Prospects for seascape repair: Three case studies from eastern Australia

By Colin Creighton, Vishnu Prahalad, Ian McLeod, Marcus Sheaves, Matthew D. Taylor and Terry Walshe

Three case studies spanning tropical, subtropical and temperate environments highlight the minimum potential benefits of investing in repair of coastal seascapes. Fisheries, a market benefit indicator readily understood by a range of stakeholders from policymakers to community advocates, were used as a surrogate for ecosystem services generated through seascape habitat restoration. For each case study, while recognising that biological information will always remain imperfect, the prospects for seascape repair are compelling.

Key words: *coastal wetlands, ecological restoration, ecosystem services, fisheries, salt marshes.*

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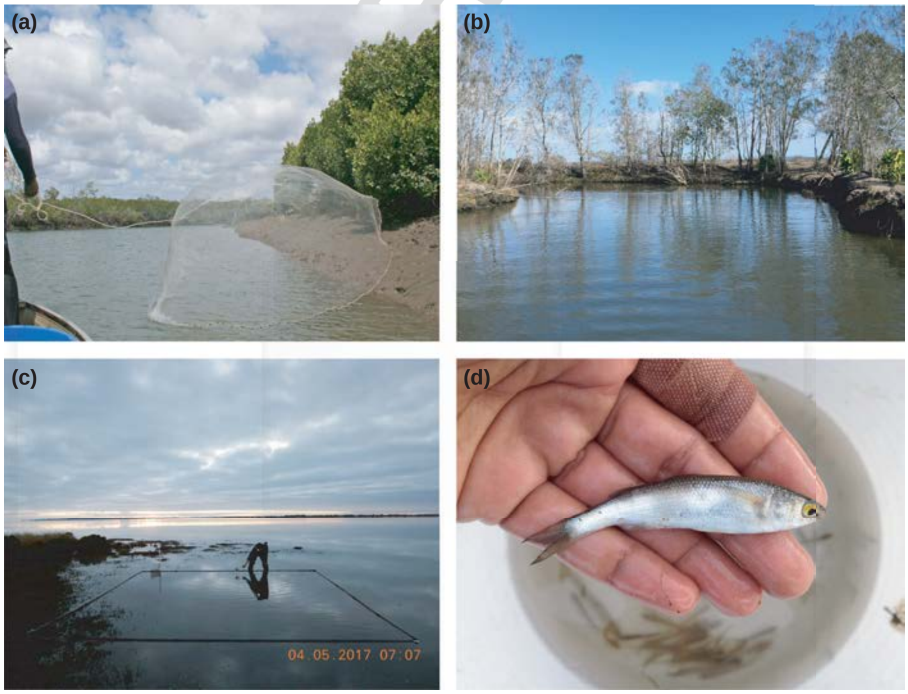

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Figure 1. Seascape habitats from eastern coastal Australia used as candidate examples to illustrate the benefits from restoration. (a) Tropical case study: cast-netting in action along a mangrove-lined creek in Australia's wet–dry tropics; (b) subtropical case study: a remnant subtidal marsh channel on the Lake Wooloweyah delta, northern New South Wales (the channel extends in about 20 m and then hits the dyke); (c) temperate case study: pop-nets in action at high tide on a saltmarsh in Tasmania's north-west coast, and (d) the focal species Yellow-eye Mullet (*Aldrichetta forsteri*).

Introduction

Coastal seascapes are a mosaic of tidally influenced habitats that include channels, gutters, mudflats, mangrove clumps, mangrove-lined channels and various communities of seagrass, saltmarshes and tidal freshwater wetlands. Their generally flat profile and proximity to the coast and human settlements make them amenable to being drained, filled and converted to farmland, sports fields, houses and canal or industrial estates (Lee *et al.* 2006; Sheaves *et al.* 2014; Rogers *et al.* 2016). Saltmarshes have often borne the brunt of anthropogenic impacts due to their 'frontline' position, being most exposed to human settlements and activities. Along the Australian coast, seascapes and especially their saltmarsh components have been cleared, drained, filled and levees constructed to exclude tidal inundation (Sinclair & Boon 2012; Prahalad 2014). More generally, modification to seascapes—especially barriers to water flow and connectivity, such as bund walls, or roads—occurs along almost every river and estuary in the more populated parts of Australia (NLWRA 2002; Creighton *et al.* 2015).

Functionally, the seascape continuum drives coastal ecological productivity and provides a range of ecosystem services (e.g. Laegdsgaard 2006; Mount *et al.* 2010; Boon *et al.* 2011; Creighton *et al.* 2015). A number of the important regulating, supporting and provisioning services such as carbon sequestration (Lawrence *et al.* 2012) and commercial and recreational fisheries (Creighton *et al.* 2015; Taylor *et al.* 2017a,2017b) are dependent on hydrological connectivity being maintained, so that fresh and tidal waters have adequate opportunities to meet. Reinstating tidal connectivity to ensure biological, chemical and hydrological fluxes is key to restoring ecosystem function and ecosystem services (e.g. Raposa & Talley 2012). Indeed, the Australian Government's conservation advice for the recovery of coastal saltmarsh listed as a threatened ecological community under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) clearly identifies the need for 'maintenance of ecological function and increased resilience' through 'permanent or intermittent connection with the sea; functioning trophic pathways; [and] structural habitat .. .' (TSSC, 2013, p. 23). There is estimated to be 164,000–245,000 ha of saltmarsh covered under this listing, with data about their decline in extent and condition highly variable across regions (for examples of high-resolution data, see Sinclair & Boon 2012 and Prahalad 2014).

Recognising the value of coastal seascape habitats, the ongoing threats to their ecosystem services and the need for ecological management and restoration, the two central questions we seek to address are: (i) What are the potential benefits that can be derived from seascape repair? and (ii) how do these benefits outweigh the costs for repair under different risk scenarios? We envisage this information would provide quantifiable potential benefits as part of business cases that might then attract public or private investment in repair. This approach accords with the extended attention being paid to environmental assets (Natural Infrastructure) in national accounts (Bureau of Meteorology 2013), and the increasing number of robust valuations of ecosystem services (e.g. through the United Nations System of Environmental-Economic Accounts framework: United Nations 2014).

Although the two questions we address are pertinent to all of Australia's seascape habitats, we focus on saltmarsh in particular, due to its vulnerable status under the EPBC Act and the need to address repair as part of the proposed Recovery Plan (TSSC 2013; Rogers *et al.* 2016). The focus on saltmarsh is further justified given the added effects of climate change and sea level rise that require coastal wetlands to retreat inland, further increasing land-use conflicts and opportunity costs for repair (Abel *et al.* 2011; Prahalad *et al.* 2019a).

To address our questions, we used three case studies (Taylor & Creighton 2018; Prahalad *et al.* 2019b; Abrantes *et al.* 2019) developed as part of a research program supported by Australian Government's National Environmental Science Program. The case studies span a range of biophysical and policy settings across tropical, subtropical and temperate Australia (Figs 1,2, Table 1). Across these case studies, we sought indicators (cf. United Nations 2014) that (i) are supported by calculations that are clear, simple and readily understood by policymaker to community advocate; (ii) reflect valuations that are well founded and based on Australia's existing commodity markets; and (iii) are conservative and generally lower bound plausible estimates of value, with only selected, usually single benefit streams used in the valuation process. Here, we employ key prawn and fish species as easily publicly understood exemplar indicators for estimating the potential benefits of seascape repair. Benefit streams are accompanied by lists of ecologically sustainable assumptions that clearly demonstrate that the values are conservative. We also list additional likely benefits thereby also demonstrating the conservative nature of the results.

The term 'value' used here refers to market clearing prices of tradable commodities. These dollar (AUD) values reflect the economic costs and potential benefits if there is investment in repair (or benefits forgone if there is no repair). By using commercially recognised species and their dollar value in the marketplace, we seek to translate what can be an obscure set of ecosystem services into commonly and readily understood metrics. In doing so, we provide groundwork for developing more detailed, contextually nuanced and locally specific business cases for seascape conservation and repair. We acknowledge though that the interpretations of value encompass a wide range of attributes beyond the scope of the present paper (e.g. nonmarket and nonuse values), and not all of these attributes are amenable or even suitable for economic valuation (see Boon & Prahalad 2017).

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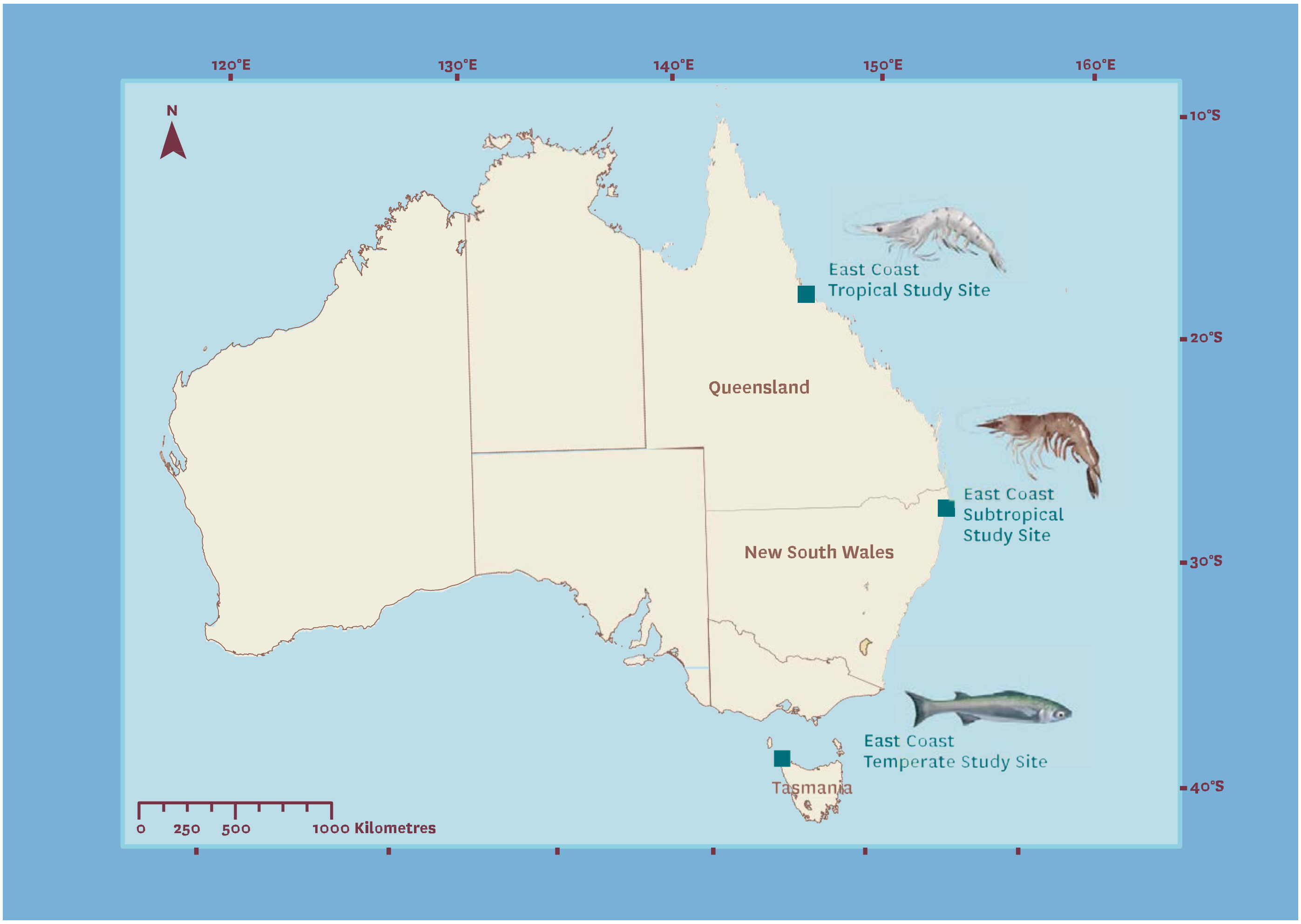

Figure 2. Location of the three case studies from eastern coastal Australia used to signify the potential fisheries benefits that can be derived from repair of tropical, subtropical and temperate seascape environments.

Case Studies

The following three case studies signify the potential benefits that can be derived from repair of coastal saltmarsh spanning tropical, subtropical and temperate seascape environments. The east coast tropical and subtropical studies selected prawn species as indicators for estimating benefits (i.e. potential increases in prawn biomass) from seascape repair. This is because prawns are iconic seafood products in the tropical and subtropical regions, generally in high demand, and are well understood as an indicator of potential market benefit by a range of stakeholders. Prawns are also annual, highly fecund species that will rapidly expand in population size by exploiting repaired habitat. In comparison, there is limited understanding of seafood derived from saltmarshes in temperate regions (Wegscheidl *et al.* 2017). The east coast temperate study therefore examined the fish assemblage in general and identified the most dominant seafood/fish species of commercial and recreational interest to illustrate both current and potential fishery value.

Case study 1: East coast tropical saltmarsh restoration (Bowling Green Bay, north Queensland)

The Banana Prawn (*Fenneropenaeus merguiensis*) fishery was chosen as the market benefit indicator. This species uses tropical estuaries as nursery grounds (Vance *et al.* 1990; Sheaves *et al.* 2012), where they rely on saltmarsh vegetation for part of their nutritional support (Abrantes & Sheaves 2009). The Banana Prawn is a commercially important food species and important target of recreational fishers throughout north Queensland estuaries. The species is also vital prey of other high profile commercial/recreational species such as Barramundi (*Lates calcarifer*). Banana Prawn is highly fecund and will recruit rapidly to repaired environments. Finally, Banana Prawn is an ideal target species because they can be sampled using cast nets, a gear type that is particularly suitable for small mangrove-lined estuaries (Fig. 1a), and provide accurate

Table 1. Case study in relation to local policy context (cf. Rogers *et al*. 2016), proposed likely policy changes, and targeted ecosystem service subsidies resulting from seascape repair (selected on the basis that they are readily understood by policymakers and decision-makers)

Climate zone	Case study area	Policy context (for both conservation and restoration, if applicable)	Prospects for seascape conservation and repair using fisheries as a policy surrogate	Changes in terms of increased fisheries production outputs resulting from seascape repair
Tropical	Bowling Green Bay, north Queensland	Saltmarshes, mangroves and tidal channels designated as fish habitat areas protected under Queensland *Fisheries Act 1994* (Rogers *et al.* 2016). Protection does not extend to nondesignated wetland areas (e.g. on pasture land). Major investment in ecosystem repair proposed under the Australian Government *Reef 2050 Long-term Sustainability Plan*.	Conserve existing saltmarsh as key fish habitats through cooperation with State Fisheries agencies (e.g. as marine protected areas under the Queensland *Fisheries Act 1994*). Invest in the repair of degraded saltmarsh by removal of tidal barriers to reinstate tidal flows.	Increase in commercially and recreationally important species populations, such as Banana Prawns (*Fenneropenaeus merguiensis*) and their key predators Barramundi (*Lates calcarifer*). Indirect additional increases in commercial and recreational piscivorous fish species abundance and biomass through enhanced food chains resulting in increased biomass of prey taxa such as Herrings (Clupeidae) and Mullet (Mugilidae).
Subtropical	Clarence River estuary, New South Wales (NSW)	Coastal saltmarsh habitat and associated ecological community are listed as an 'endangered ecological community' under NSW *Threatened Species Conservation Act 1995* (Rogers *et al.* 2016). The *NSW Marine Estate Management Strategy 2018–2028* seeks to 'reduce the cumulative impacts of existing agricultural infrastructure on freshwater flows and estuarine hydrology' (e.g. reinstatement of tidal flows to saltmarsh).	Invest in the repair of degraded saltmarsh by removal of tidal barriers to reinstate tidal flows (e.g. through the *NSW Marine Estate Management Strategy 2018–2028*).	Increase in the recruitment and trophic productivity of School Prawn (*Metapenaeus macleayi*), a commercially and recreationally important species. Additional gains in fisheries productivity through export of biomass (through outwelling) from saltmarsh to other seascape habitats.
Temperate	Circular Head region, north-west Tasmania	No recognition of saltmarshes and their values within State legislation (except for a few listed species and those areas within existing reserves). Some protection afforded under the statewide planning regime, subject to enforcement (see Prahalad *et al.* 2019a).	Conserve existing saltmarsh as key fish habitats through liaison with State Fisheries agencies (e.g. as marine resources protected areas under the *Living Marine Resources Management Act 1995*). Invest in the repair of degraded saltmarsh by removal of levees to reinstate tidal flows (see Figure 4).	Increase in three commercially and recreationally important species populations, especially of Yellow-eye Mullet (*Aldrichetta forsteri*). Additional food subsidies to piscivorous fish that are targeted by both commercial and recreational fishers from Silversides (Atherinidae) and Gobies (Gobiidae).

estimates with a high number of replicates collected (Johnston & Sheaves 2007).

The east coast tropical study (Abrantes *et al.* 2019) found that estimates of productivity of individual components of the estuary were highly variable and depended on a number of assumptions, which are difficult to validate (Rönnbäck *et al.* 1999; Minello *et al.* 2008; Rozas & Minello 2011). In comparison, estimates at the whole-of-estuary level, the seascapes level, in line with current understanding of estuarine species reliance on a mosaic of habitats (Nagelkerken *et al.* 2015; Sheaves 2017), required a relatively low number of assumptions and produced estimates with relatively low variability. Abrantes *et al.* (2019) found as a conservative estimate, a maximum juvenile prawn biomass of 6.5 g/m^2 for the 2 m wide bands along the estuary edge where prawns are found. For the estuary studied, with an edge area of 5.6 ha, the conservative total biomass of juvenile pawns was 0.36 tonnes.

The actual estuary productivity would likely be much higher because this estimate only relates to the maximum juvenile stock for a sampling occasion and does not take into account continual movements of prawns to offshore adult habitat once they reach a sufficient size. To more precisely calculate estuary productivity, information would be needed on patterns of recruitment, growth rates, mortality, predation and emigration. Suffice it to say an estimate of Banana Prawn productivity of 0.36 tonnes is probably orders of magnitude below total estuary productivity (Abrantes *et al.* 2019). While this provides a baseline estimate that can be used to demonstrate the potential benefits of seascape repair, much more extensive studies would be required to link production of Banana Prawn to particular areas of saltmarsh habitat (Sheaves & Johnston 2010; Sheaves *et al.* 2012).

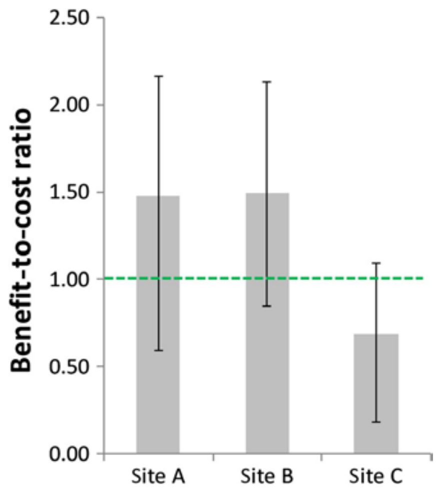

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Figure 3. Benefit–cost ratios of the three hypothetical candidate repair projects, with plausible bounds. As discussed in text, these are conservative estimates using only our indicator species and the actual benefit-to-cost ratio is generally much higher (see de Groot et al. 2013).

Case study 2: East coast subtropical saltmarsh restoration (Clarence River estuary, northern New South Wales)

The School Prawn (*Metapenaeus macleayi*) fishery was chosen as a market benefit indicator. School Prawn is highly reliant on estuarine nursery habitat and primary productivity derived from estuarine habitats for rapid growth through their early life-history stages (Hart *et al.* 2018; Raoult *et al.* 2018). The species is important to both commercial and recreational fisheries in New South Wales (Taylor *et al.* 2017a). School Prawn is fast growing and highly fecund, and given reasonable freshwater inflow to estuaries, it is unlikely to experience stock-related limitations to recruitment. The species is mostly commercially harvested; this commercial harvest provides a sought-after product for human consumption and is the most widely used bait for recreational fisheries in south-eastern Australia. Given the life-history characteristics of the School Prawn, benefits from habitat restoration are likely to be evident in this species over at most two to three years.

Based on assumptions detailed by the east coast subtropical study (Taylor & Creighton 2018), estimates indicate that reinstatement of connectivity of 27.6 ha of shallow subtidal creeks and subsequent utilisation by School Prawns (assuming good juvenile recruitment) could yield ~2500 kg of product, equating to a gross value of ~AUD24,000 and associated total output of ~AUD140,000 per year. When converted back to a per-hectare estimate, these values equate to ~AUD900 and AUD5000 per ha per year, respectively, for seascape habitat.

The benefits of habitat repair are not limited to the values estimated from direct usage of the habitat for School Prawn. Seascape habitats contain important primary producers that contribute to the overall productivity of the estuary, and consequently, they make substantial contributions to the exploited biomass harvested from estuarine systems (Taylor *et al.* 2017a,2017b). Potential gains in primary productivity when these habitats are reconnected to the broader estuary will be outwelled to other areas across the estuarine system. This can occur through mechanisms including the transport of particulate organic carbon (POC), transport of dissolved organic carbon (DOC), or consumption of marsh plants by small nekton on the marsh surface (when inundated), and subsequent movement throughout the estuary. These additional benefits are not captured in this analysis, but could contribute to a fishery-derived value of up to AUD20,000 per ha per year of areal saltmarsh that is reconnected to the estuary in the Clarence River system (Taylor *et al.* 2017a).

Any reconnected subtidal channels arising from repair (Fig. 1b), as well as outwelled productivity, will also provide habitat to directly support other target species such as Mud Crab (*Scylla serrata*), Dusky Flathead (*Platycephalus fuscus*), Yellowfin Bream (*Acanthpagrus australis*), Luderick (*Girella tricuspidata*) and Sea Mullet (*Mugil cephalus*) (Morton *et al.* 1987; Mazumder 2009; Webley *et al.* 2009). Direct support of adults and/or juveniles of these exploited species will produce fishery benefits that contribute additional value from habitat repair. Both these factors will see flow-on benefits for recreational and commercial fisheries alike.

Case study 3: East coast temperate saltmarsh restoration (Circular Head region, north-west Tasmania)

The east coast temperate study (Prahalad *et al.* 2019b) was the first documentation of fish usage of Tasmanian saltmarshes. The focus on fish and the selection of north-west Circular Head region study area stemmed from a number of reasons. The Circular Head region is home to about a fourth of all coastal saltmarshes in Tasmania and forms part of a rich seascape matrix with expansive tidal flats, seagrass beds and buffering *Melaleuca ericifolia* swamp forests (Mount *et al.* 2010). The region is very important for commercial and recreational fisheries in Tasmania. The Circular Head region saltmarshes have been subject to most extensive clearing and agricultural drainage works, with the largest potential (~629 ha or 55% of current extent) for habitat repair through tidal restoration works (Prahalad 2014).

Prahalad *et al.* (2019b) found 11 fish species using Circular Head saltmarshes with a high mean density of >72 fish per 100 m^2 (sample data from April to May 2017; Fig. 1c). The family Atherinidae (Silversides) contributed three species and 74% of the total catch numbers. Commercial and recreational species that utilise these saltmarshes in north-west Tasmanian seascapes include the following: Yellow-eye Mullet (*Aldrichetta forsteri*), Australian Salmon (*Arripis *truttaceus*) and Greenback Flounder (*Rhombosolea tapirina*). These three species contributed close to 20% of the total catch numbers. Of these, Yellow-eye Mullet (Fig. 1d) was most abundant and common, present in 24 (65%) of the 37 nets that caught fish and made up 19% of the total catch. Extended sampling throughout the year may reveal further species using saltmarshes.

Yellow-eye Mullet, Australian Salmon and Greenback Flounder are among the seven key species targeted by recreational fishers in Tasmania (Lyle *et al.* 2014). Notably, Yellow-eye Mullet and Australian Salmon help underpin recreational fisheries in the north-west region of Tasmania, with by far the greatest proportion of Mullet and Salmon (74% and 23% of statewide recreational catch in 2012–13) being caught from this region (Lyle *et al.* 2014). The commercial catch of Yellow-eye Mullet peaked in 1999/2000 and has decreased since, with 2 tonnes reported to be caught in 2015/16 (Emery *et al.* 2017). Although the Tasmanian stock of Yellow-eye Mullet is classified as 'sustainable', any repair and expansion of their nursery habitat are likely to support and enhance its carrying capacity, and hence its sustainability status. For example, given that an average of 13.6 individuals of Yellow-eye Mullet were found in a 100-m^2 area of saltmarsh (Prahalad *et al.* 2019b), restoring tidal flows to a nominal 100 ha of saltmarsh could translate to an increase in the species population by 136,000 individuals (Fig. 3). There was also evidence for rapid recruitment potential. Samples taken from rehabilitating saltmarshes behind previously breached levees supported similar fish assemblages to nearby unaltered marshes without levees. This indicates that removing tidal barriers to reconnect marshes currently behind levees is likely to return immediate benefits for fish use through expanded habitat and food resources (cf. Roman *et al.* 2002; Raposa & Talley 2012).

While Silversides (Atherinidae) are not directly targeted by fishers in Tasmania, they provide an abundant food source for other piscivorous fish that are targeted by both commercial and recreational fishers (cf. Mazumder *et al.* 2011). Most importantly, these are part of the suite of species that contribute to overall marine biodiversity and productivity of these temperate systems. These seascapes contribute more broadly to the marine food web via export of plant and animal matter to coastal waters (Melville & Connolly 2003; Svensson *et al.* 2007).

A Simple Framework for Building a Business Case for Investment in Seascape Repair

While acknowledging a suite of ecosystem services associated with repair (e.g. Jenkins *et al.* 2010), this research has emphasised benefits stemming from increased harvest for recreation and human consumption of a subset of species—readily valued benefits. If these benefits are estimated to be greater than the costs of implementation, then a prospective repair project has a benefit–cost ratio of *at least* 1 (and usually much higher: see de Groot *et al.* 2013).

Our biological understanding of the magnitude of stock increases associated with any specific repair actions remains rudimentary. Predicting with certainty the pay-off of investment in repair projects is clearly difficult. Insufficient information should always provide the impetus for careful consideration of potential risks and a cautionary approach. However, risk and uncertainty are ubiquitous features of many kinds of investment. Delaying decision-making while uncertainty is further reduced or entirely resolved carries the cost of foregone benefits, both gross (e.g. increased yields) and net (e.g. avoided risks). Repair costs are very likely to increase in the future due to declining resource condition relative to demand, and higher capital and labour costs (Blignaut & Aronson 2008). It also ignores the benefits of learning via implementation through adaptive management (Walters 1986; Burley *et al.* 2012). Here, we use the East Coast Subtropical coastal wetland restoration (Clarence River estuary, northern New South Wales) case study to lay groundwork by offering a basic decision support framework for considering investment in seascape repair under uncertainty.

A primary source of uncertainty is the size of the increase in yield or quota a repair project might bring. For example, for School Prawn, one of the key variables for which there was large uncertainty was the recruitment subsidy associated with repair of a discrete area of habitat and its implications for biomass and harvest (Taylor & Creighton 2018). Assume that we are considering repair for three hypothetical candidate sites, A, B and C, within the Clarence River estuary, all of which are motivated primarily by an increase in School Prawn abundance and availability. Although we may not know the true magnitude of the recruitment subsidy, we can use expert judgement to estimate the probability of a discrete set of possibilities and estimate associated improvements in quotas. The illustrative judgements shown in Table 2 for three hypothetical sites are the authors' own (cf. Taylor & Creighton 2018), but in other settings analysts can formally elicit judgements using accessible and proven methods (Hemming *et al.* 2018).

Considering site A first, the risk-neutral approach is to calculate the expected benefit using the probability-weighted difference between estimates with and without repair. That is, our risk-neutral best estimate of the pay-off for repair at site A is an additional harvest of 375 kg/year, on average (Table 2). If the clearing market price for School Prawn is AUD10 kg^{-1} (Taylor & Creighton 2018), we can now estimate the present value, *PV,* of the benefit:

$PV = \frac{A}{r}\left(1 - \frac{1}{(1+r)^h}\right)$, where A is the annual benefit, r is the discount rate (or interest rate), and h is the time horizon (in years) over which the repair project is to be assessed. For A = \$3,750, r = 4% or 0.04 and h = 30 years, PV = \$64,845. If the (discounted) costs of implementing the project are less than \$64,845, then the risk-neutral decision-maker will proceed with implementation, knowing that the expected ratio of benefit to cost exceeds 1. If costs are in the interval (AUD\$25,938–\$95,106; see Table 3: site A), the decision-maker needs to consider their attitude to risk, and perhaps other services that may become valuable in future (e.g. carbon and nitrogen storage, recreation: Jenkins *et al.* 2010). In addition, the prospects for transferring learning outcomes (knowledge spillover) to other speculative projects and investments may be worth considering.

After applying the calculations and data for School Prawn shown above to sites B and C, we report best estimates and plausible bounds for the present value of the benefit of repair at each of the three sites in Table 3. The estimated costs of repair for our hypothetical sites are shown in Table 4. Up-front costs include capital works and compensatory payments to landholders for inundation of otherwise productive land, among other possible impacts. Ongoing costs are to be incurred for maintenance. Using the same formula above for calculating the present value of maintenance costs (again with a 30-year time horizon and a 4% discount rate), we obtain total costs for each candidate project. Outcomes are summarised as (uncertain) benefit–cost ratios in Figure 3.

The risk-neutral decision-maker focuses on best estimates. Risk-averse decision-makers focus on lower bounds, and risk seekers on upper bounds. The priority order of the three projects depends on risk attitude where B is (weakly) preferred to A, and C is nonviable for the risk-neutral decision-maker; A is (weakly) preferred to B, and B is preferred to C for those that are risk seeking, and none of the projects may appeal to a risk-averse decision-maker.

The 4% discount rate with the 30-year time horizon has been used by similar assessments focused on wetlands restoration (e.g. Jenkins *et al.* 2010). Although social investments which accrue benefits for the future have been subject to a lower ‘social discount rate’ (and usually lower than private/individual discount rates), based on both market and ethical principles (Harrison 2010; United Nations 2014). A review of 2160 economists by Weitzman (2001) indicated a preference to use discount rates of less than 4% and decreasing to less than 1% for the distant future (i.e. a time horizon of >76 years) for climate change mitigation. Land managers themselves may choose repair under low discount rates for both market and nonmarket reasons due to varying risk perceptions, and a trial auction process could help reveal costs (e.g. Stoneham *et al.* 2003).

The purpose of the simple framework we have outlined here is to demonstrate how effective seascape repair decisions can be made despite uncertainty. It can be readily adapted to different discount rates and time horizons and extended to include continuous probabilistic judgements and additional sources of uncertainty (e.g. cost to fishers). We note, importantly, that expert judgement need not be a critical bottleneck in

Table 2. Estimated annual harvest rates (kg per year) for three hypothetical candidate repair sites

	With repair			Without repair		
	Pessimistic	Best estimate	Optimistic	Pessimistic	Best estimate	Optimistic
	P = 0.25	P = 0.50	P = 0.25	P = 0.25	P = 0.50	P = 0.25
Site A[†]	250	700	950	100	300	400
Site B	400	900	1200	200	550	700
Site C	200	600	800	150	400	500

[†]For site A, as an example, the probability weighted difference between estimates with and without repair: 0.25 × (250−100) + 0.50 × (700−300) + 0.25 × (950−400) = 375 kg/year.

Table 3. Best estimates and plausible bounds for the present value of benefits for each of three hypothetical candidate repair projects

Present value of benefit	Site A	Site B	Site C
Lower bound	\$25,938	\$34,584	\$8646
Best estimate	\$64,845	\$60,522	\$32,423
Upper bound	\$95,106	\$86,460	\$51,876

Table 4. Costs for each of three hypothetical candidate repair projects

	Site A	Site B	Site C
Costs of capital works	\$8000	\$7000	\$10,000
Costs of landholder compensation	\$10,000	\$25,000	\$20,000
Annual cost of ongoing maintenance	\$1500	\$500	\$1000
Present value of total costs	\$43,938	\$40,646	\$47,292

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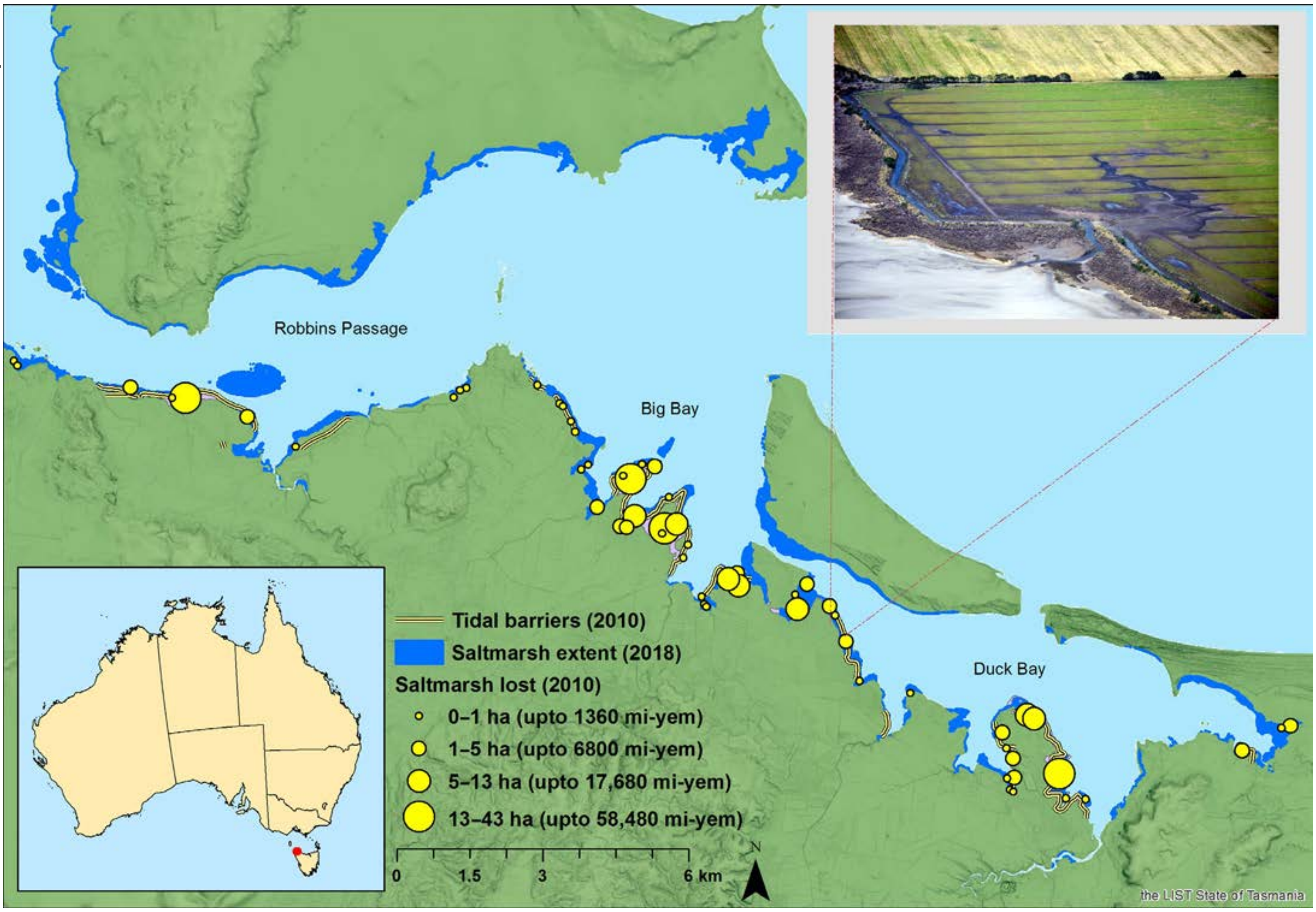

Figure 4. Location of the east coast temperate study with the potential for saltmarsh repair mapped in high resolution (based on Prahalad 2014) and the likely marginal increase in the focal species Yellow-eye Mullet (*Aldrichetta forsteri*; mi-yem, classified using Jenks natural breaks). The inset oblique image provides a closer view of the potential for saltmarsh repair through restitution of tidal flows, through engagement with private land managers. Base data from the LIST (www.thelist.tas.gov.au, State of Tasmania).

adapting this framework to develop more detailed, contextually nuanced and locally specific business cases. There are simple and accessible protocols available for eliciting the kinds of judgements used in our hypothetical example here (Burgman *et al.* 2011; Hemming *et al.* 2018). The framework explicitly argues against use of uncertainty as an excuse for inaction (also see de Groot *et al.* 2013). Even where uncertainty makes the stand-alone merit of a candidate repair project unclear, the benefits to be gained from learning through implementation and subsequent monitoring may make implementation worthwhile (Burley *et al.* 2012). Also of importance, particularly in the context of seascape habitats and their capacity for carbon storage, is the 'social welfare value' of repair that would include avoided damages due to mitigation of climate risks (Jenkins *et al.* 2010). There are many other considerations for leverage, such as benefits derived from job creation and training, as well as sustaining cultural values (Blignaut & Aronson 2008), such as connection to place (e.g. Aboriginal 'Sea Country').

Concluding Comments

The three diverse case studies have demonstrated the substantial indicative benefits that can accrue from seascape repair and may assist in the formulation of the proposed Recovery Plan for costal saltmarsh listed under the EPBC Act. While only market benefit indicator species that are readily understood by the community were used for illustration, the total benefits (as positive externalities) of repair are multiple. Equally importantly, even with just the value of the market benefit indicator species used, the argument for investment in repair is compelling (Blignaut & Aronson 2008; Turner & Daily 2008). The challenge remains that while repair delivers multiple public and private benefits, currently these drained seascape areas are generally in private ownership and are restricted from functioning as fisheries habitats (e.g. Fig. 4). The opportunity costs for restoring these fisheries habitats need to be brought into sharper focus for policymakers to community advocates by increasing the recognition of the relative costs and benefits of competing land uses.

As to the specific costs of repair works, activities are in most cases relatively simple—generally involving minor earthworks in removing small bunds and any infill to reinstate tidal connectivity and re-establish tidal channels (e.g. Prahalad 2014; Prahalad *et al.* 2019b). These are likely to be relatively inexpensive and could be rapidly undertaken by equipment such as a tractor-mounted backhoe. These costs can be integrated a part of a business case developed from the groundwork we have provided, focusing on a readily understood potential market benefit indicator as a surrogate for ecosystem service benefits accruing from seascape repair. Any business case for repair will also need to address the needs for greater clarity, rigour and demonstrable merit in identification of suitable repair sites and targets. Indeed, this provides a key challenge for scientists, determining among many prospective repair sites and market benefit indicators, all of them individually worthy to varying degrees for seascape function, which of these sites and indicators will increase the prospects for much-needed investment in saltmarsh and seascape repair.

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'Implications for Managers' Box

Documenting the potential ecosystem service benefits of seascape repair (e.g. fisheries productivity) can foster improved community and agency understanding and promote investment in an enhanced future for Australia's coastal marine biodiversity. Key steps in this process include:

- Identification of the seascape habitat (e.g. saltmarsh) and the function (e.g. tidal connectivity) that requires restoration.
- Selection of exemplar indicators (e.g. prawn and fish species) among the suite of ecosystem services that could illustrate the tangible benefits of seascape repair readily understood by policymakers to community advocates.
- Collection of biological information on selected indicators (e.g. prawn and fish species) with respect to their habitat (e.g. saltmarsh) and the broader seascape context (e.g. trophic and lifestyle relationships).
- Development of candidate scenarios for seascape repair that could secure substantial improvement in ecosystem services (primarily fisheries, but also knowledge spillover and other positive externalities), by combining the biological information with assessment of economic costs and benefits, engineering works and an understanding of social feasibility.

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