areas of the seagrass flats, whilst older fish preferred lightly grassed or bare, muddy areas	Western Port VIC	(Robertson 1977)
		Juveniles occur more in shallow waters (<1.5m) in embayments and estuaries	South-West Australia	(Connolly 1994, Hyndes et al. 1998)
		Larvae (15-20mm) enter bays and inlets and settle out into shallow	Swan Bay SA/ Review	(Hamer and Jenkins 1997)

Common Name	Species	Juvenile habitat	Comments	reference
		seagrass and algal habitats		
		Post-settlement individuals collected from seagrass beds	Port Phillip Bay	(Jenkins et al. 1996)
		Juveniles typically occur in nearshore waters protected from wind and wave activity	Review	(Hyndes et al. 1997)
Goldenline whiting	*Sillago analis*	Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Juveniles caught in *Rhizophora stylosa* mangrove forest	Tin Can Bay, QLD	(Halliday and Young 1996)
		Juveniles caught in mudflats, pneumatophore fringe and mangroves, not on seagrass	Moreton Bay QLD	(Laegdsgaard and Johnson 1995)
		Juveniles found to inhabit shallow shores including lower sections of creeks and rivers. They favour muddy-sand substrates with <1m depths	Moreton Bay QLD	(Weng 1983)
		Juveniles found in the mangrove channel, intertidal mangrove habitat and intertidal open shore habitat	Dampier Region, Northern QLD	(Blaber et al. 1985)
Sand whiting	*Sillago ciliata*	Juveniles caught in drainage creek surrounded by *Avicennia marina*	Botany Bay, NSW	(Bell et al. 1984)
		Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Juveniles caught in *Rhizophora stylosa* mangrove forest	Tin Can Bay, QLD	(Halliday and Young 1996)
		Juveniles caught in mudflats, pneumatophore fringe and mangroves, not on seagrass.	Moreton Bay QLD	(Laegdsgaard and Johnson 1995)
		Bare sand is an important habitat for juveniles	Northern NSW (8 estuaries)	(Gray et al. 1996)
		Juveniles found to inhabit shallow shores including lower sections of creeks and rivers. Prefer sandy substrates with <1m depths.	Moreton Bay QLD	(Weng 1983)
Trumpeter whiting	*Sillago maculata*	Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Juveniles caught in mudflats, pneumatophore fringe and mangroves, not on seagrass	Moreton Bay QLD	(Laegdsgaard and Johnson 1995)
		Juveniles found to inhabit shallow shores including lower sections of creeks and rivers. Occurred in muddy-sand to muddy substrates at 1-3m depth	Moreton Bay QLD	(Weng 1983)
		Juveniles found in intertidal mangrove habitat <2m and open shore intertidal habitats <2m and tidal pools	Dampier Region, Northern QLD	(Blaber et al. 1985)
	Sillago burrus	Use sheltered nearshore shallow waters (<1.5m) as nursery areas	Review	(Hyndes et al. 1996)
		Juveniles typically occur in nearshore waters protected from wind and wave activity	Review	(Hyndes et al. 1997)
		Juveniles occupy productive nearshore	South-western	(Hyndes and Potter

Common Name	Species	Juvenile habitat	Comments	reference
		waters	Australia	1997)
Northern whiting	*Sillago sihama*	Juveniles found in intertidal mangrove habitat <0.2m and small creeks <0.1m.	Dampier Region, Northern QLD	(Blaber et al. 1985)
		muddy/sandy substrate		(Blaber et al. 1995)
Stout whiting	*Sillago robusta*	Juveniles are not found in nearshore waters but remain in the deeper waters of the inner continental shelf.	Lower West Coast	(Hyndes and Potter 1996)
		Juveniles caught in soft substrate habitats in the estuary and at the river mouth	Botany Bay NSW	(Burchmore et al. 1988)
		Juveniles restricted to deeper waters	South-western Australia	(Hyndes and Potter 1997)
Tailor	*Pomatomus saltatrix*	Juveniles caught in drainage creek surrounded by *Avicennia marina*	Botany Bay, NSW	(Bell et al. 1984)
		Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Juveniles found in pneumatophore fringe but were rare in mangroves, none were found in seagrass or on mudflats	Moreton Bay QLD	(Laegdsgaard and Johnson 1995)
		Juveniles inhabit coastal nursery areas	Western Australia	(Lenanton et al. 1996)
		Juveniles inhabit and move extensively throughout estuaries. Many caught within the sheltered waters of Moreton Bay and the Southport Broadwater	Southern Qld	(Zeller et al. 1996)
Luderick	*Girella tricuspidata*	Juveniles caught in drainage creek surrounded by *Avicennia marina*	Botany Bay, NSW	(Bell et al. 1984)
		Seagrass and sand (newly settled <20mm TL)	Richmond & Wooli Wooli Rivers NSW	(Gray et al. 1998)
		Juveniles caught in *Zostera* and *Posidonia* seagrass meadows	Botany Bay, NSW	(Middleton et al. 1984)
		Juveniles caught in *Posidonia australis* seagrass meadow	Port Hacking, NSW	(Burchmore et al. 1984)
		Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Greater numbers of juveniles over seagrass beds than bare estuarine areas	Review	(Saintilan 2004)
		Recruits found in *Zostera capricorni* beds	4 estuaries NSW	(McNeill et al. 1992)
		Juveniles collected on seagrass beds	Botany Bay NSW	(Worthington et al. 1992)
Mulloway	*Argyrosomus japonicus*	Juveniles inhabit nearshore environments and estuaries	Hawkesbury River NSW	(Broadhurst and Kennelly 1994)
		Highest numbers of juveniles caught in the mid-section of the estuary (20-40km from the mouth)	Hawkesbury River NSW	(Gray and McDonall 1993)
		Juveniles more abundant in brackish estuarine waters on east coast of Australia. Smaller juveniles inhabit edge habitats, typically up against a rock wall or in a crevice for protection	Botany Bay NSW	(Taylor et al. 2006)

Common Name	Species	Juvenile habitat	Comments	reference
		Juveniles occur in estuaries and nearshore coastal environments (including surf zones). They favour deeper habitats.	Review	(Silberschneider and Gray 2008)
Black jewfish	*Protonibea diacanthus*	Juveniles caught at depth ranges between 10 and 25m.	Injinoo, Northern QLD	(Phelan et al. 2008)
Teraglin	*Atractoscion aequidens*	No reports		
Australian Bass	*Macquaria novemaculeata*	Juveniles migrate upstream from estuaries into freshwater	Review	(Mallen-Cooper 1992)
		Larvae and juveniles found in the brackish and freshwater zones of the estuary. Larvae and juveniles were always found within beds of aquatic macrophyts (*phragmites australis, Vallisneria gigantean*)	Penrith Weir	(Harris 1986)
Barracuda	*Sphyraena barracuda*	Juveniles found in intertidal mangrove habitat <2m.	Dampier Region, Northern QLD	(Blaber et al. 1985)
Queensland grouper	*Epinephelus lanceolatus*	No reports		
Mangrove jack	*Lutjanus argentimaculatus*	Juveniles found in the mangrove channel, intertidal mangrove habitat (<2m but >0.2m), small creeks, and tidal pools.	Dampier Region, Northern QLD	(Blaber et al. 1985)
		Juveniles recruit into estuaries and lower freshwater riverine habitats. Have been found in seagrass beds and freshwater areas.	Coastal streams in Qld and NSW	(Russell and McDougall 2005)
		Coastal wetlands and riparian vegetation are important for juveniles	Review	(Russell and McDougall 2003)
		Estuarine populations were comprised entirely of juveniles; no juveniles reported offshore	Creeks in Northern QLD	(Sheaves 1995)
		Juveniles penetrate nursery areas as far upstream into freshwater as physical barriers and O_2 concentrations will allow	Review	(Wolanski 2001)
		Submerged dead timber	North-eastern Qld	(Sheaves 1996)
		Wetland pools	North-eastern Qld	(Davis et al. 2012)
Golden snapper	*Lutjanus johnii*	No reports		
Moses perch	*Lutjanus russelli*	Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Juveniles caught in *Rhizophora stylosa* mangrove forest	Tin Can Bay, QLD	(Halliday and Young 1996)
		Not found in seagrass, mudflats or pneumatophore fringes, but were rare in mangrove forests	Moreton Bay QLD	(Laegdsgaard and Johnson 1995)
		Juveniles found in intertidal mangrove habitat <2m, small creeks and tidal pools.	Dampier Region, Northern QLD	(Blaber et al. 1985)
		Estuarine populations were comprised entirely of juveniles; no juveniles reported offshore	Creeks in Northern QLD	(Sheaves 1995)

Common Name	Species	Juvenile habitat	Comments	reference
		Submerged dead timber	North-eastern Qld	(Sheaves 1996)
Crimson snapper	*Lutjanus erythropterus*	Most age-0 found in silty and coarse sand/rubble inshore estuarine habitats	Northern Australia	(Fry et al. 2009)
		Juveniles occur in large bays of the central GBR, predominantly in seagrass beds. Restricted to depths <15m with high silt and clay fractions.	Review	(Wolanski 2001)
Saddletail snapper	*Lutjanus malabaricus*	Age-0 snapper occurred in inshore, estuarine; silty, muddy, coarse sand/rubble	Northern Australia	(Fry et al. 2009)
		Juveniles occur in large bays of the central GBR, predominantly in seagrass beds. Restricted to depths <15m with high silt and clay fractions.	Review	(Wolanski 2001)
Red emperor	*Lutjanus sebae*	Juveniles have a wider depth range than *L. erythropterus* and *L. malabaricus*. They can be found over both terrigenous and carbonate sediments (5-62m)	Review	(Wolanski 2001)
Redthroat emperor	*Lethrinus miniatus*	Juvenile habitat unknown, individuals <150mm FL have never been sighted	Review	(Williams et al. 2006)
Spangled emperor	*Lethrinus nebulosus*	Settles in seagrass beds after pelagic larval phase.	Review	(Arvedlund and Takemura 2006)
		Juveniles form large schools in shallow, sheltered sandy areas.	Review	(Grandcourt et al. 2006)
Grass sweetlip	*Lethrinus laticaudis*	No reports		
Blackspotted estuary cod	*Epinephelus malabaricus*	Estuarine populations comprised only of juveniles	Creeks in Northern QLD	(Sheaves 1995)
		Submerged dead timber	North-eastern Qld	(Sheaves 1996)
Goldspot estuary cod	*Epinephelus coioides*	Estuarine populations comprised only of juveniles	Creeks in Northern QLD	(Sheaves 1995)
		Submerged dead timber	North-eastern Qld	(Sheaves 1996)
Barred javelinfish	*Pomadasys kaakan*	Juveniles in estuaries	Northern Queensland	Sheaves (2006, 2009)
Silver javelinfish	*Pomadasys argenteus*	Juveniles found in the mangrove channel, intertidal mangrove habitat (<2m but >0.2m) and small creeks.	Dampier Region, Northern QLD	(Blaber et al. 1985)
Blue threadfin	*Eleutheronema tetradactylum*	No reports		
King threadfin	*Polydactylus macrochir*	Estuary	Fitzroy River	(Halliday et al. 2008)
		Estuaries	South Queensland	(Moore et al. 2011)
Barramundi	*Lates calcarifer*	Juveniles migrate upstream from estuaries into freshwater	Review	(Mallen-Cooper 1992)
		Juveniles caught in temporary intertidal pools on saltpans, larger juveniles in main stream.	Gulf of Carpentaria and Qld east coast	(Russell & Garrett 1983, Davis 1986, Russell & Garrett 1988, Sheaves et al. 2007, Davis et al. 2012)
		Submerged dead timber	North-eastern Qld	(Sheaves 1996)
Mackerel: spotted	*Scomberomorus munroi*	No reports		

Common Name	**Species**	**Juvenile habitat**	**Comments**	**reference**
Mackerel: grey	*Scomberomorus semifasciatus*	Juveniles found in the mangrove channel and deep water open shore habitat.	Dampier Region, Northern QLD	(Blaber et al. 1985)
Mackerel: school	*Scomberomorus queenslandicus*	Juveniles found in deep water open shore habitat.	Dampier Region, Northern QLD	(Blaber et al. 1985)
Mackerel: spanish	*Scomberomorus commerson*	Juveniles found in the mangrove channel and deep water open shore habitat.	Dampier Region, Northern QLD	(Blaber et al. 1985)
Mullet: diamondscale	*Liza vaigiensis*	Juveniles found in the mangrove channel, intertidal mangrove habitat (<2m but >0.2m), deep water, intertidal pools (<2m) and tidal pools.	Dampier Region, Northern QLD	(Blaber et al. 1985)
Mullet: sea	*Mugil cephalus*	Juveniles caught in drainage creek surrounded by *Avicennia marina*	Botany Bay, NSW	(Bell et al. 1984)
		Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Mugil sp. juveniles caught in mudflats, pneumatophore fringe and mangroves at Deception bay, but not at Fisherman Island	Moreton Bay QLD	(Laegdsgaard and Johnson 1995)
		Juveniles found in the mangrove channel, intertidal mangrove habitat (>0.2m but ,2m) deep water open shore habitats and intertidal open shore habitats (<2m).	Dampier Region, Northern QLD	(Blaber et al. 1985)
Giant queenfish	*Scomberoides commersonnianus*	Juveniles caught within/adjacent to mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Juveniles caught in *Rhizophora stylosa* mangrove forest	Tin Can Bay, QLD	(Halliday and Young 1996)
		muddy/sandy substrate	Gulf of Carpentaria	(Blaber et al. 1995)
Barred queenfish	*Scomberoides tala*	Juveniles in estuaries	Northern Queensland	Sheaves (2006, 2009)
Amberjack	*Seriola dumerili*	Pelagic, fish aggregation device (FAD), (report from outside Australia)		(Sinopoli et al. 2007)
Samsonfish	*Seriola hippos*	No reports		
Yellowtail kingfish	*Seriola lalandi*	Pelagic, fish aggregation device (FAD)		(Dempster 2004)
Bigeye trevally	*Caranx sexfasciatus*	Muddy substrate in mangrove forests	Trinity inlet	(Blaber 1980)
		Juveniles in estuaries	Northern Queensland	Sheaves (2006, 2009)
Golden trevally	*Gnathanodon speciosus*	Juveniles caught in *Rhizophora stylosa* mangrove forest	Tin Can Bay, QLD	(Halliday and Young 1996)
		Juveniles found in the mangrove channel	Dampier Region, Northern QLD	(Blaber et al. 1985)
Giant trevally	*Caranx ignoblis*	Juveniles caught in mangrove forest	Moreton Bay, QLD	(Morton 1990)
		Juveniles in estuaries	Northern Queensland	Sheaves (2006, 2009)
Papuan trevally	*Caranx papuensis*	Juveniles in estuaries	Northern Queensland	Sheaves (2006, 2009)
Swallow-tailed dart	*Trachinotus coppingeri*	No reports		

References for Appendix Table 1

Arvedlund, M. and Takemura, A. (2006) The importance of chemical environmental cues for juvenile L*ethrinus nebulosus* Forsskål (Lethrinidae, Teleostei) when settling into their first benthic habitat. *Journal of Experimental Marine Biology and Ecology,* **338,** 112-122.

Bell, J., Pollard, D., Burchmore, J., Pease, B. and Middleton, M. (1984) Structure of a fish community in a temperate tidal mangrove creek in Botany Bay, New South Wales. *Marine and Freshwater Research,* **35,** 33-46.

Blaber, S. J. M. (1980) Fish of the trinity inlet system of North Queensland with notes on the eology of fish faunas of tropical Indo-Pacific estuaries. *Australian Journal of Marine and Freshwater Research,* **31,** 137-146.

Blaber, S. J. M. and Blaber, T. G. (1980) Factors affecting the distribution of juvenile estuarine and inshore fish. *Journal of Fish Biology,* **17,** 143-162.

Blaber, S. J. M., Brewer, D. T. and Salini, J. P. (1989) Species composition and biomasses of fishes in different habitats of a tropical northern Australian estuary: Their occurrence in the adjoining sea and estuarine dependence. *Estuarine, Coastal and Shelf Science,* **29,** 509-531.

Blaber, S. J. M., Brewer, D. T. and Salini, J. P. (1995) Fish communities and the nursery role of the shallow inshore waters of a tropical bay in the Gulf of Carpentaria, Australia. *Estuarine, Coastal and Shelf Science,* **40,** 177-193.

Blaber, S., Young, J. and Dunning, M. (1985) Community structure and zoogeographic affinities of the coastal fishes of the Dampier region of north-western Australia. *Marine and Freshwater Research,* **36,** 247-266.

Broadhurst, M. K. and Kennelly, S. J. (1994) Reducing the by-catch of juvenile fish (mulloway *Argyrosomus hololepidotus*) using square-mesh panels in codends in the Hawkesbury River prawn-trawl fishery, Australia. *Fisheries Research,* **19,** 321-331.

Burchmore, J. J., Pollard, D. A. and Bell, J. D. (1984) Community structure and trophic relationships of the fish fauna of an estuarine *Posidonia australis* seagrass habitat in Port Hacking, New South Wales. *Aquatic Botany,* **18,** 71-87.

Burchmore, J., Pollard, D., Middleton, M., Bell, J. and Pease, B. (1988) Biology of four species of whiting (Pisces: Sillaginidae) in Botany Bay, NSW. *Marine and Freshwater Research,* **39,** 709-727.

Davis B, Johnston R, Baker R, Sheaves M (2012) Fish utilisation of wetland nurseries with complex hydrological connectivity. PLoS ONE 7(11): e49107.

Dempster, T. (2004) Biology of fish associated with moored fish aggregation devices (FADs): Implications for the development of a FAD fishery in New South Wales, Australia. *Fisheries Research,* **68,** 189-201.

Fry, G., Milton, D., Velde, T., Stobutzki, I., Andamari, R., Badrudin and Sumiono, B. (2009) Reproductive dynamics and nursery habitat preferences of two commercially important Indo-Pacific red snappers *Lutjanus erythropterus* and *L. malabaricus*. *Fisheries Science,* **75,** 145-158.

Gavin, S. A. and Potter, I. C. (2000) Variation in age compositions and growth rates of *Acanthopagrus butcheri* (Sparidae) among estuaries: Some possible contributing factors. *Fishery Bulletin,* **98**.

Grandcourt, E. M., Al Abdessalaam, Thabit, Z., Al Shamsi, Ahmed, T. and Francis, F. (2006) Biology and assessment of the painted sweetlips (D*iagramma pictum* (Thunberg, 1792)) and the spangled emperor (L*ethrinus nebulosus* (Forsskål, 1775)) in the southern Arabian Gulf. *Fishery Bulletin,* **104,** 75-88.

Gray, C. A., Chick, R. C. and Mcelligott, D. J. (1998) Diel changes in assemblages of fishes associated with shallow seagrass and bare sand. *Estuarine, Coastal and Shelf Science,* **46,** 849-859.

Gray, C. and Mcdonall, V. (1993) Distribution and growth of juvenile mulloway, *Argyrosomus hololepidotus* (Pisces: Sciaenidae), in the Hawkesbury River, south-eastern Australia. *Marine and Freshwater Research,* **44,** 401-409.

Gray, C., Mcelligott, D. and Chick, R. (1996) Intra- and inter-estuary differences in assemblages of fishes associated with shallow seagrass and bare sand. *Marine and Freshwater Research,* **47,** 723-735.

Griffiths, S. P. (2001) Factors influencing fish composition in an Australian intermittently open estuary. Is stability salinity-dependent? *Estuarine, Coastal and Shelf Science,* **52,** 739-751.

Halliday, I. A., Robins, J. B., Mayer, D. G., Staunton-Smith, J. and Sellin, M. J. (2008) Effects of freshwater flow on the year-class strength of a non-diadromous estuarine finfish, king threadfin (*Polydactylus macrochir*), in a dry-tropical estuary. *Marine and Freshwater Research,* **59,** 157-164.

Halliday, I. and Young, W. (1996) Density, biomass and species composition of fish in a subtropical *Rhizophora stylosa* mangrove forest. *Marine and Freshwater Research,* **47,** 609-615.

Hamer, P. A. and Jenkins, G. P. (1997) Larval supply and short-term recruitment of a temperate zone demersal fish, the King George whiting, *Sillaginodes punctata* Cuvier and Valenciennés, to an embayment in south-eastern Australia. *Journal of Experimental Marine Biology and Ecology,* **208,** 197-214.

Hamer, P. A., Jenkins, G. P. and Gillanders, B. (2003) Otolith chemistry of juvenile snapper *Pagrus auratus* in Victorian waters: Natural chemical tags and their temporal variation. *Marine Ecology Progress Series,* **263,** 261-273.

Hannan, J. (1998) Fish recruitment in estuaries. *Fisheries NSW [Fish. N.S.W.]. Spring 1998, p,* **36**.

Harris, J. (1986) Reproduction of the Australian bass, *Macquaria novemaculeata* (Perciformes : Percichthyidae) in the Sydney Basin. *Marine and Freshwater Research,* **37,** 209-235.

Hyndes, G. A. and Potter, I. C. (1996) Comparisons between the age structures, growth and reproductive biology of two co-occurring Sillaginids, *Sillago robusta* and *S. bassensis*, in temperate coastal waters of Australia. *Journal of Fish Biology,* **49,** 14-32.

Hyndes, G. A., Platell, M. E. and Potter, I. C. (1997) Relationships between diet and body size, mouth morphology, habitat and movements of six Sillaginid species in coastal waters: Implications for resource partitioning. *Marine Biology,* **128,** 585-598.

Hyndes, G. A., Platell, M. E., Potter, I. C. and Lenanton, R. C. J. (1998) Age composition, growth, reproductive biology, and recruitment of King George whiting, *Sillaginodes punctata*, in coastal waters of southwestern Australia. *Fishery Bulletin,* **96,** 258-270.

Hyndes, G. A., Potter, I. C. and Hesp, S. A. (1996) Relationships between the movements, growth, age structures, and reproductive biology of the teleosts *Sillago burrus* and *S. vittata* in temperate marine waters. *Marine Biology,* **126,** 549-558.

Hyndes, G. and Potter, I. (1997) Age, growth and reproduction of *Sillago schomburgkii* in south-western Australian, nearshore waters and comparisons of life history styles of a suite of Sillago species. *Environmental Biology of Fishes,* **49,** 435-447.

Jenkins, G. P. and Hamer, P. A. (2001) Spatial variation in the use of seagrass and unvegetated habitats by post-settlement King George whiting (Percoidei: Sillaginidae) in relation to meiofaunal distribution and macrophyte structure. *Marine Ecology Progress Series,* **224,** 219-229.

Jenkins, G. P., Wheatley, M. J. and Poore, A. G. B. (1996) Spatial variation in recruitment, growth, and feeding of postsettlement King George whiting, *Sillaginodes punctata*, associated with seagrass beds of Port Phillip Bay, Australia. *Canadian Journal of Fisheries and Aquatic Sciences,* **53,** 350-359.

Laegdsgaard, P. and Johnson, C. R. (1995) Mangrove habitats as nurseries: Unique assemblages of juvenile fish in subtropical mangroves in eastern Australia. *Marine Ecology Progress Series,* **126,** 67-81.

Lenanton, R., Ayvazian, S., Pearce, A., Steckis, R. and Young, G. (1996) Tailor (*Pomatomus saltatrix*) off Western Australia: Where does it spawn and how are the larvae distributed? *Marine and Freshwater Research,* **47,** 337-346.

Mallen-Cooper, M. (1992) Swimming ability of juvenile Australian bass, *Macquaria novemaculeata* (Steindachner), and juvenile barramundi, *Lates calcarife* (Bloch), in an experimental vertical-slot fishway. *Marine and Freshwater Research,* **43,** 823-833.

Mcneill, S. E., Worthington, D. G., Ferrell, D. J. and Bell, J. D. (1992) Consistently outstanding recruitment of five species of fish to a seagrass bed in Botany Bay, NSW. *Australian Journal of Ecology,* **17,** 359-365.

Middleton, M. J., Bell, J. D., Burchmore, J. J., Pollard, D. A. and Pease, B. C. (1984) Structural differences in the fish communities of *Zostera capricorni* and *Posidonia australis* seagrass meadows in Botany Bay, New South Wales. *Aquatic Botany,* **18,** 89-109.

Moore, B. R., Welch, D. J. and Simpfendorfer, C. A. (2011) Spatial patterns in the demography of a large estuarine teleost: King threadfin, *Polydactylus macrochir*. *Marine and Freshwater Research,* **62,** 937-951.

Morton, R. M. (1990) Community structure, density and standing crop of fishes in a subtropical Australian mangrove area. *Marine Biology,* **105,** 385-394.

Phelan, M. J., Gribble, N. A. and Garrett, R. N. (2008) Fishery biology and management of *Protonibea diacanthus* (Sciaenidae) aggregations in far northern Cape York Peninsula waters. *Continental Shelf Research,* **28,** 2143-2151.

Potter IC, Hyndes GA (1994) composition of the fish fauna of a permanently open estuary on the southern coast of australia, and comparisons with a nearby seasonally closed estuary. Marine Biology 121:199-209

Robertson, A. (1977) Ecology of juvenile King George whiting *Sillaginodes punctatus* (Cuvier & Valenciennes) (Pisces: Perciformes) in Western Port, Victoria. *Marine and Freshwater Research,* **28,** 35-43.

Robertson, A. I. and Duke, N. C. (1990) Mangrove fish-communities in tropical Queensland, Australia: Spatial and temporal patterns in densities, biomass and community structure. *Marine Biology,* **104,** 369-379.

Russell, D. and Garrett, R. (1983) Use by juvenile barramundi, *Lates calcarifer* (Bloch), and other fishes of temporary supralittoral habitats in a tropical estuary in northern Australia. *Marine and Freshwater Research,* **34,** 805-811.

Russell, D. J. and McDougall A. J. (2003), Queensland Dept. of Primary Industries and Fisheries Research & Development Corporation (Australia) (2003) Biology, management and genetic stock structure of mangrove jack (*Lutjanus argentimaculatus*) in Australia. Department of Primary Industries, Fishery Research and Development Corporation, Brisbane.

Russell, D. J. and McDougall, A. J. (2005) Movement and juvenile recruitment of mangrove jack, *Lutjanus argentimaculatus* (Forsskål), in northern Australia. *Marine and Freshwater Research,* **56,** 465-475.

Saintilan, N. (2004) Relationships between estuarine geomorphology, wetland extent and fish landings in New South Wales estuaries. *Estuarine, Coastal and Shelf Science,* **61,** 591-601.

Sarre GA, Potter IC (2000) Variation in age compositions and growth rates of *Acanthopagrus butcheri* (Sparidae) among estuaries: some possible contributing factors. Fish Bull 98:785-799

Sheaves M (2006) Scale dependent variation in composition of fish fauna among tropical estuarine sandy embayments Marine Ecology Progress Series 310:173-184

Sheaves M (2006) Scale dependent variation in composition of fish fauna among tropical estuarine sandy embayments Marine Ecology Progress Series 310:173-184

Sheaves M, Johnston R, Abrantes K (2007) Fish fauna of dry sub-tropical estuarine floodplain wetlands. Marine and Freshwater Research. 58(10) 931-943

Sheaves M, Johnston R (2009) Ecological drivers of spatial variability among fish fauna of 21 tropical Australian estuaries. Marine Ecology Progress Series 385: 245-260

Sheaves M, Johnston R (2009) Ecological drivers of spatial variability among fish fauna of 21 tropical Australian estuaries. Marine Ecology Progress Series 385: 245-260

Sheaves, M. (1995) Large lutjanid and serranid fishes in tropical estuaries: Are they adults or juveniles? *Marine Ecology-Progress Series,* **129,** 31-40.

Silberschneider, V. and Gray, C. A. (2008) Synopsis of biological, fisheries and aquaculture-related information on mulloway *Argyrosomus japonicus* (Pisces: Sciaenidae), with particular reference to Australia. *Journal of Applied Ichthyology,* **24,** 7-17.

Sinopoli, M., D'anna, G., Badalamenti, F. and Andaloro, F. (2007) FADs influence on settlement and dispersal of the young-of-the-year greater amberjack (Seriola dumerili). *Marine Biology,* **150,** 985-991.

Taylor, M. D., Laffan, S. D., Stewart Fielder, D. and Suthers, I. M. (2006) Key habitat and home range of mulloway *Argyrosomus japonicus* in a south-east Australian estuary: Finding the estuarine niche to optimise stocking. *Marine Ecology Progress Series,* **328,** 237-247.

Weng, H. T. (1983) Identification, habitats and seasonal occurrence of juvenile whiting (Sillaginidae) in Moreton Bay, Queensland. *Journal of Fish Biology,* **23,** 195-200.

Williams, A. J., Davies, C. R. and Mapstone, B. D. (2006) Regional patterns in reproductive biology of *Lethrinus miniatus* on the Great Barrier Reef. *Marine and Freshwater Research,* **57,** 403-414.

Wolanski, E. (2001) Oceanographic processes of coral reefs: Physical and biological links in the great barrier reef*,* USA, CRC Press.

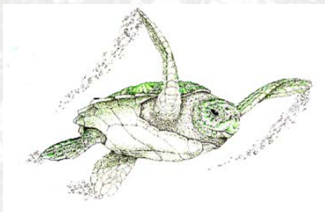
Worthington, D., Ferrell, D., Ncneill, S. and Bell, J. (1992) Growth of four species of juvenile fish associated with the seagrass *Zostera capricorni*, in Botany Bay, NSW. *Marine and Freshwater Research,* **43,** 1189-1198.

Zeller, B., Pollock, B. and Williams, L. (1996) Aspects of life history and management of tailor (*Pomatomus saltatrix*) in Queensland. *Marine and Freshwater Research,* **47,** 323-329.

Appendix 3b: Project No. 2012/037

A Business Case for Obtaining Funding for Future Fish-Habitat Research

Peter Wulf



AWOFTAM Enviro and Legal

July 2013

JAMES COOK UNIVERSITY AUSTRALIA

Centre for Tropical Water and Aquatic Ecosystem Research TropWATER

Estuary & Tidal Wetland Ecosystems Research Group

Executive Summary

This Business Case identifies potential funding opportunities to fill research gaps based on the report of Sheaves *et* al to advance the research needs to greater understand the life-cycle habitat requirements of coastal fisheries species. This Business Case sets out how the priority research areas can be studied based on the opportunities for Government and external investment into that research.

The primary opportunity to gain additional funding outside the normal funding bodies such as the Fisheries Research and Development Corporation, Australian Research Council, Commonwealth and State Departments of Agriculture, Fisheries and Forestry; Commonwealth Scientific and Industrial Research Organisation etc, is via both proponents proposing to development within the coastal and marine zones, and via access to monies paid for offsets through both the Commonwealth and Queensland Governments. Both levels of Government have offset policies documents that to allow research to be integrated into a project's offset requirements as an indirect offset. The Commonwealth has a structure in place that allows for research to be contracted while the Queensland Government has the Fisheries Research Fund that contains arrangements that allows third parties such as universities and research institutions to gain access to monies for the purpose of undertaking research. There are also a number of projects identified within the Business Case that would link within the projects proposed by Sheaves *et al* that are suggested as possible projects industry would see benefit in being undertaken.

The author suggests that the most effective way to obtain research funding is to time discussions effectively and be involved in the environmental assessment process for a project so as baseline data can be collected by the researcher within this process. All projects that the author has been involved in undergo a lengthy planning process prior to an environmental assessment is commenced. For example, projects at Abbot Point were discussed with industry and government for about a year prior to the commencement of any environmental assessment. Once the actual assessment commences, researchers may have lost their opportunity to be involved through the evolution of the environmental assessment. Therefore immediately on hearing of the project and prior to the release of a referral and/or initial advice statement under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) or *State Development and Public Works Organisation Act 1971* (Qld), researchers should contact proponents and demonstrate how their research work would fall within the gambit of an indirect offset, how regulators would see that it would be a beneficial project to fall within the concept of an indirect offset, show how that it is important in respect of what should be funded as part of a research component of an offset strategy and importantly, how the research would increase the proponent's understanding of their environmental impact (preferably in a positive manner) and/or provide the proponent with evidence that their project will provide positive benefits to the community's understanding the life-cycle habitat requirements of coastal fisheries species.

It is suggested that researcher follow the market and look for tenders where proponents are seeking to engage consultants to undertake work associated with their projects, including for example, the preparation of both the referral and/or initial advice statement. Early engagement is of potential benefit for both the proponent and the researcher. For early engagement to be successful, it is essential that researchers develop an understanding of the actual proposed projects themselves and the details of likely potential impacts. Failing to do this may be viewed by a proponent as being treated as a "blank cheque" by a research body which is unlikely to lead to successful engagement. A tangible partnership is required where the researcher can address the high priority needs of the proponent using an appropriate skill set.

Introduction

The Fisheries Research and Development Corporation (FRDC) has provides funding to the Queensland Fisheries Research Advisory Body (QFRAB) for priority research into fisheries in Queensland. Following a prioritisation evaluation by QFRAB of a number of projects in 2012, funding was provided to James Cook University to undertake research leading to a greater understanding of the life cycle habitat requirements of coastal fisheries species. This funding constituted approximately $400,000 from both the FRDC and the Queensland Government through an agreed funding model.

On 28th February 2012, a workshop was conducted in Townsville to discuss the draft proposed project that had been selected by QFRAB but not fully approved by the FRDC Board. The outcomes of the workshop were that Sheaves *et al* would undertake a gap analysis and prepare a report that could be used to give QFRAB and FRDC a greater understanding of the research needs that could be funded by FRDC or other entities in the future. A further outcome of the workshop was the development of a Business Case (this document). This Business Case identifies potential funding opportunities and/or ways to approach industry to provide support to fill research gaps identified by gap analysis. Collaboration and co-investment where possible are critical pathways to assist research outputs being translated into research outcomes. This Business Case sets out how the author believes the overall priority research areas can be funded and therefore studied based on the opportunities for Government and external investment into that research.

Research Needs

Sheaves *et al* identified 18 critical research gaps that they believed need to be filled by research.

1. *Mapping, baselines and monitoring;*
2. *Formalising fisher knowledge on fish habitat utilisation;*
3. *Connectivities supporting life-history functions;*
4. *Environmental conditions that facilitate or impair connectivity;*
5. *How the habitat value of artificial structures can be maximised;*
6. *Information on non-target species;*
7. *Habitat values of deeper and unvegetated habitats;*
8. *Habitat resource utilisation;*
9. *Detailed identification of spawning habitats;*
10. *The exact settlement process;*
11. *The range of nursery habitats utilised;*
12. *The habitats utilised at different stages of nursery residence;*
13. *Synergies among habitats that support nursery function;*
14. *Non-habitat nursery resources requirements;*

15. *Stage-specific habitat and non-habitat resource requirements;*

16. *Geographic variation in nursery ground value;*

17. *Relative contributions to adult stocks from different nursery habitats; and*

18. *Processes regulating growth and survival of juveniles in nursery grounds*

This Business Case discusses some of these research needs broadly, but cannot possibly undertake a full assessment of how individual topics can be filled as this would be beyond the scope of the author due to the limited information provided by Sheaves *et al* in their gap analysis. However, this Business Case can and has identified funding opportunities that may link with those proposed by Sheaves *et al*. As an example, McPhee *et al* (2012) is how the second project identified Sheaves *et al* (formalising fisher knowledge on fish habitat utilisation) can be funded by industry and at the same time provide researchers with valuable information. This approach is discussed later in this document.

Standard Funding Bodies

In this Business Case, a focus is on projects that can be funded wholly or partly through the FRDC. Additional Government's funding includes:

- Commonwealth and State Fisheries agencies within the Departments of Agriculture, Fisheries and Forestry;
- Commonwealth Scientific and Industrial Research Organisation; and
- Australian Research Council.

It is not proposed that the FRDC will be able to fund all projects identified in Sheaves *et al* and a number of projects should be developed where other funding sources are being targeted. It is further not proposed to discuss these normal funding options are it is expected that researchers would already have an understanding of the process for gaining funding from these organisations.

Additionally, funding can also be obtained from organisations such as the Great Barrier Reef Foundation. The Commonwealth Government has committed $12.5 million to the Foundation towards a four year program of research commencing in July 2013. The overarching goal of the program is the provision of knowledge to inform management of the Reef in the face of a changing and increasingly variable climate. A total of 7 projects are available for funding in the 2013 open selection round including:

- Project 1: Attribute - Coral Health: Bleaching and Disease;
- Project 2: Attribute - Habitat structure: Structural Complexity and Community Composition;
- Project 3: Attribute - Calcification: Corals, CCA and Foraminifera;
- Project 4: Attribute - Seagrass: Connectivity, Abundance and Growth Rates;
- Project 5: Solutions and Adaptation: Ocean Acidification: Increasing the Available Carbonate Chemistry Data for the Great Barrier Reef;
- Project 6: Solutions and Adaptation: Ocean Acidification: Developing a Carbon Budget for the Great Barrier Reef; and
- Project 7: Solutions and Adaptation: Modelling the Feasibility of Small-Scale Biological and Chemical Buffering

It is possible that some of the research gaps identified by Sheaves *et al* could fall within Project 5 and could gain funding through this program. Researchers should make themselves aware of the opportunities available for funding in the near future.

Research Funding through Indirect Offset Monies

Both Commonwealth and Queensland Governments have developed Offset Policies. Offsets are defined as measures that compensate for the so called residual adverse impacts of a project on the environment, whether they be on a terrestrial and/or marine environment. Offsets provide environmental benefits to counterbalance the impacts that remain after avoidance and mitigation measures where these cannot protect the environment. These remaining, unavoidable impacts are termed residual impacts. The concept on an offsets is to help achieve long-term environmental outcomes, while providing flexibility for proponents seeking to undertake projects that will have residual impacts.

When a proponent intends to undertake a project that will have residual impacts, they are required to develop an offsets package. For example, this may be called for example, a Biodiversity Offset Strategy or other titles and these are developed during the later periods of an environmental assessment process. The development of an offset strategy will usually involve significant consultation with the regulators (for example the Commonwealth Department of Sustainability, Environment, Water, Population and Communities, the Great Barrier Reef Marine Park Authority, Queensland Office of Coordinator General, Queensland Department of Agriculture, Fisheries and Forestry etc). An offset strategy will identify the strategic location of offsets in areas where the range of values to be lost from potential development occur. These offset investment hubs will be used to manage and protect those values to ensure long-term environmental outcomes at the wider landscape scale. Offsets are most effective when provided in the same region where the impact occurs. The offset investment hubs enable the integration of multiple offsets within an area, as opposed to small fragmented offsets across a wider area. Offsets are easily undertaken in terrestrial environments; however, in marine environments, they are more difficult to ensure long term protection unless there is significant assistance from regulators to ensure long-term environmental outcomes.

Offsets are separated into what are defined as direct and indirect/other compensatory offsets. Direct offsets are those actions that provide a measurable conservation gain on the environment that is being impacted. Direct offsets are an essential component of a suitable offsets package. Under the Commonwealth and Queensland legislation, a minimum of 90% of the offset requirements for any given impact must be met through direct offsets. However, the author can advise the reader for example, that is not possible to offset projects specifically within a World Heritage Area (eg Great Barrier Reef World Heritage Area) and therefore a deviation is possible where a proponent can demonstrate that it would be effective to do so Further, the Commonwealth offset policy allows for a deviation from the 90% direct offset requirement where it can be demonstrated that a greater benefit to the environment is likely to be achieved through increasing the proportion of other compensatory measures in an offsets package or; and of more importance for researchers, where scientific uncertainty is so high that it is not possible to determine a direct offset that is likely to benefit the specific aspect that is protected under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth). This can be the case in some poorly understood ecosystems in the Commonwealth marine environment (and could also include marine areas within the Great Barrier Reef World Heritage Area). Conservation gain in the marine environment may include improving protection of important protected species habitat, such as sea grass, or by addressing pressures on a specific species or its habitat, such as removing derelict fishing nets and other marine debris.

There are two key types of information utilised in planning an offset proposal, determining what types of activities would be appropriate as offsets for a given impact, and determining the specific size and scope of an offsets package. In determining the appropriateness of the offset activities proposed, the regulator will consult the relevant Commonwealth approved recovery plan, threat abatement plan, conservation advice, ecological character description, management plan and/or listing document should they be relevant. Where Commonwealth approved guidance documents are not available or are insufficient in detail, the regulator will review additional information sources such as state and territory management plans or peer-reviewed scientific literature to inform priority offset activities.

If the regulator is satisfied that the offset activities are suitable, they will consider whether appropriateness of the magnitude and composition of the proposed offset package in detail on a case-by-case basis. There are a range of considerations taken into account at both the impact site and the proposed offset site. Proponents will need to include detailed information pertaining to these considerations in their offsets proposal.

Things that need to be considered at the impacted site include the:

1. presence and conservation status of protected matters likely to be impacted by the proposed action;
2. specific attributes of the protected matter being impacted at a site, for example: the type of threatened species or ecological community habitat, the quality of habitat, population attributes such as recruitment or mortality, landscape attributes such as habitat connectivity, or heritage values;
3. scale and nature of the impacts of the proposed action, including direct and indirect impacts; and
4. duration of the impact (not of the action).

Things that need to be considered at the offset site include the:

1. extent to which the proposed offset actions correlate to, and adequately compensate for, the impacts on the attributes for the protected matter
2. conservation gain to be achieved by the offset. This may be through positive management activities that improve the viability of the protected matter or averting the future loss, degradation or damage of the protected matter
3. current land tenure of the offset and the proposed method of securing and managing the offset for the life of the impact
4. time it will take to achieve the proposed conservation gain
5. level of certainty that the proposed offset will be successful. In the case of uncertainty, such as using a previously untested conservation technique, a greater variety and/or quantity of offsets may be required to minimise risk
6. suitability of the location of the offset site. In most cases this will be as close to the impact site as possible. However, if it can be shown that a greater conservation benefit for the impacted protected matter can be achieved by providing an offset further away, then this will be considered.

Offsets that deliver social, economic and/or environmental co-benefits are encouraged.

As to how indirect offsets may be utilised by researchers, the author provides an overview of the relevant policies that could provide funding.

Commonwealth Offset Policy

Indirect Offset Funding

Indirect offsets are those actions that do not directly offset the impacts on the environment, but are anticipated to lead to benefits for the impacted protected Matter of National Environmental Significance, for example funding for research or educational programs. For example, research into effective re-vegetation techniques for a particular ecological community may be an appropriate component of an offsets package for an action that involves clearing of that ecological community.

Appendix A of the Commonwealth Offsets Policy provides criteria for research and educational programs, which are where researchers should target their endeavours to gain funding. Under the Policy, a suitable research or education program must:

1. endeavour to improve the viability of the impacted protected matter, for example;
    - signage in key areas to educate the public regarding the risks to a threatened animal, or
    - research into effective re-vegetation techniques for a threatened ecological community
2. be targeted toward key research/education activities as identified in the relevant Commonwealth approved recovery plan, threat abatement plan, conservation advice, ecological character description, management plan or listing document. Where Commonwealth approved guidance documents are not available or are insufficient in detail, the department will consider additional information sources such as state and territory management plans or peer reviewed scientific literature to inform priority offset activities
3. be undertaken in a transparent, scientifically robust and timely manner
4. be undertaken by a suitably qualified individual or organisation in a manner approved by the department
5. consider best practice research approaches.

If a research or education program is to be accepted by regulators, the proponent is required to:

1. select an institutional or individual host (for the purpose of executing the program) through an internationally available open tender process or provide evidence that the program can be successfully undertaken in-house. The department will not be responsible for processing tenders. Where appropriate, the tender should complement an existing research institution's (e.g. National Environmental Research Program Hub) work program as it relates to the matter of national environmental significance. This will be the responsibility of the proponent; however, the department will require that proponents follow the department's guidelines
2. provide updates on progress and key findings to the department through periodic reporting
3. ensure that funds are managed appropriately and that auditable financial records are kept and maintained
4. apply a 'no-surprises' policy to the publication, whereby research publications and outputs are provided to the department at least 5 working days before release.

Any research programs that will be accepted by regulators must:

1. be tailored to at least a postgraduate education level; however, there will be scope to engage other educational levels in educational programs (see below)
2. present findings that can be peer-reviewed
3. publish findings in an internationally recognised peer-reviewed scientific journal or be of a standard that would be acceptable for publication in such a journal. Publications should be submitted to free open access journals. Data and information collected should have creative commons licensing and be free and accessible
4. provide research outputs that inform future management decisions on the protected matter and, where possible, be readily applicable to other similar matters (species groupings etc).

Any education programs that will be accepted by regulators must:

1. be likely to vary in scope, mode of delivery and duration according to the target audience and the protected matter, (for instance, school or community programs, signage or printed materials)
2. seek to attain measurable outcomes. Note that it may be difficult to ascertain the scope of influence of educational programs as it can be difficult to link education activities to behavioural change and subsequent improvement in the viability of the protected matter
3. be targeted toward behavioural change and subsequent improvement in the viability of the protected matter.

An additional way that researchers can be specifically engaged to undertake research is through what are called advance offsets. Advanced offsets are a supply of offsets for potential future use, transfer or sale and the like. An example of an advanced offset is the protection or improvement of habitat for the conservation of a specific aspect before an impact is undertaken. Advanced offsets are encouraged where practical, given that they provide a means to better manage the risks associated with the time delay in realising the conservation gain for a protected matter.

Should a proponent believe that an advanced offsets would be beneficial to their project, then this provides researchers the opportunity to both undertake something similar to consultancy work that would monitor and record baseline data associated with the establishment of the offset and improvements over time but at the same time, provide the ability to undertake researcher. The author believes that the undertaking of advanced offsets can provide valuable benefits to proponents and therefore, researchers should develop proposals to undertake research that can also be used as baseline data. This for example could be a PhD; however, unlike standard academic programs where there is delay in the setting up of experiments and the like, proponents will expect that this preparation be undertaken prior to seeking funding. As an example, a PhD would take up to four years for the research to be finalised, whereas consultant work is usually undertaken and completed within 12 months. Researchers should be very conscious of these timing aspects which will be discussed later in this Business Case.

Queensland Marine Offset Policy

Fisheries Queensland with the Queensland Department of Agriculture, Fisheries and Forestry has developed the marine fish habitat offset policy. This policy follows a similar process as identified above with respect to direct and indirect offsets. For the marine environment, the selection of proposed offset requires proponents to provide 'like for like' proposals as 'marine fish habitat for 'marine fish habitat' being the first priority. Where proposed direct offsets are not possible, or the use of proposed direct offsets does not fully address all residual development impacts, indirect offsets may then be considered.

Queensland has an Environmental Offsets Policy (EOF) and this policy has seven guiding principles:

1. Offsets will not replace or undermine existing environmental standards or regulatory requirements, or be used to allow development in areas otherwise prohibited through legislation or policy;
2. Environmental impacts must first be avoided, then minimised, before considering the use of offsets for any remaining impact;
3. Offsets must achieve an equivalent or better environmental outcome;
4. Offsets must provide environmental values as similar as possible to those being lost;
5. Offset provision should minimise the time-lag between the impact and delivery of the offset;
6. Offsets must provide additional protection to environmental values at risk, or additional management actions to improve environmental values; and
7. Offsets must be legally secured for the duration of the offset requirement.

Like the Commonwealth Policy, offset funding (in-kind or as a financial contribution) may be provided as indirect offset where a link with marine fish habitats and fisheries resources is identifiable (research etc). The Queensland Government has established the Fisheries Research Fund which is used where financial contributions are accepted as an indirect offset. Alternately, Fisheries Queensland may arrange for a third party such as a researcher organisation to deliver the offset under a Deed of Agreement or departmental contract. This is a perfect example where researchers can be involved in undertaking research that can be used to assist proponents.

Contributions in-kind or as a financial payments as an indirect offset for the loss of fish habitats are administered through the Fisheries Research Fund under the *Fisheries Act 1994* (Qld); or, what would be preferable to researchers, through an agreement between the proponent and third party in order to meet the associated costs for one or more of the following:

- Applied research, investigative resource inventories, fish habitat mapping projects: projects conducted by an organisation or tertiary institute linked to Fish Habitat Research and Management Program research and management stream priorities to assist fish habitat management and research outcomes; or investigative resource inventories and habitat mapping to aid fish habitat management activities;
- Education, training or extension – i.e. provision of signage or educational materials for marine fish habitat information/ management and associated costs for programs relating to fish habitat management, education and awareness for community benefit (including, for example: natural resource management programs; and Marine Fish Habitat Honours Scholarships Program), and/or
- Enhancement, restoration, rehabilitation or creation – associated management and delivery costs of rehabilitation or fish habitat protection projects as outlined in a) and b) (above) including costs of:
- third party land stewardship payments or to improve freehold fish habitats adjoining a declared Fish Habitat Area, under a covenant;
- fish habitat components of a natural resource management plan; and/or
- Fish habitat exchange or increased security – associated management and delivery costs, as outlined in c) above.

If an offset is going to be secured through an agreement, there needs to needs to be a legally binding Offset Deed of Agreement with the Queensland Department of Agriculture, Fisheries and Forestry and a contract between a third party (e.g. researcher) and Fisheries Queensland, prepared using Department of Agriculture, Fisheries and Forestry's contract based on priorities in the Fish Habitat Research and Management Program) to stipulate:

- the terms of use of all project and research findings and distribution of information, including publication of research findings and intellectual property rights;
- milestones for offset delivery beyond one financial year or overlapping two or more financial years,
- and for the contract to be forwarded for the third party's perusal and agreement prior to each party signing (and retaining a copy); or
- a Letter of Agreement between Fisheries Queensland and a tertiary institution for the DAFF Marine Fish Habitat Scholarships Program; and
- selection of fish habitat projects that demonstrate a local connectivity with the fish habitat that is approved for disturbance.

Accordingly, like the Commonwealth Policy, there are several mechanisms that would allow researchers to leverage funds from the Queensland programs to undertake specific research that fits within the gaps identified by Sheaves *et al*.

Direct Industry Funded Specific Research

There are a number of opportunities for researchers to obtain funding from industry and for example, Government Owned Corporations that would target the highest priorities for the sectors. While it outside the realms of possibility to identify all potential projects and opportunities, a number of potential opportunities are highlighted below that the author considers would be valuable for industry that also align with the research gaps identified by Sheaves *et al.* The example projects have been identified during consultations to prepare this Business Case.

Fish Ladders and Access to Upstream Environments

The literature has identified that species such as Barramundi and some other species do not use the 1 in 18 fish passage devices that are often installed with coastal barriers. However the author is aware that that to date there has been no attempt to use something with a less slope. With many coastal barriers still barring fish passage for species that optimally require freshwater environs as part of their life cycle, industry believe that there is a need for something to be developed that industry could see as being cost effective during construction and also allows them to comply with their regulatory requirements.

Contribution of various types of seagrass assemblages to fisheries production

Fisheries Queensland with the Queensland Department of Agriculture, Fisheries and Forestry has adopted the global value of total ecosystem services for marine fish habitats through extrapolation and adjustment of the estimated value for estuaries (Costanza *et al* 1997), with fish habitat and fisheries specific components of direct use and non-use. The fisheries specific ecosystem services component of approximately 7 % of the total ecosystem services for estuaries (extrapolates to 3,703 AUD ha-1 yr-1 in 2010) is adopted as the minimum ecosystem services value.

The research suggests that in terms of fisheries production, not all seagrass is equal. However, when industry develop infrastructure that may have an impact on seagrass meadows; offsets are applied at a standard value which is often at the high end of the range based on Constanza *et al* 1997. Sparse tropical seagrass beds in clear water that cover vast areas in open embayments do not have the same habitat direct value as denser areas in inshore turbid areas, particularly when associated with other habitats such as mangroves. McPhee *et al*. (2012) provides additional comment on the issue of the value of seagrass to fisheries. The author based on industry comments would suggest that a model of valuation based on field sampling is essential for better estimates of direct fisheries value. This could include a desktop study that identifies types of seagrass habitat (e.g. Zostera/Halodule), the physical factors that influence this habitat in terms of fisheries production, information on fisheries production from the various types of habitat (commercial/recreational finfish, crustacean etc.) and then a relative value on each habitat type. Depending in the data that is available from the desktop assessment, in terms of offsets required by regulators, this could provide a valuable understanding on how to calculate offsets across a project.

Contribution of created habitat for fisheries production

During the workshop, the author presented an overview of industry's view on the potential benefits of hard structures installed for example with the construction of port infrastructure. Sheaves *et* al discussed the potential fisheries value of these habitats to fisheries. Some questions include what is the value (economic, environmental and social) of these artificial habitats. What sort of use do the piers in various locations have? Do they provide a spill over effect for commercially important species or do they become a habitat that is solely utilised by species that remain during their entire life period. For example, anecdotal knowledge suggests that Lucinda Jetty is a temporary life cycle habitat for Giant Trevally as well as numerous other species and the author has personally observed adult barramundi utilising the wharf structure at the Port of

Townsville. Industry would be interested to understand the potential benefits of this habitat and the contribution it makes to fisheries standing stock and production.

Recovery of fisheries production after material placement

While there have been numerous studies of the recovery of spoil grounds, the recovery of spoil grounds for fisheries production is an emerged issue for many ports. From an assessment of the literature, the author could find no direct studies in Australia which have assessed this issue including the utilisation of the spoil ground by harvested stock (prawns, scallops, bugs), as well as the ability of trawl fishers to access the area due to safety (bogging of nets). This issue is now likely to be something that will require additional investigation regarding any new and future spoil grounds in Queensland water. An additional benefit of the study is that it would also provide assessment of the demersal fish fauna in general.

These aspects and the mechanisms to gain access to funding for these research topics are discussed later in this Business Case but it should not be assumed that a proposal to merely research these topics would be immediately funded by industry etc as a blank cheque. Any research in these topics would need to very targeted and demonstrate how it will benefit industry. The approach for obtaining funding for these projects is discussed below.

Benefits to Proponents

There are a number of significant benefits for both industry and researchers through linking projects. A number of the projects (although the list above is not extensive) were also identified by Sheaves *et al* as being priorities to fill the known research gaps in the scientific literature for the benefit of improving fisheries sustainability, and ensuring successful recruitment. For example, with respect to the 2nd, 3rd and 4th projects identified above, industry is concerned as to the perceived detrimental impacts on fisheries sustainability by Governments, regulators, non-government organisations and the general public more broadly. The majority of industry pride themselves in protecting the environment as much as possible when undertaking development and therefore want to demonstrate their commitment to not only the environment but also to the scientific literature. Where their projects may impact on marine habitats as an example, industry may be required to invest in offsets that often do not directly benefit the areas adjacent to or in proximity to the project proposed for the enhancement of for example, recruitment and/or critical habitats. The need to fund offsets to what can be very large areas depending on the offset ratio can result in significant cost implications and moreover, the non-achievement of a final design of infrastructure that could have cost implications but at the same time, result in a less favourable environmental outcome. Further, the current regulatory arrangements for marine plants as an example (seagrass etc) stipulate that the impact on an area of seagrass (whether 100% cover or 0.00001% cover) is offset in the same way.

Research could assist industry by demonstrating for example, whether seagrass beds within a project footprint has the potential to provide habitat for recruitment and juveniles, and if so, the port could potentially be modified to minimise the impacts on these areas. The current regime of assessing offsets is someone historical (based on 1991 science) given the current knowledge of seagrass meadows and the habitat they provide and therefore, a number of demonstration cases would assist researchers, industry and regulators to better understand the relative importance of these areas and the value that should be placed on them. By understanding this aspect of the environment better, this would allow for project designs to be enhanced to meet the needs of the environment and also, offset monies, whether through direct and/or indirect aspects could be better spent on achieving valuable enhancement for fisheries sustainability.

Strategic Timing and Engagement with Proponents

The Business case has identified a number of mechanisms how researchers can leverage proposed projects to gain funding, including both from offset funding and from specific projects. However, the importance of timing and how the proposed research is presented to a proponent is critical to the success of a research project being funded.

The author suggests that the most effective way to obtain research funding is to time discussions effectively and be involved in the environmental assessment process for a project so as baseline data can be collected by the researcher within this process. Project proponents need to be approached in the context of a legitimate partnership to assist addressing their needs with specific and relevant expertise, and not treated as a "blank cheque book". All projects that the author has been involved in undergo a lengthy planning process prior to an environmental assessment is commenced. For example, projects at Abbot Point were discussed with industry and government for about a year prior to the commencement of any environmental assessment. Once the actual assessment commences, many researchers may have lost their opportunity to be involved through the evolution of the environmental assessment, particular if they do not have links to the proponent or consulting companies undertaking the environmental assessment. Therefore immediately on hearing of the project and prior to the release of a referral and/or initial advice statement under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) or *State Development and Public Works Organisation Act 1971* (Qld), researchers should contact proponents and demonstrate how their research work would fall within the gambit of an the environmental assessment process and as potentially an indirect offset and/or future monitoring, how regulators would see that it would be a beneficial project to fall within the concept of an indirect offset, show how that it is important in respect of what should be funded as part of a research component of an offset strategy and importantly, how the research would increase the proponent's understanding of their environmental impact (preferably in a positive manner) and/or provide the proponent with evidence that their project will provide positive benefits to the community's understanding the life-cycle habitat requirements of coastal fisheries species.

Further, an important opportunity for researchers is that offsets that deliver an outcome prior to the impact commencing are encouraged, as they minimise effects resulting from offset time delays and this follows from the above that proponents could achieve multiple benefits from engaging researchers to undertake work for them.

Discussion

This Business Case has identified numerous opportunities for researchers to gain funding from outside the normal sources.

With respect to the specific research areas identified through consultation with industry, the author suggests that a research proposal could be developed that could leverage funds from industry with matching funding through FRDC, ARC Linkage Grants, and other schemes etc in order to maximise the contributions from ports/industry to understand the benefits of this infrastructure. During the development of the Cumulative Impact Assessment for Abbot Point, a number of areas of fisheries research that could directly benefit and interest to the industry and researchers included:

- Further work on habitat requirements and habitat connectivity for key fished species;
- Identification of "hotspots" for fish and invertebrate recruitment with a focus on developing an approach that has the capacity to predict the likely presence of hotspots in other areas;

- Further work on evaluating the value on an area basis of habitat and combinations of habitat for key fished species;
- Research into the role port infrastructure plays in terms of fisheries production and the role of spillover in supporting adjacent fisheries;
- Investigating the impacts of suspended sediment on the physiology, survival and external appearance of coral trout; and
- Development of a community based approach for monitoring recreational fish catches and key identified biological and ecological aspects of important target species. A key focus of this monitoring could be focussed on fishing activities among construction and operational workforces.

If a joint arrangement could be made between a research funding body and industry, the author believes that industry would make a similar contribution to that gained from the normal research funding and this therefore could double the amount available for research (for example, a $100,000 project into a $200,000 project).

As to offsets, the funding of fisheries research is identified as a legitimate offset by all levels of Government. In Queensland, there is a significant broad-scale association between landscape connectivity and commercial fisheries catch. Given that habitat connectivity is a key issue, restoring habitat connectivity can represent a very valuable environmental offset, including for development that does not itself impact habitat connectivity.

In terms of its application, the Western Basin Project at Gladstone committed $5 million to support initiatives for future research, studies and/or appropriate works for fish habitat rehabilitation and enhancements with Fisheries Queensland. However, the exact proportion of this commitment going towards research is unclear, although it is highly likely that with the current policies of the Queensland Government, the majority of that money would be kept in house and no funding will be available to researchers except for that currently being spent by Gladstone Ports Corporation to undertake a number of studies that were part of their overall Biodiversity Offset Strategy that they themselves say Government are no longer able to undertake. With respect to industry, previous offsets in at least one instance have gone towards research infrastructure, namely a significant contribution from the Port of Brisbane towards the construction of the current University of Queensland Moreton Bay Research Facility on North Stradbroke Island. This can be used as precedence for researchers to seek funding for the purposes of research facilities and the like.

The author suggests that researcher follow the market and look for tenders where proponents are seeking to engage consultants to undertake work associated with their projects, including for example, the preparation of both the referral and/or initial advice statement. Early engagement is of potential benefit for both the proponent and the researcher. For early engagement to be successful, it is essential that researchers develop an understanding of the actual proposed projects themselves and the details of likely potential impacts. Failing to do this may be viewed by a proponent as being treated as a “blank chequebook” by a research body which is unlikely to lead to successful engagement. A tangible partnership is required where the researcher can address the high priority needs of the proponent using an appropriate skill set.

All of the above provide researchers with the opportunity to leverage funding that will not only fill gaps within the scientific literature but also provide Governments and proponents with surety as to their future environmental outcomes.

Conclusion

This Business Case identifies potential funding opportunities to fill research gaps based on the report of Sheaves *et* al to advance the research needs to greater understand the life-cycle habitat requirements of coastal fisheries species. This Business Case sets out how the priority research areas can be studied based on the opportunities for Government and external investment into that research.

The primary opportunity to gain additional funding outside the normal funding bodies such as the FRDC, ARC, Commonwealth and State Departments of Agriculture, Fisheries and Forestry through normal research grants. Further, there are a number of opportunities where researchers can access monies from both proponents proposing to development within the coastal and marine zones, and via access to monies paid for offsets through both the Commonwealth and Queensland Governments. Both levels of Government have offset policies documents that to allow research to be integrated into a project's offset requirements as an indirect offset.

This Business Case has also identified a number of projects that would link within the projects proposed by Sheaves *et al* that are suggested as possible projects industry would see benefit in being undertaken.

The author suggests that the most effective way to obtain research funding is to time discussions effectively and be involved in the environmental assessment process for a project so as baseline data can be collected by the researcher within this process. Therefore immediately on hearing of the project and prior to the release of a referral and/or initial advice statement under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) or *State Development and Public Works Organisation Act 1971* (Qld), researchers should contact proponents and demonstrate how their research work would fall within the gambit of an indirect offset, how regulators would see that it would be a beneficial project to fall within the concept of an indirect offset, show how that it is important in respect of what should be funded as part of a research component of an offset strategy and importantly, how the research would increase the proponent's understanding of their environmental impact and benefit the community's understanding the life-cycle habitat requirements of coastal fisheries species.

It is suggested that researcher follow the market and look for tenders where proponents are seeking to engage consultants to undertake work associated with their projects, including for example, the preparation of both the referral and/or initial advice statement. Early engagement is of potential benefit for both the proponent and the researcher. For early engagement to be successful, it is essential that researchers develop an understanding of the actual proposed projects themselves and the details of likely potential impacts. Failing to do this may be viewed by a proponent as being treated as a "blank cheque" by a research body which is unlikely to lead to successful engagement. A tangible partnership is required where the researcher can address the high priority needs of the proponent using an appropriate skill set.

Appendix 3c: Project No. 2012/037

Decision Support System to Direct Investment to Research Needed to Support Long-Term Sustainability of Coastal Fisheries Habitats

Marcus Sheaves

20 August 2013

Introduction

Among the most critical factors influencing an investor's decision to support a public-good project is the strength and clarity of information on the reasons for and benefit of the investment. Decision Support Systems (DSS) have long been used across a diversity of enterprises to furnish this type of input (e.g. Markus & Tanis 2000, Aktaş et al. 2007), so provide a logical tool to underpin business decisions about investments in research needed to support coastal fisheries habitats.

Decision Support Systems (DSS) are knowledge systems that provide information relevant to a decision in a simplified, summarised or integrated form that is accessible to those charged with making decisions. DSSs can be *Passive* or *Active*. Passive DSSs make information available in a 'packaged' form but do not provide analysis of the information and are not specific to a particular situation or problem (Barnett et al. 1987). Active DSSs are computer-based tools that are specific to a task and provide integration and analysis of inputs leading to a model outcome providing assessment of the issue at hand given particular input scenarios (Costanza et al. 1991). They provide a means of organising and evaluating large bodies of information (Cortés et al. 2000), and provide the substantial advantage that they can take uncertainty into account (De Kort & Booij 2007), making the 'advice' they provide much more robust than that from simple opinion. Active DSS can also be used to enhance the allocation of resources, identify negative trends, and provide feedback on the likely success of particular actions (Cortés et al. 2000, Hobbs & Harris 2001). Active DSS can be as simple as a water allocation model (De Kort & Booij 2007), or a linked series of hydrodynamic, water allocation, digital elevation models, combined with geographic information system (Duvail & Hamerlynck 2003), or as complex as an advanced probabilistic model (Liu et al. 2013).

A DSS for Investment in Coastal Fisheries Resilience

Decisions about investments to support coastal fisheries habitat research would be greatly facilitated by a DSS aimed at directing future investment based on risks to coastal fisheries assets, ecosystems and habitats and opportunities to protect these assets and ensure their long-term sustainability by reducing vulnerabilities and increasing resilience across the fishery.

Many different models and approaches are possible but each would need to be evaluated on the basis of its cost-effectiveness trade-off. The many gaps identified in the literature review phase of this project, and the dispersed nature of the available information, clearly indicate a need to collect the available information together in an organised framework. The compilation of this Passive DSS to integrate, gather together and organise the available knowledge is a crucial first step needed to underpin attempts to attract investment in coastal fisheries habitat research. This data base would enable access to the raw material needed to populate business cases specific to particular situations and particular investors, in an organised framework. This would in itself be an expensive exercise requiring the resources of at least a Tactical Research Fund (TRF) grant.

The value of the data base or Passive DSS would be greatly enhanced if an Active DSS could be developed. There are many forms that this could take with a variety of levels of complexity (e.g. Adriaenssens et al. 2004, Lauría & Duchessi 2006, March & Hevner 2007, Wei et al. 2013). Two potential candidate approaches, which have recently been used in a widely range of contexts in Australia, are graph-theoretic and multiple criterion approaches (Saaty 1990), such as qualitative models (e.g. Dambacher & Ramos-Jiliberto 2007), and Bayesian Belief Networks (BBNs) (e.g. Lauría & Duchessi 2006). Both approaches can provide excellent and robust predictions, even when some input is of uncertain quality or background information is incomplete. These approaches are both relatively simple and do not necessarily require extensive, detailed data, so should be ideal for developing an Active DSS to help direct investments to support coastal fisheries habitat research in Australia. However, these would require extensive development and time, personnel and financial commitments at the level of a large research grant.

What is needed?

A DSS to help direct investment in research needed to support the long-term sustainability of coastal fisheries habitats should simultaneously address (i) the identification and prioritisations of fisheries habitat needs, and (ii) establishing the attractiveness of investment into fisheries habitat research by clearly defining benefits to potential investors. Both components are necessary because available funding for coastal fish habitat research is far below what is needed, so attracting new investment is critical. At the same time, it is also crucial to ensure that investment is directed into the areas of greatest need to ensure investment is applied wisely. Consequently, a well-designed DSS should help to identify needs and potential outcomes of actions, help define alternative investment possibilities and strategies, and provide outputs in forms that address both prioritising needs and clearly defining the benefits of investment.

Recommendations

1. ***A Comprehensive Database:*** Developing an integrated data base to gather together and organise the available knowledge is a crucial first step needed to underpin attempts to prioritise needs, determine investment decisions and attract investment in coastal fisheries habitat research. It would provide the raw material needed to populate business cases specific to particular situations and particular investors.
2. ***An Active Decision Support System:*** The ability to validate investment needs and benefits, and direct investment decisions would be greatly enhanced by the development of a robust,

computer based Decision Support System able to simplify and integrate the information in the knowledge base into predictive models relating identified needs and potential outcomes to actions and alternate investment possibilities and strategies.

References

Adriaenssens V, Baets BD, Goethals PLM, Pauw ND (2004) Fuzzy rule-based models for decision support in ecosystem management. Science of The Total Environment 319:1-12

Aktaş E, Ülengin F, Önsel Şahin Ş (2007) A decision support system to improve the efficiency of resource allocation in healthcare management. Socio-Economic Planning Sciences 41:130-146

Barnett GO, Cimino JJ, Hupp JA, Hoffer EP (1987) An evolving diagnostic decision-support system. Jama 258:67-74

Cortés U, Sànchez-Marrè M, Ceccaroni L, R-Roda I, Poch M (2000) Artificial intelligence and environmental decision support systems. Applied Intelligence 13:77-91

Costanza R, Daly HE, Bartholomew JA (1991) Goals, agenda, and policy recommendations for ecological economics. Ecological economics: the science and management of sustainability Columbia University Press, New York:1-20

Dambacher J, Ramos-Jiliberto R (2007) Understanding and Predicting Effects of Modified Interactions Through a Qualitative Analysis of Community Structure. The Quarterly Review of Biology 82:227-250

De Kort IA, Booij MJ (2007) Decision making under uncertainty in a decision support system for the Red River. Environmental Modelling & Software 22:128-136

Duvail S, Hamerlynck O (2003) Mitigation of negative ecological and socio-economic impacts of the Diama dam on the Senegal River Delta wetland (Mauritania), using a model based decision support system. Hydrology and Earth System Sciences Discussions 7:133-146

Hobbs RJ, Harris JA (2001) Restoration ecology: repairing the earth's ecosystems in the new millennium. Restoration ecology 9:239-246

Lauría EJM, Duchessi PJ (2006) A Bayesian Belief Network for IT implementation decision support. Decision Support Systems 42:1573-1588

Liu J, Wu C, Liu W (2013) Bayesian Probabilistic Matrix Factorization with Social Relations and Item Contents for recommendation. Decision Support Systems 55:838-850

March ST, Hevner AR (2007) Integrated decision support systems: A data warehousing perspective. Decision Support Systems 43:1031-1043

Markus ML, Tanis C (2000) The enterprise systems experience–from adoption to success. Framing the domains of IT research: Glimpsing the future through the past 173:207-173

Saaty TL (1990) How to make a decision: the analytic hierarchy process. European journal of operational research 48:9-26

Wei G, Wang J, Chen J (2013) Potential optimality and robust optimality in multiattribute decision analysis with incomplete information: A comparative study. Decision Support Systems 55:679-684