R&D Priorities – Australia's estuaries, embayments and nearshore marine environments

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Abstract / Summary
Southern Australia's estuaries and inshore waters are the most degraded of all Australia's ecosystems. Yet naturally, estuaries and inshore waters are globally the most productive and in Australia's case, with its narrow continental shelf, are much of the basis of our fisheries and biodiversity. These sheltered water support critical life cycle components of the majority of our recreational and professional fishing target species and are a key component of our Australian lifestyle. As already well demonstrated in USA, UK and the EU transitional waters initiatives, repair of past damage to foster recovery of productivity within these key ecosystems is now a very attractive investment. Flow on benefits will be substantial - ecologically, economically and socially with outcomes of healthy high quality seafood, enhanced urban & coastal lifestyle, re-established habitat for rare & endangered fish, birds & vegetation, world heritage area repair, improved flood management and increased regional employment. This paper therefore focuses on the R&D required to underpin the repair and ongoing management of these high value ecosystems for both improved productivity and enhanced conservation values.

1. Background
Broad Management-Orientated Definition - In this paper we adopt a broad definition of the term 'estuary', orientated towards human use and management: estuaries are defined as all semi-enclosed coastal waterbodies where marine water from the ocean mixed with freshwater draining from the land, and/or any coastal environment where marine and fluvial sediments occurred together (e.g. National Land and Water Resources Audit 2002). This management-orientated definition is much broader than the long-standing and widely accepted biophysical definition of an estuary as 'a body of water in which river water mixes with and measurably dilutes sea water' (e.g. Reid 1961,Hodgkin 1994).

Continuing Degradation of Ecosystems and Productivity –There is an ongoing trend of degradation of Australia's inshore and nearshore ecosystems and the loss of fish habitat, of seagrass-beds, mangroves, saltmarshes and fresh to brackish sedge and paperbark floodplain wetlands. In turn, this loss of habitat is associated with changes in fisheries catches and there is now abundant evidence that Australia is progressively losing commercial and recreational fisheries on a nation-wide scale. Fisheries resources are important for high value secure food supply, for the commercial, recreational and indigenous fishing sectors, and also have ramifications from lifestyle and tourism perspectives (e.g. Smith 1981; Creighton 1982; Skilleter and Loneragan 2007).

Excessive Nutrients, Algae and Hypoxia - Micro-tidal systems are particularly prone to extreme eutrophication and thus hypoxia, which is clearly a major problem in many estuaries in southern Australia with their limited tidal range and often alterations to tidal flow that has accompanied development (e.g. Diaz 2002; Vaquer-Sunyer and Duarte 2008). This is of particular relevance for the two Gulfs and other inverse estuaries in South Australia. According to Diaz (2002) "no other environmental variable of such ecological importance to estuarine and coastal ecosystems around the world has changed so dramatically, in such a short period of time, as dissolved oxygen". Furthermore, Diaz points out that this threatens the "loss of fisheries and biodiversity and alteration of food webs in these systems".

Reduced fisheries productivity - Over 75 % of Australia's commercial fish catch, and in some regions up to 90% of all recreational angling catch, spends part of its life cycle within estuaries and inshore wetlands (Copeland and Pollard 1996; Lloyd 1996; Bryars *et al.* 2003; New South Wales Department of Primary Industries 2007, 2008; Jerry 2013). Total populations of many inshore fisheries species have declined (e.g. Creighton 1982), and, should habitat continue to be lost, it is almost inevitable that fish populations will continue to decline. Major fish kills in estuaries, often associated with the drainage of floodplain wetlands, the activation of acid sulfate soils, and alterations to freshwater flows, have been frequent events in New South Wales, e.g. Clarence and Richmond River systems in 2009, 2010, 2011, and 2013 (Ryder and Mika 2013; see also White *et al.* 1997; Wilson *et al.* 1999; Johnston *et al.* 2003a).

Example - Prawn and scale-fish fisheries, New South Wales - The School Prawn *Metapenaeus macleayi* is an annual, highly fecund stock that, if habitat is present, provides a resilient and highly productive commercial and recreational fishery. Yet, in estuaries such as the Shoalhaven River, both the commercial and recreational fisheries have been lost since the early 1980's due to deteriorating estuarine condition. Similar comments apply to the Western School Prawn *Metapenaeus dalli* and the reduced productivity in the estuaries of south-western Western Australia (Potter *et al.* 1986, 1989; Smith *et al.* 2007).

In New South Wales, School Prawn and Eastern King Prawn *Penaeus plebejus* fisheries are considered fully exploited and overfished, respectively (NSW Industry and Investment 2010; Rowling *et al* 2010). Catch rates are now at most ~75% of those catch rates that were maintained historically during the 1970s and 1980s, and some rivers only support recreational prawn catches (New South Wales Industry and Investment 2010). The Estuarine General Fishery in New South Wales has never surpassed the levels of production of the 1960s and 1970s. For commercially valuable fisheries, such as Dusky Flathead *Platcephalus fuscus*, Sea Mullet *Mugil cephalus*, Sand Whiting *Sillaginodes punctatus* and *Sillago ciliate*, Luderick *Girella tricuspidata*, Mulloway *Argyrosomus japonicus*, and Yellowfin Bream *Acanthopagrus australis,* average catches have declined markedly from those that were maintained in the 1960s and 1970s (New South Wales Industry and Investment 2010; Silberschneider and Gray 2008).

Part of the decline in these fisheries could be due to improvements in the rigour of fisheries management to ensure sustainability, as well as resource sharing as the recreational sector has increased in effort. Part could be due also to profitability issues, such as increasing input costs of diesel and labour or price competition from imported products. Part could also be due to loss of resilience due to a combination of environmental degradation and the impacts of fishing. For example, loss of egg production capacity as large females are removed by fishing, thus reduced opportunity to respond to infrequent favourable conditions for breeding. Nevertheless, the broad and consistent trends for most species in wild fisheries along the New South Wales coast indicate that the underlying factors of water quality and habitat loss predominate. Specifically, the reductions in total populations are likely to be due firstly to limitations to recruitment, growth and productivity due to loss of habitat and changes in tidal and freshwater flow regimes; secondly, massive water quality induced kills are likely to have had an impact on total biomass, the almost total loss of some species (e.g. Sydney Rock Oysters and Mud Oysters *Ostrea angasi* from many NSW floodplain estuaries) and possibly overall species composition of estuary fish populations. Much of the water-quality decline, especially in changed pH, pollutants such as heavy metals, and anoxic or low dissolved-oxygen conditions are due to the draining of the critical estuarine habitats, the floodplain wetlands, salt marshes and accompanying seagrass-lined channels (Wood 2007; Government of South Australia 2009, 2012; Grabowski and Peterson 2007).

To put it bluntly – when indicators such as the highly fecund annual stocks such as prawns are in decline and when what must be regarded as Australia's "native inshore carp", the highly fecund algae-feeding *Mugil cephalus* are also in decline its time for R&D to focus on how best to repair the overall productivity of Australia's estuaries, embayments and nearshore marine environments.

2. Opportunities for repair– what needs to be done

Comprehensive work undertaken by Creighton in consultation with relevant stakeholders, has identified five relatively discrete repair themes (Creighton, 2013):

i) restoring longitudinal and lateral connectivity to ensure fish passage and nutrient flux (Sheaves *et al.* 2014). This will involve removal of barrages, inadequate culverts and causeways and other blockages to the movement of animals and plants, their propagules, tidal and freshwater flows, and the flux of nutrients;

ii) rehabilitating degraded floodplain wetlands, which can be achieved in part via removing or manipulating barrages to allow more natural fluxes of water, and reshaping landforms to remove drains and levees. Acid sulfate soil will require particular attention (Boys et al 2012, Cook *et al.* 2000);

iii) re-establishing native mussel and oyster reefs, which provide valuable habitat and nursery areas for many estuarine fish species, as well as performing valuable water-quality improvement functions;

iv) protecting and, if required, re-establishing seagrass beds. The provision of seagrass-friendly moorings in areas subject to heavy recreational boating is likely to be an important component of this action; and

v) acknowledging the defining characteristic of estuaries – that they are the meeting place of fresh waters and marine waters –by maintaining both adequate freshwater flows to the lower reaches of coastal floodplain rivers (Gillanders and Kingsford 2002) and tidal flows from the ocean.

3. Research Priorities

3.1 Theme - Ecosystem ecology and responses

Event management for landscape optimization

Undertake multi-objective analysis of selected flood-prone systems, such as southern Queensland (e.g. Mary River) and a northern New South Wales river (e.g. Richmond or

Clarence), to understand how best to optimize floodplain management across multiple land uses and objectives. For this study, good hydrographic models are needed as a base. The research would establish how best to utilize wetlands, levees, dredging, flood infrastructure, roading, flood storage and so on for the multiple objectives of fisheries, biodiversity, water quality, urban and infrastructure flood protection and agriculture.

Output – *Multi-criteria analysis method for optimizing outcomes for the landscape to deliver both human use/ economic and ecological benefits.*

Tidal hydrology and repair of morphology

Sedimentation from catchment loads and infrastructure such as training walls, crossings and causeways has changed tidal hydrodynamics and therefore net primary productivity. Repair dredging (e.g. Manning entrance plus many within-estuary sites), alterations to historic training walls (e.g. Middle Wall, Clarence; Googleys Lagoon, Camden Haven) and alterations to causeways and current sedimentation patterns (e.g. Clarence – Shallow Channel, Romiaka Channel, Oyster Channel and Palmers Channel feeding Lake Wooloweyah) may all be useful repair techniques. When considering improved tidal ventilation, it will also be essential to incorporate the flow on benefits of how such works could improve wetland productivity and contribute to repaired habitat as part of initiatives such as seagrass re-establishment.

Output – *designed guidelines for repair of selected estuaries that also provide a model for application in other inshore waterways.*

What is the likely total population of key species, how does population vary with climate and how should this be used to improve fisheries management, including resource sharing?

Whilst recreational effort is increasing in inshore / nearshore, particularly around major urban centers, variable climate impact in fish and crustacean population fluctuations. If the variation in populations and the drivers for these variations are documented, a suite of likely carrying capacities can also be projected. This could form the basis for the impacts of any major development and any major repair activities, which may lead to better development and investment decisions. The flow-on of linking professional fishing effort to stock availability and any resource sharing rules would also make commercial fisheries more profitable and sustainable in the long term.

Output – *changed paradigms for fishing effort management, resource sharing and development approvals by considering cumulative impacts based on a carrying capacity approach.*

Developing accurate assessments of the standing stocks, stock dynamics and specific productivity and value of particular estuaries, estuary reaches or estuary sub-habitats.

Effective repair and revitalization of estuary function depends on being able to identify the specific values of different assets (whole estuaries, estuary reaches, sub-habitats [e.g. transitional or seasonal wetlands, seagrass beds mangrove banks]). This relies on accurate information on productivity and productivity dynamics (e.g. accurately understanding the distribution and dynamics of fisheries species biomass). However, this information is rarely available for any estuary or estuary component, despite the fact that this is also key information needed to support decisions on development, determining offsets, etc.

Output – *increased ability to efficiently and cost effectively direct repair, remediation, offsets and development decisions to provide the optimal fisheries outcomes.*

Priority locations – do they exist for Australian inshore species?

New Zealand research suggests some species may have priority location nursery habitats forup to 80% of their stock in a particular estuary, later dispersing widely. Does this occur in Australia (possibly Murray/ King George Whiting in Spencer Gulf)? For example, Murray River estuary

and Coorong lagoons provide priority habitat for *A. japonicas* (Ferguson et al, 2008). Nursery areas for snapper are likely to include upper parts of the SA Gulfs and probably were the shellfish reefs of sheltered embayments such as Port Phillip and Moreton Bay. (e.g. Fowler et al 2003). If so, how would we best protect / manage these extra important areas?
Output – *better understanding of locational preferences as a basis for improved ecosystem and population management.*

The freshwater–brackish–saline interface and net primary productivity
Brackish, intermixed systems are globally the most productive ecosystems. How can we change catchment hydrographs and inshore hydrodynamics back towards a more sinusoidal long recession curve-mixing system that facilitates large brackish areas inshore?
Output – *Better understanding of catchment hydrology linked to net primary productivity, especially important for more regulated estuary systems.*

Larval recruitment – has it been influenced by training walls and other structures that impact on tidal flows?
Major wave-dominated estuaries pre-settlement were a maze of entrance sand spits. Much of the spawning (Mullet, Bream, Whiting, Mulloway) presumably occurred in those estuaries with a high probability of rapid larval recruitment back into the sheltered waters. Where do these species spawn now and can any manipulation of estuarine entrance areas assist higher recruitment back into estuaries? A further likely impact of changed hydrodynamics is disrupted cues to assist larvae in locating high quality nursery habitat.
Output – *Better understanding of larval dispersal and opportunities to enhance recruitment to nursery areas.*

3.2 Theme - Human interactions with ecosystems

Mixing the public and private benefits of waterway and wetland conservation – should fishers pay farmers and other land users?
Much of the challenge with waterway / nearshore management lies in the public benefits that these assets provide compared to the private benefits that come from land development. On Australia's floodplains and coastal catchments, development has been for private benefit, especially agriculture and grazing with now increasingly urban development, at the expense of the more public benefits of biodiversity, water quality and fisheries. Fisheries can also lead to private benefit when professionally harvested for food or caught as part of recreation and lifestyle. How can these various benefit streams be brought together to ensure ongoing investment in ecosystem repair and management for benefit of all?
Output – *Exploration of the opportunities for cross-subsidization between public and private beneficiaries; better understanding of the externalities to our economic systems.*

Sustainable fisheries management – should this be based on habitat condition and the habitat's potential for productivity?
Historically fisheries management has been preoccupied with management of single species through input controls such as fishing gear, size of boat, temporal closures etc. Fisheries management is gradually moving towards output controls based on the presumed, sometimes modeled and monitored, size of the population available for catch and therefore some estimate of 'sustainable yield'. However, with well over 70% of all professional catch Australia-wide having an estuary-dependent phase in their lifecycle, these estimates of sustainable yield should also be taking into account factors affecting the whole ecosystem rather than species level only. Although ecosystem-based fisheries management practices have progressed understanding of fishing impacts at an ecosystem level, more has to be done. For example, habitat condition, improvement or decline, provides a basic level upon which, through repair, sustainable yield can

be increased, or, as is currently the case, do nothing so that sustainable yield will continue to decline regardless of what controls are placed on effort.
Output – *Linking habitat condition to sustainable yield should give further impetus to better management of inshore and nearshore habitats, or, at least, foster understanding that further degradation has a direct impact on seafood security, jobs and recreational lifestyle.*

Fostering local stewardship – what works?
Recreational fishers have a lead role in estuary and nearshore management, repair and protection in both the UK and USA. Australia has over 3.4 million recreational fishers. Galvanizing this sector of the population to a lead role in management, repair and protection will reduce the need for ongoing government investment as greater stewardship is developed.
Output – *Schemes and engagement models in place overseas and in some states could be explored to provide a kitbag of possible schemes for Australia for the various recreational fisher groups to consider.*

Understanding and valuing the multiple outcomes that accrue from good management
Multiple benefits besides fishery productivity accrue from good management. These include flood control, coastal biodiversity, extreme climate event buffering, good water quality, scenic landscape and general public amenity, and carbon mitigation. Most of these are public benefits. Understanding these benefits and their overall value can influence public investment and community behaviour.
Output – *A better understanding of the role and benefits of improved management.*

Evaluation and reporting of effectiveness of policy, legislation and regulations – what works?
Various states have differing levels of environmental policy and legal frameworks pertaining to the management of inshore waters, estuaries, nearshore and wetlands. The effectiveness of these instruments is rarely evaluated. Evaluation and reporting are fundamental to generating continuous improvement, which leads to greater efficient, effective and appropriate use and management of resources. this paper focuses on repair attests to their aggregate failure in maintaining productivity for the Australian public good and seafood food security.
Output – *An evaluation of the various approaches to policy, legislation and regulations, and the development of model provisions may be the first step towards improved policy and regulatory frameworks in all jurisdictions.*

Resource sharing within repaired inshore and nearshore environments
By virtue of their location and being the more sheltered easily accessible waters, estuaries, embayments and nearshore marine environments are generally areas of high recreational effort. Professional catch also has a high inshore dependence. Rebuilding habitats such as mussel or oyster reefs in Port Phillip or Moreton Bay is likely to lead to increased recreational pressure. How can any increases in productivity be best shared? If recreational fishing was to fully fund a mussel reef, then should all the benefits accrue to recreational fishing? Is this a vehicle whereby increased private sector investment in repair could be encouraged?
Output – *Exploration of the various options for resource sharing and how it might link to investment in repair.*

4. Realisation

Infrastructure perspective – existing science infrastructure is sufficient for the suite of science. While many state agencies have recently reduced available laboratory and vessel infrastructure, all states still maintain sufficient infrastructure for their purposes in universities and agencies. Better coordination of projects and programs would allow for greater sharing and more efficient use of existing infrastructure.

Science Capability – much of the capability previously residing within state agencies is now with leading universities and research organizations. There are groups and teams of highly competent scientists in all states – eg Murdoch, WAMSI and Curtin in WA; SARDI and Univ. of Adelaide in SA; UTAS and CSIRO in Tasmania; DPI Vic, Melbourne and Victoria Univ. in Victoria; NSW Fisheries Univ. of Wollongong, NSW Univ. Hydrology Lab and Sydney Univ. Marine Institute in NSW; JCU, AIMS and CSIRO in Qld. For Northern Australia, the priorities are more around protective management and policy development than repair. Science capability resides in Charles Darwin Univ., AIMS and agencies for these purposes.

Co-investment in Repair Works–All the R&D priorities proposed will be best done using Australian coasts, estuaries and inshore environments as a "living laboratory". Creighton, 2013 outlines a proposed investment package of $350M which includes first order works, R&D, monitoring, evaluation and communication. In light of budgetary limitations, this level of Australian Govt. investment may be achieved through a series of individual investments. In progress so far from the works perspective is:

- $40M initially allocated under Reef Rescue II towards "system repair"….but only a proportion of this is contracted and not all projects focus on estuary and wetland systems;
- $300K from the US Nature Conservancy to foster a trial of shellfish beds in Port Phillip; and
- several existing and some planned acquisitions of key wetlands and their repair in NSW – via NSW Fisheries and National Parks Service.

Many State governments, including SA, Vic, NSW and QLD already reallocate revenue collected from recreational fishing licences / boat registrations to improving recreational experiences. As the various community groups recognise, the key part of the experience needing investment is re-establishing healthy and bio-diverse ecosystems. Several states are likely to offer to partner with a R&D initiative that focuses on repair. For example, South Australia has been working on seagrass restoration and rehabilitation for many years.

Coordination – Strong and strategic coordination is essential for this initiative to be successful. In fact, part of the reason for the demise of these otherwise highly productive ecosystems is the limited integration and coordination, to date, in catchment use / floodplain management / coastal development. There are multiple players and multiple benefits derived from these landscapes. Cohesive and collaborative R&D focused on key issues and well linked to repair works will be essential if Australia is to derive maximum benefit from R&D investment.

Funding–Potential sources of funding, preferably well coordinated and focused, could include:

- National Environmental Science Program;
- FRDC and possibly a component of the $100M election commitment to RDCs for enhanced primary industry productivity;
- State Govts. with their various recreational fishing and boating licence reallocation systems; and
- Private sector and NGOs as already demonstrated by the US Nature Conservancy.

5. Conclusions

Much has been learnt scientifically regarding the impacts of our land practices and water allocation decisions on Australia's estuaries, embayments and nearshore marine environment. Science has provided greater understanding of the consequences due to changes to water quality and sediment load, the mobilisation of salts by dryland salinity, the loss of biodiversity, the reduction of fisheries productivity and others. The ongoing need for scientific understanding of these issues is greatly acknowledge through existing funding allocation mechanisms.

It is now timely for R&D to focus on repairing Australia's most degraded ecosystems and the multiple economic and environmental services they provide so that we can add the concepts of estuarine repair and land use optimisation to the toolkits of enhanced food security, primary industry development and environmental repair.

6. References

Craig A. Boys, Frederieke J. Kroon, Tim M. Glasby and Kevin Wilkinson 2012 *Improved fish and crustacean passage in tidal creeks following floodgate remediation* Journal of Applied Ecology 2012, 49, 223–233

Bryar S, Neverauskas VP, Brown P, Gilliland J, Gray L, Halliday L (2003)*Degraded seagrass meadows and evidence for eutrophication in Western Cove, Kangaroo Island.*Primary Industries and Resources South Australia: Adelaide.

Cook FJ, Hicks W, Gardner EA, Carlin GD, Froggatt DW(2000) Export of acidity in drainage water from acid sulphate soils *Marine Pollution Bulletin***41**, 319-326.

Copeland C, Pollard D (1996)*The value of NSW commercial estuarine fisheries.*New South Wales FisheriesCronulla NSW

Creighton C (1982) *The Camden Haven Fishing and Oyster Industry.*Report to NSW Coastal CouncilUniversity of New England Armidale NSW

Creighton C (2013) *Revitalising Australia's Estuaries– the busines case for repairing coastal ecosystems* FRDC project #2012/036http://frdc.com.au/research/Documents/2012-036-Business-Case.pdf

Diaz, RJ 2002. Hypoxia and anoxia as global phenomena. In *Proceedings of the sixth international symposium, fish physiology, toxicology, and water quality*, Ed Thurston RV, 183–202. Ecosystems Research Division Athens Georgia USA

Fowler et al (2003) *Dynamics in 0+ recruitment and early life history for snapper (Pagrus auratus, Sparidae) in South Australia.*

Gillanders BM, Kingsford MJ (2002)Impact of changes in flow of freshwater on estuarine and open coastal habitats and the associated organisms. *Oceanography and Marine Biology: an Annual Review***40**, 233-309.

Government of South Australia (2009) *Murray Futures Lower Lakes and Coorong Recovery. Securing the Future, A Long-term Plan for the Coorong, Lower Lakes and Murray Mouth* Department for Environment and Heritage: Adelaide.

Grabowski JH, Peterson CH (2007)Restoring oyster reefs to recover ecosystem services. In *Ecosystem Engineers: Plants to Protists* (Eds CuddingtonK, Byers J, Wilson W, Hastings A) pp 281-298.Academic Press Boston USA

Hodgkin EP (1994)Estuaries and coastal lagoons. In *Marine Biology*(Eds Hammond LS, Synnot RN)pp.315-332.Longman Cheshire Melbourne Victoria

Johnston SG, Slavich PG, Sullivan LA, Hirst P (2003a)Artificial drainage of floodwaters from sulfidic backswamps: effects on deoxygenation in an Australian estuary. *Marine and Freshwater Research***54,** 781-795.

Johnston S, Kroon F, Slavich P, Ciblic A, Bruce A (2003b)*Restoring the Balance – Guidelines for managing floodgates and drainage systems on coastal floodplains*m NSW Agriculture Wollongbar NSW
Kroeger T (2012) *Dollars and Sense: Economic Benefits and Impacts from two Oyster Reef Restoration Projects in the Northern Gulf of Mexico*The Nature Conservancy, USA
http://www.nature.org/ourinitiatives/regions/northamerica/oyster-restoration-study-kroeger.pdf -

Lloyd D (1996) *Seagrass: a lawn too important to mow*Great Barrier Reef Marine Park AuthorityTownsville QLD

National Land and Water Resources Audit) (2002) *Australian Catchment, River and Estuary Assessment 2002* Commonwealth of Australia: Canberra

New South Wales Department of Primary Industries (2006)*NSW Detailed Weir Survey.Reducing the Impact of Weirs on Aquatic Habitat*Report to the New South Wales Environmental Trust, Sydney

New South Wales Department of Primary Industries (2007) *Seagrasses*Primefact 639

New South Wales Department of Primary Industries (2008) *Mangroves*Primefact 746

New South Wales Industry and Investment (2010) *Status of Fisheries Resources in NSW, 2008/2009 School Prawn/Eastern King Prawn/Dusky Flathead* Cronulla NSW

NSW Department of Primary Industries (2011) *Case studies in restoring connectivity of coastal aquatic habitats: floodgates, box culvert and rock-ramp fishway* Cronulla NSW

Potter IC, Pen JW, Brooker KS (1986) Life cycle of the western school prawn, *Metapenaeus dalli* Racek, in a Western Australian estuary. *Australian Journal of Marine and Freshwater Research***37**, 95-103.

Reid GK (1961)*Ecology of Inland Waters and Estuaries*van Nostrand New York USA

Rowling K, A Hegarty and M Ives Eds 2010 *Status of Fisheries Resources in NSW 2008/09*. Industry & Investment NSW, Cronulla NSW

Ryder D, Mika S (2013) *Clarence River Water Chemistry and Benthic Communities: Response to the 2013 Floods* School of Environmental and Rural Science, University of New England Armidale NSW

Silberschneider and Gray 2008 FRDC Project No. 2002/05; Age, growth, maturity and the overfishing of the iconic sciaenid, Argyrosomus japonicus, in south-eastern, Australia. *Fisheries Research* 95:220-229

Sheaves M, Baker R, Nagelkerken I, Connolly R (2014) True value of estuarine and coastal nurseries for fish: incorporating complexity and dynamics. *Estuaries and Coasts* (on line)

Skilleter GA, Loneragan NR (2007) *Spatial Arrangement of Estuarine and Coastal Habitats and the Implications for Fisheries Production and Diversity* Marine and Estuarine Ecology Unit, University of Queensland: St Lucia.

Smith DJ (2007) The politics of innovation: Why innovations need a godfather. *Technovation* **27** 95-104

Smith G (1981) Southern Queensland's oyster industry. *Journal of the Royal Historical Society of Queensland* **11** 45–58.

Vaquer-Sunyer R, Duarte CM, (2008) Thresholds of hypoxia for marine biodiversity *Proceedings of the National Academy of Sciences* **105** 15452-15457.

White I, Melville MD, Wilson BP, Sammut J (1997) Reducing acidic discharges from coastal wetlands in eastern Australia. *Wetlands Ecology and Management* **5** 55-72.

Wilson BP, White I, Melville MD (1999) Floodplain hydrology, acid discharge and change in water quality associated with a drained acid sulfate soil. *Marine and Freshwater Research* **50** 149-157.

Wood A (2007) *Poor Man River: Memoirs from the River Murray Estuary* Digital Print Australia: Adelaide SA