Report to The Thomas Foundation and Noosa Parks Association on assessment of aquatic restoration and management options for Noosa Estuary and Lakes

January 9, 2015

Aims of the assessment

The Nature Conservancy (TNC), with support from The Thomas Foundation (TTF) and the Noosa Parks Association (NPA) undertook an evaluation of options for restoration and natural resource management of the Noosa River and Lakes system, and Laguna Bay (hereafter referred to as Noosa Estuary).

The purpose of this assessment is to allow TTF, NPA, Noosa Shire Council, and TNC to:

i) Consider options for the future restoration and natural resource management of the Noosa Estuary;

ii) Identify further research needs to support informed decisions about these options.

This report

- Outlines the findings of the assessment.
- Describes the assessment approach.
- Provides an initial recommendation on restoration priorities.
- Proposes key next steps and science needs.
- This report is complementary to a presentation by The Nature Conservancy (Dr Eddie Game) and The Thomas Foundation (Rowland Hill) to the Noosa Shire Council on November 14, 2014.

Recommendations in brief

The restoration option considered likely to deliver the greatest improvement in the aquatic biodiversity and fish abundance of Noosa Estuary is recreation of oyster reef habitat. We considered restoration options as distinct from options that involved the management of activities within Noosa Estuary, a number of which are described in the report.

Many oyster species naturally form reef structures where large numbers of oysters are growing on top of the shells of older oysters, forming a consolidated reef (Figure 1). Where they exist, oyster (and other shellfish) reefs provide critical nursery and feeding grounds for fish and crab populations, increasing the biodiversity and abundance of aquatic resources in the surrounding waters[1]. They also consolidate sediment, improve water quality, and can increase the productivity of other nearby habitats such as seagrass and mangroves[2].

We anticipate that oyster reef restoration would focus on *Saccostrea glomerata* (Sydney rock oyster, see Figure 2) as this is the most abundant native oyster in Noosa Estuary. There is also the possibility that reefs could be developed using may be multi-species including others that are found in Noosa Estuary such as *Isognomon ephippium* (Rounded Tooth pearl oyster, see Figure 3). The reconstruction of *Saccostrea glomerata* reefs has not to our knowledge been done before so any attempt to do this in Noosa Estuary would be somewhat experimental but also of international significance.

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[1] Peterson CH, Grabowski JH, Powers SP. 2003. *Estimated enhancement of fish production resulting from restoring oyster reef habitat: Quantitative valuation.* Marine Ecology Progress Series 264: 249–264.

[2] Grabowski, J.H., et al., 2012. *Economic valuation of ecosystem services provided by oyster reefs.* Bioscience **62**(10): p. 900-909.

Figure 1 Reconstructed oyster reef in Mobile Bay, Alabama.

The principal reasons why oyster reefs were considered by the team of experts to be the priority habitat restoration activity are that Noosa Estuary has extensive mangrove habitat, and a reasonable amount of seagrass habitat, such that investment in increasing the area of these habitats is likely to be subject to diminishing returns. In contrast, reefs formed from oysters appear likely to have been a historical component of Noosa Estuary[3] but are now almost entirely missing. As such, restoring oyster reef habitat is likely to make an important contribution to restoring the ecology of Noosa Estuary. Additionally, oysters still exist in Noosa Estuary and appear on most hard structures (e.g., wharf pylons, see Figure 2) and in some places on the substrate (e.g., Weyba Creek), suggesting that water quality is unlikely to be a limiting factor in the development of oyster reefs and that reef restoration has a reasonable chance of success.

In order to more thoroughly evaluate the potential for oyster reef restoration in Noosa Estuary, it would be a priority to investigate current rates and distribution of oyster recruitment within the estuary.

These recommendations are not an indication of TNC's commitment to further work in the Noosa Estuary.

[3] Beck, M., D. R. Brumbaugh, L. Airoldi, A. Carranza, L. D. Coen, C. Crawford, O. Defeo, G. J. Edgar, B. Hancock, M. C. Kay, H. S. Lenihan, M. W. Luckenback, C. L. Toropova, G. Zhang, and X. Guo. 2011. Oyster reefs at risk and recommendations for conservation, restoration, and management. Bioscience **61**:107-116.

Figure 2 Sydney rock oysters (*Saccostrea glomerata*) on a concrete wall in Noosa Sound.

Figure 3 Rounded Tooth pearl oyster (*Isognomon ephippium*) from Weyba Creek, Noosa.

Assessment approach

To provide a rapid and efficient assessment of restoration and management options for Noosa Estuary, TNC used an expert driven approach. The assessment was centred around a two day workshop (October 30 & 31, 2014) facilitated by TNC Senior Scientist Dr Eddie Game and based on the process of Structured Decision Making. Structured Decision Making is a process that emphasizes the rapid and effective generation and evaluation of options, while trying to minimize the numerous psychological traps and biases that commonly present in assessments based on expert judgement[4]. Ten expert participants were chosen based on their substantive knowledge of topics related to the ecology of Noosa Estuary, the management and restoration of estuary habitats, and the ability to apply this knowledge to the case of Noosa Estuary. The full list and bios of experts who participated in the workshop is provided in Appendix 1. A number of additional experts were also consulted prior to the workshop as part of preparing the background material contained in Appendix 2. These additional experts are also identified at the bottom of Appendix 1.

Restoration and management objectives and indicators

Identifying a set of restoration and management options depends on having clear objectives that the options are desired to work towards. The objective provided to the experts at the workshop were:

1. To increase fish abundance in Noosa Estuary.
2. To increase aquatic biodiversity in Noosa Estuary.
3. To ensure the estuary's biodiversity and ecological health match that of the terrestrial biosphere

When using multiple experts to evaluate the consequence that any restoration or management option is likely to have for these objectives, it is essential that all experts are judging the same thing. In the case of objective #1 above for example, one expert might be evaluating the consequence of mangrove restoration for bream whereas another might be thinking of whiting; this will lead them to evaluate the consequence differently. This problem is known in expert elicitation as *underspecification*. To address this issue, the experts were asked to come up with a set of indicators that would reflect the intention of the objectives, and for which consequences would be evaluated separately. A large number of possible indicators were considered with those selected being considered representative of different aspects of Noosa's aquatic biodiversity and ecology, and the range of ways that the people interact with this biodiversity. Table 1 provides the list of chosen indicators along with the rationale behind their selection.

[4] Gregory, R., L. Failing, M. Harstone, G. Long, T. McDaniels, and D. Ohlson. 2012. Structured Decision Making: A Practical Guide to Environmental Management Choices. Wiley-Blackwell, Oxford, UK.

Table 2 List of indicators used for the evaluation of restoration and management options in Noosa Estuary along with the rationale for their selection.

Indicator	**Rationale**
School prawn (*Metapenaeus macleayi*) abundance	School prawns are a critical part of the Noosa Estuary ecosystem. Their entire lifecycle occurs within the estuary and as detritivores they play a crucial role in converting detritus (mainly organic material in lake sediments) into useful energy for a wide range of estuary species. School prawns are a key food source for many fish species and probably one of the key drivers of fish productivity in the Noosa system. They can be both commercially and recreationally harvested.
Bream (*Acanthopagrus sp.*) abundance	Bream represent one of the principal recreational fishing species in the Noosa Estuary, and are also characteristic of a range of fish species that utilize structured habitats within the estuary, like fallen logs, reefs, and mangroves.
Whiting (*Sillago sp.*) abundance	Whiting are an important recreational fish species but are also important for the visual perception of fish abundance in the estuary as they are the species visitors will see most commonly close to shore. Whiting are also characteristic of fish that predominately utilize sandy and soft bottom habitats.
Mullet (*Mugil cephalus*) abundance	Mullet are an important commercial and recreational fish species in Noosa Estuary. Like school prawns, mullet are detritivores so play the same important role in nutrient cycling in the estuary, and also between the estuary and nearby surf zone. Mullet availability within the estuary is likely to be a major driver for the abundance of other large fish species.
Bird (various species) abundance	The abundance of bird species that use the estuary in different ways (such are raptors and wading birds) can be a good indicator of the availability of good quality habitat and a healthy, productive ecosystem. They are also one of the most visible estuary fauna and valued highly be visitors.
Yabby (*Trypaea australiensis*) abundance	Marine yabbies are an important part of sand and mudflat ecosystems. They are also an important bait source for recreational fishing.
Crab (various species) abundance	Crabs of various species occupy all the aquatic habitats of Noosa Estuary. Some, like mud crabs, are important recreational species, but all crabs represent an important ecosystem component as a key food source for many fish species.
Aquatic species diversity	The overall diversity of species in the estuary is a good indication of ecosystem health and the diversity of healthy habitats.

Restoration and management options

One of the main purposes of the expert workshop was to identify the range of potential restoration and/or management options that could be considered in an effort to achieve the objectives outlined above. Evaluating a diverse set of alternative options is at the heart of good science-based decision making. To this end, the expert participants were asked to think broadly and freely about restoration and management options, and were explicitly instructed not to consider the socio-political feasibility or desirability of the options. This was done to limit the risk that experts would prematurely discard potential options because of perceived socio-political feasibility issues. Although societal values must be a critical part of any decision about restoration and management of Noosa Estuary, we did not believe that this group of experts were the right people to consider such values, especially in the absence of community consultation. Instead, the experts were asked only to consider the technical feasibility of proposed options. It is important, therefore, to be clear that these options do not constitute recommendations, only the set of possible options that were identified and evaluated in the workshop.

A total of 14 options were identified (see Table 2). Broadly, these include 7 restoration options and 7 options that focus on management of existing activities within Noosa Estuary. These options are moderately specific, which was necessary so that experts were conceiving of the same thing during their subsequent evaluations. This, however, means that there are likely multiple ways to execute each of these options. The 14 options span a wide range of habitats and activities, and while not exhaustive, is likely to represent most of the spectrum as far as types of aquatic restoration and management that could occur in Noosa.

Table 2 Restoration and management options identified during the expert workshop.

Option	Key actions
	Restoration options
Restoration of seagrass	• Restore seagrass habitat through improved control and redesign (e.g., swing moorings) of boat moorings
Oyster reef restoration	• Create oyster reefs initially in Weyba Creek and Lake Weyba
Living shorelines	• Replace hardened shoreline protection with structures that incorporate mangroves and oyster reefs • Improve biological connectivity and extent of habitat mosaic between Noosa and Tewantin
Provide habitat/hard substrate stepping stones	• Sub-tidal reef structures in the main channel between Noosa and Tewantin • Improve biological connectivity through increase hard substrate and habitat mosaics
Prawn restocking	• Restocking of prawns into the lakes and river
Restoration of Kin Kin catchment	• Assess current inputs and status of catchment • Improved land management practices
Habitat provision for Raptors	• Improve habitat availability for iconic species raptor species by supplemental feeding • Local education campaign and initiative

Management options	
North Shore management/vehicle closure	• Create a “Restoration Zone” to restrict access • Provide a buffer between recreational and commercial activities • Ensure that any conservation zone includes both terrestrial dunes, beach and near-shore areas
Wake management “between the lakes”	• Manage boat speed and wake • Improve commercial boat design
Estuary zoning (emphasis on rec. fishing)	• Reduce the recreational catch • Increase catch and release programs including training / education • Provide support for improved fish habitat • Permitting
Cessation of commercial prawn trawling	• Closure of fishing areas particularly between the lakes • Buyback of fishing licences • Modified fishing practices • Decreased or limited catch (size or timing)
Better management of commercial mullet fishery	• Limit catch on Noosa North Shore • Provide pathways to increase product value • Modify fishing practices - education
Transform gill-net fishery to higher value fishery	• Transform gill net industry to high value line caught industry
Stormwater management	• Improve the quality of water runoff flowing into the estuary through wetlands and other design features such as flow restrictors and pollution traps

Expert evaluation of options

Following the identification of the options presented above, the experts were asked to provide their judgment on the likely consequence of these options for the indicators identified earlier. Initially judgement was sought on whether undertaking the activities associated with an option would lead directly to an increase (or possibly a decrease) in the abundance of each indicator group, and then subsequently the relative magnitude of the likely increase. These assessments are presented in Table 3.

In addition to assessing the consequence of options for the ecological indicators, the experts were asked to identify other benefits likely to be associated with undertaking each option. For each option, the expert group also identified some key uncertainties associated with the option. These uncertainties can help flag priority science tasks needed in order to more thoroughly evaluate that option. Where possible, the experts were asked for indicative costs of the options. In most cases these costs were highly uncertain because there were different ways that each option could be executed and financed. Finally, for each option the experts were asked to conduct a *pre-mortem*. This is a risk identification exercise where each person was asked to imagine that the option had been undertaken and it was now 5 years into the future and something had gone very wrong with the project. Each person is then asked to describe what they imagined went wrong with the project. This has proved an effective way to elicit risk information[5]. These additional pieces of assessment are also presented in Table 3.

Evaluation results

Based on the judgement of the experts involved in the workshop, the two options likely to have the largest positive impact on the suite of indicators species are, oyster reef restoration, and cessation of commercial prawn trawling (Table 3). Compared with the other restoration activities considered, the recreation of oyster reefs within Noosa Estuary was predicted to ultimately lead to relatively larger increases in important, structure using recreational fish species (represent by bream in the indicator list), crab populations, and the overall biodiversity of the estuary. The principal reasons why oyster reefs were considered likely to have relatively larger impact than restoration of other habitats such as mangroves and seagrass, is that that Noosa Estuary has retained a large amount of intact mangrove habitat (Figure 4) such that it is unlikely to be a limiting feature in the system. Therefore restoring additional mangrove habitat, while positive, is likely to only have a small impact on the objectives considered here. Similarly for seagrass; there is a reasonable amount of seagrass remaining in Noosa Estuary, and only a small number of places where additional restoration would likely be successful.

Figure 4 Healthy mangrove habitat, Lake Cootharaba, Noosa.

[5] Game, E. T., J. A. Fitzsimons, G. Lipsett-Moore, and E. McDonald-Madden. 2013. Subjective risk assessment for planning conservation projects. Environmental Research Letters **8**:045027.

Table 3 Expert evaluation of restoration and management options for Noosa Estuary. The predicted consequence for a range of indictors is illustrated with arrows. The direction of the arrow indicates either a predicted increase or decrease, and the relative size of the arrow provides a relative measure of the extent of the change likely as a result of each option (i.e., a larger arrow means a relatively larger expected impact for that indicator). Also presented for each option are associated ancillary benefits, key uncertainties, an estimate of cost, and potential risks to success of the option.

Option	Key actions	Consequence for chosen indicators								Other benefits	Key uncertainties	Cost estimate	Pre-mortem
		Prawns	Bream	Whiting	Mullet	Birds	Yabbies	Crabs	Biodiversity				
Restoration of seagrass	• Restore seagrass habitat through improved control and redesign (e.g., swing moorings) of boat moorings	↑	↑	↑		↑ *#		↑	↑	• Increased fisheries productivity • Increased availability of habitat • Carbon sequestration • Improved management of boat mooring areas	• Negative sentiment from community who want "clean" sandy beaches rather than seagrass	$5k per boat mooring	• Community backlash and lack of support • Vessels anchoring rather than using available seagrass friendly moorings
Oyster reef restoration	• Create oyster reefs initially in Weyba Creek and Lake Weyba		**↑**	↑		↑ *		**↑**	**↑**	• Improved water quality • Sediment stabilisation • Citizen engagement • Increased fishing aggregation • Enhancing existing mangrove and seagrass habitat	• Possible disease transmission • Natural recruitment rates • Survival of oysters • Design of reefs • Future magnitude of water quality improvements	$100K per year initially for 5 year pilot then ongoing	• No community support or community backlash • Increased oyster disease transmission • Increased *E. coli* • No impact on the receiving environment • Loss of other habitats
Living shorelines	• Replace hardened shoreline protection with structures that incorporate mangroves and oyster reefs • Improve biological connectivity and extent of habitat mosaic between Noosa and Tewantin		↑			↑ *	↓	↑	↑	• Increased public awareness and ownership • Erosion protection • Improved natural aesthetics • Atonement for past actions	• Engineering viability • Public support through shoreline stewardship	$1000+	• Exacerbate erosion in some areas • Community backlash • Inability to manage marine plants due to legislative implications
Provide habitat/hard substrate stepping stones	• Sub-tidal reef structures in the main channel between Noosa and Tewantin • Improve biological connectivity	↓	↑			↑ *		↑	↑	• Oysters recruiting naturally and associated benefits • Increased recruitment of some fisheries species • Fish aggregation	• Engineering complexities / modified hydrodynamics • Meta-population dynamics • Size and spacing of	$100k+	• Navigation hazards • Fish attraction not production • Invasion by exotic species • Suffocate action • Reduction in soft

↑ – Positive effect on indicator species

↓ – Negative effect on indicator species

* shorebirds (e.g. migratory waders, oystercatchers etc.); # raptors; ^ seabirds; § consequence not able to be assessed due to a lack of specificity about the actions to be taken

Option	Key actions	Consequence for chosen indicators								Other benefits	Key uncertainties	Cost estimate	Pre-mortem
		Prawns	Bream	Whiting	Mullet	Birds	Yabbies	Crabs	Biodiversity				
	through increase hard substrate and habitat mosaics										habitat blocks • What substrate to use		sediment habitat
Prawn restocking	• Restocking of prawns into the lakes and river	↑	↑							• Improved water quality • Improved benthic habitat quality and sediment turnover • Increased recreational fishing benefits through DIY bait and target species	• Unclear as to the current status of the stocks and therefore if restocking would be required • Current carrying capacity of lakes and river • Displacement of rare species	Requires further info	• Displacement of existing species • Change in fishing practices / target species • No measurable improvement in fisheries
Restoration of Kin Kin catchment	• Assess current inputs and status of catchment • Improved land management practices	§	§	§	§	§	§	§	§	• Improved water quality • Improved connectivity for fish species • "Insurance" for other restoration options	• Current condition of the catchment • Extent of erosion / accretion	Initial $100k; up to $1M+for actions	• No measurable improvement in fisheries
Habitat provision for Raptors	• Improve habitat availability for iconic species raptor species by supplemental feeding • Local education campaign and initiative					↑ #			↑	• Visual indicator of restoration success • Increased community engagement • Community monitoring program • Estuarine health indicator • Increased tourism opportunities	• Current carrying capacity for raptors in the estuary • Extent of roost use	$100K	• Birds don't use artificial roosts • Not tangible benefit to community • Possible mortality from human interaction
North Shore management /vehicle closure	• Create a "Restoration Zone" to restrict access • Provide a buffer between recreational and commercial activities • Ensure that any conservation zone includes both		↑	↑	↑	↑ *#^			↑	• Increase in fish movement / energy transfer between estuary and coast • Possible increased larval fish supply / food for other species • Reduced fishing pressure	• Size of impact • Moving fishing pressure elsewhere	$200K	• Community backlash • No measurable improvement in fisheries • Poaching

↑ – Positive effect on indicator species

↓ – Negative effect on indicator species

* shorebirds (e.g. migratory waders, oystercatchers etc.); # raptors; ^ seabirds; § consequence not able to be assessed due to a lack of specificity about the actions to be taken

Option	Key actions	Consequence for chosen indicators								Other benefits	Key uncertainties	Cost estimate	Pre-mortem
		Prawns	Bream	Whiting	Mullet	Birds	Yabbies	Crabs	Biodiversity				
	terrestrial dunes, beach and near-shore areas												
Wake management "between the lakes"	• Manage boat speed and wake • Improve commercial boat design			↑	↑	↑ *#	↑	↑		• Increased aesthetic value • Improved safety for all users • Shoreline stabilisation through wake management • Integrity of ecotourism ventures • Improved water filtration/quality	• Implementation ability • How to achieve outcomes • Policing	?	• Lost investment due to failure • Loss of shoreline access and appreciation of the estuary • Increased pressure elsewhere
Estuary zoning (emphasis on rec. fishing)	• Reduce the recreational catch • Increase catch and release programs including training / education • Provide support for improved fish habitat • Permitting		↑	↑	↑	↑ *#^	↑	↑	↑	• Improved fishing practice resulting in improved fish stocks	• Needs to be part of the package for improved commercial fishing management • Community response • Increased fishing pressure from elsewhere	?	• Community backlash • No measurable improvement in fisheries
Cessation of commercial prawn trawling	• Closure of fishing areas particularly between the lakes • Buyback of fishing licences • Modified fishing practices • Decreased or limited catch (size or timing)	↑	↑	↑	↑	↑ *#		↑	↑	• Improved water quality • Improved benthic habitat quality and sediment turnover • Increased recreational fishing benefits through DIY bait and target species	• Actual catch rates and current stock assessment • Possibility for natural recovery		• Violence and backlash from fishing community • No recovery of stocks
Better management of commercial mullet fishery	• Limit catch on Noosa North Shore • Provide pathways to increase product value • Modify fishing practices -				↑	↑ *#^			↑	• Improved efficiency in commercial practices • Improved water quality • Increased commercial value of	• Area too limited in size to have a measurable impact on local stocks • Shifting fishing pressure elsewhere - mullet all caught further north	?	• Violence and backlash from fishing community • No recovery of stocks

↑ – Positive effect on indicator species

↓ – Negative effect on indicator species

* shorebirds (e.g. migratory waders, oystercatchers etc.); # raptors; ^ seabirds; § consequence not able to be assessed due to a lack of specificity about the actions to be taken

Option	Key actions	Consequence for chosen indicators								Other benefits	Key uncertainties	Cost estimate	Pre-mortem
		Prawns	Bream	Whiting	Mullet	Birds	Yabbies	Crabs	Biodiversity				
	education									product • Increased habitat value and productivity • Reduction in habitat destruction	• Actual catch rates and current stock assessment		
Transform gill-net fishery to higher value fishery	• Transform gill net industry to high value line caught industry		↑	↑	↑				↑	• Improved efficiency in commercial practices • Improved water quality • Increased commercial value of product	• Current fish stocks and impact of fishing practice	?	• Backlash from commercial fishers • Inability to adopt new fishing practices • No improvement in fish stocks
Stormwater management	• Improve the quality of water runoff flowing into the estuary through wetlands and other design features such as flow restrictors and pollution traps	§	§	§	§	§	§	§	§	• Enhance biogenic habitat quality and resilience due to reduced external pressures • Increased viability of restoration success	• Magnitude of improvement possible given there is limited future development	$500K+	• No tangible benefit to water quality

↑ – Positive effect on indicator species

↓ – Negative effect on indicator species

* shorebirds (e.g. migratory waders, oystercatchers etc.); # raptors; ^ seabirds; § consequence not able to be assessed due to a lack of specificity about the actions to be taken

In contrast, Noosa Estuary has very little hard substrate such as biogenic reefs. Reefs formed from oysters appear likely to have been a historical component of Noosa Estuary[6,7,8] but are now almost entirely missing. As such, restoring oyster reef habitat is likely to make an important contribution to restoring the ecology of Noosa Estuary and particularly its fisheries productivity. Other notable benefits of oyster reef restoration would likely include improved water quality because of the filtration conducted by oysters[9], enhanced productivity of existing mangroves and seagrass species as the connection between habitats is important for many species, additional recreational fishing areas as many fish are likely to be attracted to oyster reefs for feeding, and numerous citizen engagement opportunities in their development and subsequent monitoring.

Oyster reef restoration would likely focus on *Saccostrea glomerata* (Sydney rock oyster, see Figure 2) as this is the most abundant native oyster in Noosa Estuary. There is also the possibility that reefs could be developed using may be multi-species including others that are found in Noosa Estuary such as *Isognomon ephippium* (Rounded Tooth pearl oyster, see Figure 3). Because the reconstruction of *Saccostrea glomerata* reefs has not previously been undertaken, there are uncertainties around the design of the restored reefs (e.g., what engineered structures to use), and the magnitude of the benefits that could be expected. Similarly, although oysters are naturally present in the Noosa Estuary, it is uncertain whether recruitment and survival of oysters is adequate to re-establish reefs without hatchery raised spat. Another risk is that the establishment of large number of oysters in the estuary could lead to increased incidence of oyster disease that may harm the existing oyster populations in the estuary.

With regard to managing existing activities within Noosa Estuary, the option likely to deliver the greatest benefit towards the objectives identified here was the cessation of commercial prawn trawling. The principal reasons for this predicted impact are that the school prawns targeted by the commercial fishery are a critical part of the Noosa Estuary aquatic ecosystem (as identified in Table 1), and their current abundance is likely to be much reduced from historical levels. Additionally, the use of beam-trawls to capture the prawns is likely to do major damage to benthic habitats, such that cessation of trawling will deliver a range of fisheries related benefits through both the increased abundance of prawns and the increased integrity of benthic habitats in the estuary. Because any future management of the prawn fishery is unlikely to involve either TTF or TNC, we have considered it further in our recommendations.

For the options that involved restoration of the Kin Kin catchment and storm water management, the experts involved did not feel able to evaluate the likely consequences because the current level of impact each of these has on the Noosa Estuary aquatic environment was not clearly known.

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[6] Beck, M., D. R. Brumbaugh, L. Airoldi, A. Carranza, L. D. Coen, C. Crawford, O. Defeo, G. J. Edgar, B. Hancock, M. C. Kay, H. S. Lenihan, M. W. Luckenback, C. L. Toropova, G. Zhang, and X. Guo. 2011. Oyster reefs at risk and recommendations for conservation, restoration, and management. Bioscience **61**:107-11

[7] Brown, E. R. 2000. Cooloola Coast: Noosa to Fraser Island: The Aboriginal and Settlers Histories of a Unique Environment. Univ. of Queensland Press.

[8] Lergessner, J. G. 2006. Oysterers of Moreton Bay. James Lergessner.

[9] Zu Ermgassen, P. S., M. D. Spalding, R. E. Grizzle, and R. D. Brumbaugh. 2013. Quantifying the loss of a marine ecosystem service: filtration by the eastern oyster in US estuaries. Estuaries and coasts **36**:36-43.

Rapid field assessment

In addition to the expert workshop, TNC undertook a rapid preliminary field assessment in Noosa Estuary. The assessment was facilitated by the Noosa Parks Association. The purpose of this assessment was to look at potential locations for habitat restoration activities, with an emphasis on oyster reef restoration. The people involved in this field assessment were Bryan DeAngelis (a coastal habitat restoration expert with TNC's North America program), Dr Simon Walker (a Brisbane based marine ecologist with many years' experience working on habitat restoration in South East Queensland estuaries), and Dr Eddie Game (marine biologist and TNC's lead scientist in the Asia-Pacific region).

Although there has been substantial modification of aquatic habitats in Noosa Estuary (e.g., the development of Hayes Island), the remaining contribution of mangrove, seagrass, and unstructured benthic habitats (e.g., sandy bottom) is high. While the relative contributions from each of these habitats to estuary productivity may be reduced because of external stressors (e.g., sedimentation or pollution), there appears to be limited opportunity for active restoration of those habitats. Regarding these mangrove and seagrass habitats, effort would likely be better spent managing existing habitat for improved health and resiliency, and thus ecosystem services, by reducing anthropogenic impacts.

The most noticeable lack of habitat was structured, biogenic habitat from reef-forming bivalves. In this regard, Noosa contrasts to other nearby systems such as Pumicestone Passage which has rather extensive intertidal shellfish reef habitat. *Saccostrea glomerata* (Sydney rock oyster) was regularly observed in much of the southern portions of the estuary, particularly in the slower moving, backwaters. Nearly all hard substrate showed evidence of oyster settlement (Figure 5). From a restoration planning perspective, this is a very positive sign. It hints at the possibility of potentially eliminating the need for hatchery-derived oysters to increase reproductive output beyond recruitment-limiting conditions. While settlement (and apparent recruitment) of oysters was observed in multiple locations where hard substrate existed, in most instances it was restricted to the intertidal zone (e.g., top and middle panel Figure 5). This effect may be the result of predation pressure of oysters that are fully sub-tidal such that oysters are found in greatest densities in a band near the upper limit of their exposure tolerance. Should this be the case, it is unlikely to be a limiting factor to potential oyster reef restoration works in Noosa Estuary because many of the candidate areas for oyster restoration are intertidal.

One small sub-tidal reef was observed, being comprised on the oyster species *Isognomon ephippium* (Rounded Tooth pearl oyster, see Figure 6). This was found in a deep section of Weyba Creek and although heavily impacted by sediment, it is suggestive of the possibility that reconstructed oyster reef may ultimately be comprised of multiple species.

Based on our field assessment, the most promising candidate sites for pilot oyster reefs restoration are likely to be sites in Weyba Creek and Lake Weyba.

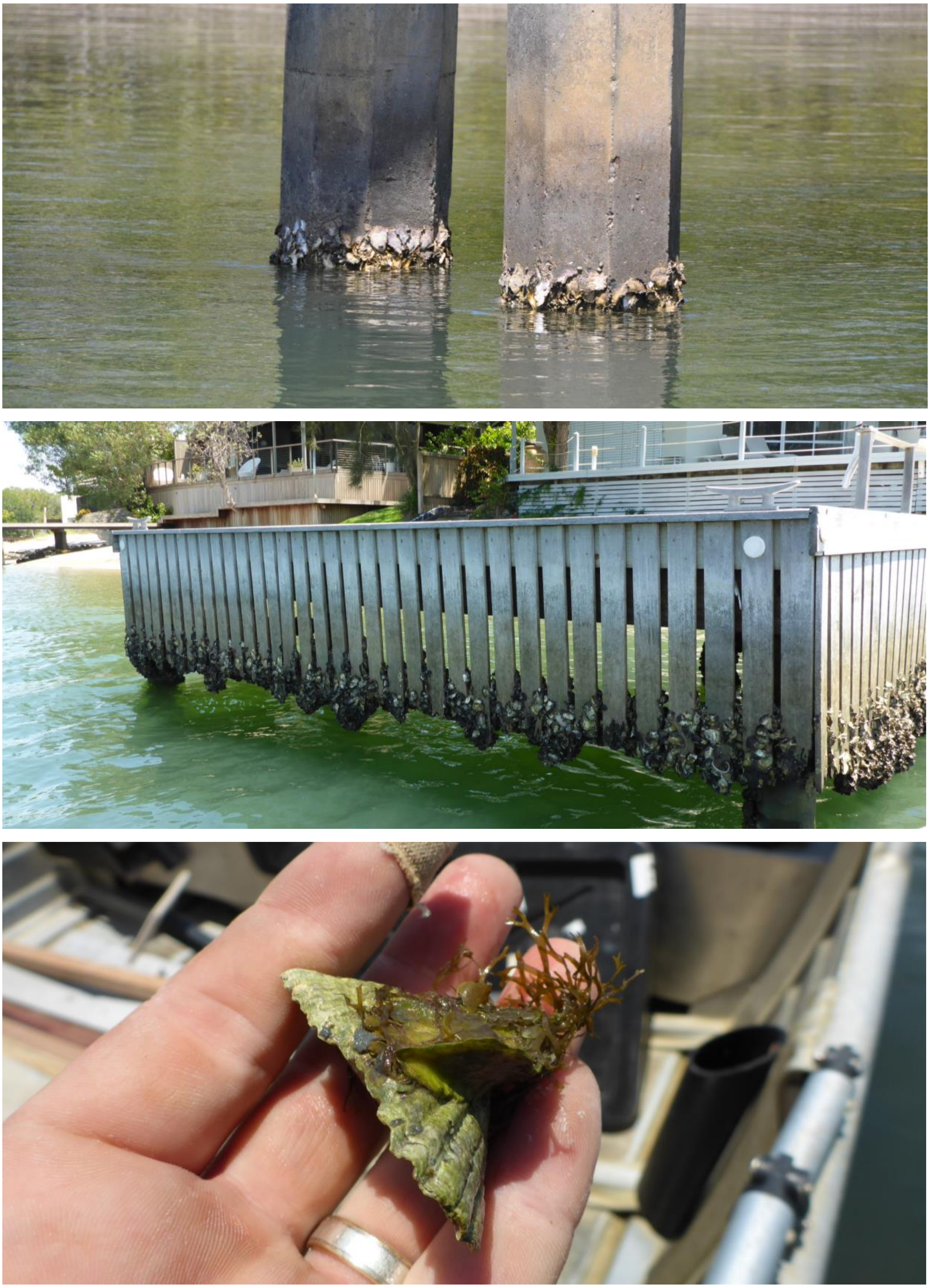

Figure 5 Examples of oyster settlement in Noosa Estuary. Top shows oysters on bridge pylons, middle shows oyster on wooden jetty batons, and bottom shows a juvenile oyster on the dead shell of another bivalve species.

Figure 6 Section of oyster reef comprised of *Isognomon ephippium* (Rounded Tooth pearl oyster) found in Weyba Creek.

Recommendations and future research needs

Based on the information gathered during this assessment, our recommendation is that to increase fish abundance and aquatic biodiversity in Noosa Estuary, the priority *restoration* actions would be to pilot the development of oyster reefs. This recommendation does indicate a commitment by TNC to be involved in an oyster reef restoration project in Noosa Estuary. In order to make a better informed judgment about the potential and design of these reefs, some additional research is necessary. Most urgent amongst the additional research tasks is an assessment of current oyster settlement and recruitment in Noosa Estuary. This research would indicate whether there is enough oyster recruitment in Noosa Estuary to reconstruct reefs without supplement from hatcheries, and also provide important insights into the design and placement of pilot reefs.

Based on the key uncertainties identified by the experts for a range of restoration and management options, it was also clear that an assessment of current fish and prawn stocks in Noosa Estuary, and a model of their harvest would be invaluable in evaluating different management options and the potential of Noosa Estuary to sustain a boutique sustainable seafood industry.

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Supplemental files attached to this report

Appendix 1 – List of experts that participated workshop or consulted during this assessment

Appendix 2 – Background material on Noosa Estuary prepared for the expert workshop

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Appendix 1
Expert workshop participants

Assoc. Prof. Greg Skilleter
The University of Queensland

Greg is currently a Reader in Marine Ecology at the University of Queensland. He is an internationally recognised expert on assessing the mechanistic links between coastal habitat mosaics and fisheries, including restoration of coastal habitats following natural and man-made impacts. Greg has previous relevant experience working in Noosa Estuary on the impacts of dredging and habitat creation on benthic communities (including fish and prawns). Greg's research group currently focus on assessing the impacts of large-scale human influences such as climate change and nutrient enrichment on the coastal environment. Greg provides leading expertise on the interactions between fish, prawns and other benthic species and their coastal habitats, and a pragmatic approach to assessing ways to improve fisheries production in the Noosa Estuary into the future.

Prof. Neil Loneragan
Murdoch University

Neil is currently a distinguished Professor of Marine Ecology and Conservation at Murdoch University in WA and Leader of the Environmental and Conservation Cluster. Prior to joining Murdoch, Neil spent 14 years working for the CSIRO in fisheries research throughout Queensland and SE Asia. He is internationally recognized for his work in evaluating the significance of coastal habitats for fisheries production and biodiversity, the spatial arrangements of habitats and their significance for fish and crustacean communities, and how restocking and stock enhancement can be used to rebuild marine systems. Neil has led numerous assessments of the value of coastal habitat for fisheries in Australia and SE Asia. In particular he was instrumental in assessing how the loss of seagrass due to a cyclone affects fisheries production in Exmouth, WA. Neil is a member of the International Steering Committee for the International Symposia for Stock Enhancement and Sea Ranching (www.searanching.org). He was also on the International Advisory Board for two interdisciplinary projects by the University of Wageningen (The Netherlands), which assessed the sustainability of particular fishing practices in SE Asia and the central Pacific.

Assoc. Prof. Thomas Schlacher
The University of the Sunshine Coast

Thomas is an internationally recognised expert in coastal ecology, focussed particularly at the interface between estuaries and the ocean. Noosa and the Sunshine Coast is Thomas' backyard, and he has built a considerable body of literature examining the impacts of humans on coastal ecosystems and how to best manage and restore these systems to improve condition. Of particular relevance to this project is his research on nuisance algal blooms and the impacts of coastal urbanisation on estuarine fisheries using accurate pollution indicators, nutrient flow and dynamics in coastal systems, and assessing the human impacts and restoration of sandy beaches.

Dr Emma Jackson
Central Queensland University

Emma has over 15 years experience as a seagrass ecologist assessing the landscape ecology and effects of human pressures on the state of structural benthic habitats (particularly seagrass and biogenic reef) and the subsequent changes in ecosystem function and services. She is particularly interested in the structure and functioning of seagrass habitats at a landscape scale (fragmentation, depth squeeze, connectivity) and is currently engaged in the large-scale restoration of seagrass habitats in Port Curtis, including researching methods suitable for restoration in Eastern Australia. She bridges the knowledge gap between science and policy including assessing the conservation importance of coastal habitats, and identifying suitable indicators for monitoring change and targets for habitat restoration.

Dr Melanie Bishop

Macquarie University

Melanie is a recognised expert in estuarine ecology including assessing natural and human-mediated processes that control coastal biodiversity and its important ecosystem functions. She uses manipulative field experiments to investigate effects of local and global changes, often producing results that could not have been predicted using theoretical or modelling approaches alone.

She brings relevant skills in restoration of estuaries, particularly in identifying existing stressors in the system and working on relevant solutions to reduce or remove these prior to restoration activities. She is particularly interested in the use of bio-engineers (habitat transforming species, such as oysters) to restore degraded habitats. Recent research highlights include providing one of the first assessments of how positive interactions among species can maintain biodiversity and change during environmental stressors. This research provides a useful mechanistic understanding for restoring functional ecosystems on large scales.

Dr Paul Maxwell

Manager Science & Innovation - Healthy Waterways

Paul currently leads science and innovation at Healthy Waterways. He is responsible for ensuring that the science underpinning the healthy waterways assessments is rigorous and independent. He is an expert in assessing resilience in coastal ecosystems, particularly the feedback mechanisms that maintain the structure and function of seagrass ecosystems. He has a background in working on integrating science, effective communication and management, including working on the multi-disciplinary Environmental Health Monitoring Program in SE Queensland.

Dr Ben Diggles

Managing Director – Digsfish Services Pty Ltd

Ben provides independent aquatic animal health consulting service for the fisheries and aquaculture industries across New Zealand, Australia, Asia and the South Pacific. He is particularly skilled in importing, biosecurity and environmental risk assessment. He also has extensive understanding of environmental management systems, aquatic animal welfare, disease diagnosis in a wide range of aquatic animals, development of feeding attractants for aquaculture and recreational fishing. Ben is collaborating with local fishing groups to spearhead a campaign for restoration of oyster reefs in Pumicestone Passage, SE Queensland.

Steve Skull

Regional Manager – Alluvium Consulting

Steve draws on a 20 year career in natural resource management to work on a diverse array of projects, spanning water resource management and planning, environmental regulation and nature conservation for a wide range of industries including mining and major infrastructure providers. While working for local government he was responsible for the development, delivery and evaluation of environmental policies and programs covering waterway management, climate change, biodiversity, peak oil and sustainability. Steve has also been intimately involved with natural resource management planning and implementation at regional scales. In South East Queensland he was the inaugural chair of the Executive Officers Group supporting the CEOs Committee for NRM. In this role he led the development and coordination of priority projects to ensure the successful implementation of the SEQ NRM Plan. Throughout his career Steve's work has been recognised by a number of prestigious environmental awards including the International River Foundation's National Riverprize, the Healthy Waterways Minister's Grand Prize and the Banksia Awards.

Dr Simon Walker
Director – Ecological Service Professionals Pty Ltd
Adjunct Research Associate – The University of Queensland

Simon is an aquatic ecologist with an extensive knowledge and understanding of freshwater, estuarine and marine and issues affecting environmental and fisheries management. He is particularly skilled in sustainable resource management, rehabilitation of estuarine and freshwater habitats, biodiversity assessment and constraints mapping, and assessing the adaptive capacity of coastal ecosystems to climate change. Simon has worked on numerous projects that have been pivotal in environmental management decisions of coastal developments, ports and resource projects, particularly in the effective use of marine and freshwater resources coupled with sustainable development. He has broad project experience throughout Australia and in developing countries in the South Pacific. In particular he has recent relevant experience rehabilitation fish habitat in the Maroochy River and restoring saltmarsh and mangrove habitats for the Port of Brisbane and QLD Department of Transport and Main Roads.

Bryan DeAngelis
North America Coastal Habitat Restoration Coordinator – The Nature Conservancy

Bryan DeAngelis has been working in marine restoration , education, research in the US and Caribbean for over a decade. Bryan spent 8 years in coastal habitat restoration as an employee of the National Oceanic and Atmospheric Administration's Habitat Restoration Center. At NOAA Bryan gained extensive experience developing, managing, and implementing a wide variety of habitat restoration projects and techniques, with a special emphasis on monitoring and measuring project performance. It was with NOAA that Bryan gained his introduction to the bivalve restoration field as the Coordinator of the North Cape Lobster and then later the Shellfish Restoration Programs; two multi-million dollar Natural Resource Damage Assessment projects designed to restore lobster and bivalve resources and services lost due to a large oil spill on the south coast of Rhode Island. In January 2013, Bryan was hired by TNC to serve as the North America Coastal Habitat Restoration Coordinator and to serve as the Coordinator for the National Partnership between TNC and NOAAs Community-based Restoration Program. This Partnership with NOAA has funded nearly 150 restoration projects throughout the US and territories. These projects span the range of habitat types from salmon habitat in the Northwest to coral restoration in Puerto Rico, the US Virgin Islands and Hawaii, with sponge habitat, mangrove, salt marsh, seagrass and plenty of bivalve restoration projects in between.

Additional experts consulted

Jock McKenzie
Coordinator – MangroveWatch Hub, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University

Rob Coles
Principal Research Scientist – Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University

Mike Rasheed
Principal Research Scientist – Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University

Dr Samantha Miller
Principal Policy Officer – Queensland Department of Agriculture, Fisheries and Forestry