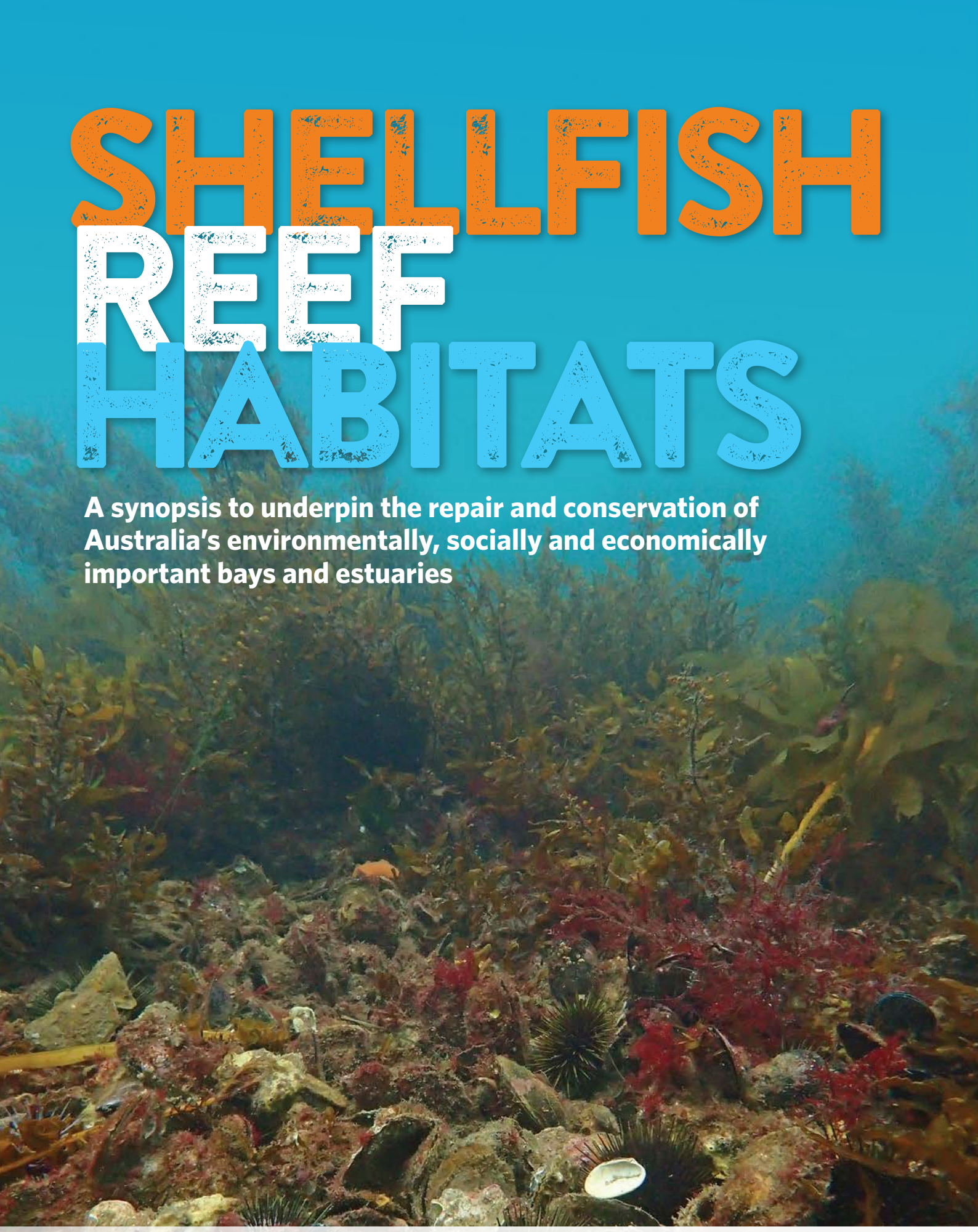
SHELLFISH REEF HABITATS

A synopsis to underpin the repair and conservation of Australia's environmentally, socially and economically important bays and estuaries



The Nature Conservancy Australia

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TropWATER
Centre for Tropical Water and Aquatic Ecosystem Research

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Important Disclaimer

Front cover: (Plate 1) Mixed flat oyster and mussel reef, George's Bay Tasmania. *C Gillies*

Shellfish reef habitats: a synopsis to underpin the repair and conservation of Australia's environmentally, socially and economically important bays and estuaries

A Report for the National Environmental Science Programme: Marine Biodiversity Hub

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Plate 2. Mixed flat oyster and mussel reef. George's Bay, Tasmania. *C. Gillies*

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Executive Summary

This report describes the historic extent and current knowledge of Australian shellfish reefs and identifies knowledge gaps and future research priorities with the aim of supporting restoration efforts.

Shellfish reefs are complex, three-dimensional living structures, which provide food, shelter and protection for a range of other invertebrate and fish species. They occur in bays, estuaries and nearshore coastal waters in both tropical and temperate regions across every state within Australia. Shellfish reefs largely occur in the intertidal and upper subtidal regions of bays, estuaries and nearshore waters with the exception of the native flat oyster (*Ostrea angasi*) which can form reefs at depths of up to 30 m. There are more than 2000 bivalve species likely to occur in Australian coastal waters, yet only eight oyster and mussel species are known to form clearly defined reef structures across multiple locations and at scale.

Prior to the 20th century, shellfish reefs were common features of estuarine and coastal systems and were of importance as a food source for Indigenous Australians, with considerable quantities of reef-forming species occurring in coastal food middens. Early maritime explorers such as Cook, Flinders, Eyre and Vancouver regularly referred to extensive shellfish reefs in voyage reports and journals. From early European settlement of Australia, vast quantities of oysters and mussels were harvested for food and as a source of lime for mortar used in the early construction of roads and buildings.

Throughout the 1800s and early 1900s, dredge and hand-harvest oyster fisheries were likely to have occurred in over 150 locations across eastern and southern Australia, including major coastal embayments such as Moreton Bay, Sydney Harbour, Port Phillip Bay, Gulf St Vincent, Derwent River and Princess Royal Harbour. As shellfish resources closest to Australia's first settlements rapidly became depleted, shellfish fisheries expanded to include more distant bays and estuaries. Whilst the total State or Australia-wide catch for any one year is unknown, records from single estuaries (e.g. 10 tonnes per week for Western Port, Victoria; 22 million oysters per year from 5 estuaries in Tasmania) indicate oyster fishing constituted some of the largest and most valuable fisheries, and indeed one of the most valuable marine industries, of the 1800s.

From historical fishery reports and media articles it is clear that early harvesting efforts were unsustainable, which led to the regulation of shellfish fisheries from as early as 1853 in Tasmania and South Australia. The oyster industry was the first (of any) fishery to be regulated by legislation in South Australia, Tasmania and Victoria, with New South Wales, Queensland and Western Australia to follow within 30 years. Yet the regulation of shellfish harvesting did little to halt the destruction of shellfish reefs and by the late 20th century, shellfish reefs had all but disappeared, with all major oyster fisheries closed by 1960.

Today, only a fraction of natural shellfish reefs still survive, notably in Hinchinbrook Channel (Queensland) Sandon River (NSW) and Georges Bay (Tasmania). Poor water quality and sedimentation as a result of catchment clearance, urbanisation and industrial pollution and diseases such as Queensland Unknown (QX) and *Bonamia* likely exacerbated the loss of historic shellfish reefs and may hinder their natural revival.

Examples from the United States and elsewhere have demonstrated that when restoration occurs at large scales, ecological function can be repaired and ecosystem services can be restored. The process of restoring shellfish reefs can provide both short- and long-term employment opportunities and established reefs can provide long-term economic gains for coastal communities, particularly in fishing tourism and coastal protection. The benefits provided by shellfish reefs include food provision, water filtration, fish production, coastal protection and habitat for other species. Several projects (in Queensland, New South Wales, Victoria, South Australia and Western Australia) have recently begun the process of restoring shellfish reefs for the purpose of recovering a near extinct habitat and to improve fish habitat, water quality and coastal protection. Momentum is continuing to build, with a number of other shellfish reef restoration projects expected to begin across Australia within the next 12-24 months.

Given the need for further knowledge on the ecology and function of Australian shellfish reefs, increasing public awareness of their historic loss and growing appetite for restoration, we recommend 12 key actions that can be undertaken by government, researchers, not-for-profit organisations and the community in order to ensure their conservation and long-term success of shellfish reef restoration efforts:

Communication, engagement and learning

1. **Improve community knowledge** and awareness of the value of shellfish reef habitat through the development of communication campaigns and materials;
2. **Increase Indigenous engagement** in restoration activities by capturing and communicating Indigenous knowledge and stories and invest in programs which support the inclusion of Traditional Ecological Knowledge in shellfish reef management and restoration;
3. **Promote the exchange of knowledge and develop partnerships** with international organisations, governments and universities involved in shellfish reef restoration.

Research and science

4. **Quantify the ecosystem service benefits and ecology of Australian shellfish reefs** (including nitrogen cycling, filtration capacity, fish production, shoreline protection and biodiversity) to better understand their ecological, social and economic value;
5. **Develop the business case** to articulate the potential environmental, social and economic return on investment for shellfish reef restoration;
6. **Develop routine shellfish health monitoring protocols for restoration** to assess disease prevalence and determine disease risk to restoration projects and aquaculture;
7. **Undertake an assessment of genetic diversity** in existing shellfish populations to determine threat of 'genetic bottlenecks'.

Management

8. **Invest in the development of early restoration projects** to build momentum, expertise and capacity in Australia's marine restoration community;
9. **Review marine habitat data to determine extent of remaining shellfish reefs, why they still exist and key threats** to determine nomination for "threatened ecological community" evaluation processes;
10. **Update relevant Federal and State government agency marine wetland definitions to include shellfish reef habitat;**
11. **Consider the designation of new Ramsar wetland sites to include shellfish reefs** and prioritise the inclusion of shellfish reef habitat surveys when updating the Information Sheet on Ramsar Weltands (RIS) for existing sites;
12. **Undertake a sustainability review of current wild harvest oyster and mussel fisheries** to determine level of risk to shellfish reef communities.

These actions combined with long-term financial and community support for individual restoration projects will serve to underpin the repair and conservation of Australia's shellfish reefs and will improve the overall health and resilience of Australia's environmentally, socially and economically important bays and estuaries.

TABLE 1. SUMMARY OF HISTORIC SHELLFISH REEF FISHERIES AND CAUSES OF DECLINE

State	Tasmania	North Queensland/GBR	SE Queensland
Main fishery species	*O. angasi*	*S. cucullata;* *S. glomerata*	*S. glomerata*
Evidence of Indigenous use (shell middens, cultural references)	Yes (*O. angasi; M. galloprovincialis*) throughout coastal Tasmania	Yes (*S. glomerata; T. hirsute; I. ephippium; S. cucullata; O. angasi*)	Yes (*S. glomerata; T. hirsute;* Pteriidae spp.)
Number of estuaries/coastal areas with historic shellfish fishery	16+	11	30 +
Peak harvest years	1860-1870	*S. cucullata* 1920-1946; *S. glomerata* 1870- 1920	1860-1910
Highest reported number of people employed in single estuary	Unknown	14	>200 (Moreton Bay)
Highest reported number of vessels in single estuary	17 (double handed boats, Spring Bay)	4 (Mackay 1945)	>127 (Moreton Bay)
Date of first oyster legislation	1853 (*Oyster Fisheries Act*, TAS)	1863 (*Oyster Act*, QLD)	1863 (*Oyster Act*, QLD)
Date of first spatial closure	1853	Unknown	Unknown
Time between first colonial settlement and first oyster legislation	49 years (Hobart settled in 1804)	30 years (Brisbane settled in 1823)	30 years (Brisbane settled in 1823)
Date of first fishery closure	1908	Never closed	Never closed
Highest peak harvest recorded (per year)	22 million oysters from 5 estuaries	In 1946, 1,500 sacks of oysters (around 135 tonnes) from Rockhampton region	21,000 sacks in 1891 (at 90 kg/ sack = 1890 tonnes)
Earliest attempt at restoration	1885	No attempts known	No attempts known
Number of estuaries/locations with existing shellfish reef(s)	1	Five known reefs of *I. ephippium. S. cucullata* and *S. echinata* still exist in low numbers throughout GBR coastline	Not known, subtidal reefs thought to be functionally extinct
Key causes of decline	Overharvest, disease, sedimentation	Overharvest, destructive fishing methods, sedimentation associated with flood events	Sedimentation and water quality decline causing disease and recruitment failure, plus dredging of subtidal reefs

New South Wales	Victoria	South Australia	Western Australia
S. glomerata	*O. angasi; M. edulis galloprovincialis*	*O. angasi*	*O. angasi*
Yes (*S. glomerata; O. angasi; T. hirsuta*)	Yes (*O. angasi; M. edulis galloprovincialis*)	Yes (*O. angasi; M. galloprovincialis*)	No, considered taboo
21+	4	67	3
Up to 1860s	Oysters: 1840-1860, Mussels: 1970-1987	1850 (?)-1900	1850 (?)-1880
Unknown	100 (Western Port 1850s)	50	Unknown
64 (Clarence River, 1883)	Oysters: unclear but 100 possibly overall, mussel/scallop fishery in Port Phillip Bay: 80-90 boats 1980s.	25 Cutters Coffin Bay (2 people per boat)	Unknown
1868 (*Oyster Beds Act*, NSW)	1859 (*Oyster Fisheries Act*, VIC)	1853 (*Oyster Beds Act*, SA)	1881 (*Oyster Fisheries Act*, WA)
Prior to 1864	1859	1873	1881
80 years (Sydney settled in 1788)	24 years (Melbourne settled 1835)	17 years (Adelaide settled in 1836)	52 (Perth settled in 1829)
1868	1886 Western Port; 1888 Port Albert; 1996 Port Phillip	1895 was recommendation of Inspector to suspend all dredging	Never closed but collapse by 1890
Historical unknown, 1976-77 aquaculture production = 9166 tonnes	Oysters: estimate of 10 tonnes/week in 1850s at Western Port, Mussels: Port Phillip Bay approx. 1000 tonnes in 1975 and in 1986	3549 bags (approx. 1,242,150 individuals) in 1890, believed to be higher prior to these catch statistics	Unknown
1883	1860s - 1900, many leases granted to attempt cultivation and reseeding, under the *Oyster Act of 1859*	1887	1895
6+ (but varying condition)	Oysters = none, although oysters still present, Mussels = at least Gipplsand Lakes, probably some small areas in Port Phillip Bay	0	Unknown
Historical overharvest, disease, sedimentation, water quality	Overharvest, habitat modification, sedimentation, water quality, chemical pollution, disease	Overexploitation (overharvest and degradation of hard substrate). Sedimentation and poor water quality may have limited recovery	Overharvest, habitat modification, sedimentation, disease

Introduction

By Chris Gillies

The Nature Conservancy, Carlton, Victoria.

Shellfish reefs: the 'forgotten' habitat

In 2009, The Nature Conservancy released a report entitled *Shellfish Reefs at Risk* (Beck et al. 2009) which heightened international attention on the stark loss of shellfish reef habitat across the globe. The report documented that over 85% of shellfish reefs have been lost from coastal areas globally, with 99% of shellfish reefs 'functionally extinct' in Australian coastal waters (Figure 1). For many, this report highlighted for the first time the very existence of a once common marine habitat and alarmingly, its near total loss across several continents, including Australia.

The near extinction of a valuable resource that sustained early Australian colonial expansion for 100 years and which has gone largely unnoticed by the general public and researchers alike, makes for an intriguing story that is not only important to the ecological history of Australia but to its cultural and economic identity as well. The lack of living memory of the extent of shellfish reefs and the value they once provided to Australia's economic and cultural development can potentially undermine long-term progress towards shellfish reef recovery. Hence, further work is required to determine the historic extent and current distribution, the benefits provided by shellfish reefs and their capacity to support productive and unique marine ecological communities and threatened species. Such information is useful for not only planning and implementing restoration and coastal management objectives but can also serve as a 'hook' in which to garner support and capture the attention of the broader public in marine conservation.

Shellfish reefs: natural risk management

The loss of shellfish reef habitat, in addition to the loss and degradation of other important marine habitats such as seagrass meadows, saltmarshes and mangrove forests, greatly inhibits our ability to manage the health of coastal environments and ensure they remain environmentally, economically and socially productive. Traditional coastal management often concentrates on minimising the amount of pollution, nutrients and sediments entering our coastal waterways, yet without healthy habitats, the course of *processing* nutrients and sediments into clean waters, abundant fish, food and habitat for other species cannot occur. The repair and restoration of marine habitats, therefore, is critical to the success of long-term management of coastal systems and the scaling-up of marine habitat restoration will enhance recreational opportunities, fish abundance and water quality for the benefit of future generations. The cost of undertaking such repair for Australia's *natural blue infrastructure* – marine habitats such as shellfish reefs, seagrasses and saltmarshes – is relatively modest (AU $350 million) in comparison to the cost of upgrading typical grey infrastructure projects such as roads or rail. The return on investment can be reached in just five years, based on improvements to fisheries alone (Creighton et al. 2015). Such an investment would not only improve the environment but would provide economic benefits in terms of jobs and long term income to many coastal communities in need (see section 10.2, Edwards et al. 2013).

This report synthesises the available information on the historic extent and current knowledge of shellfish reefs across Australia and identifies knowledge gaps and future research priorities for shellfish reef restoration. This information will be an important 'first step' to underpinning the scale-up of current and future restoration efforts across Australia and support the repair of Australia's socially and economically valuable bays and estuaries.

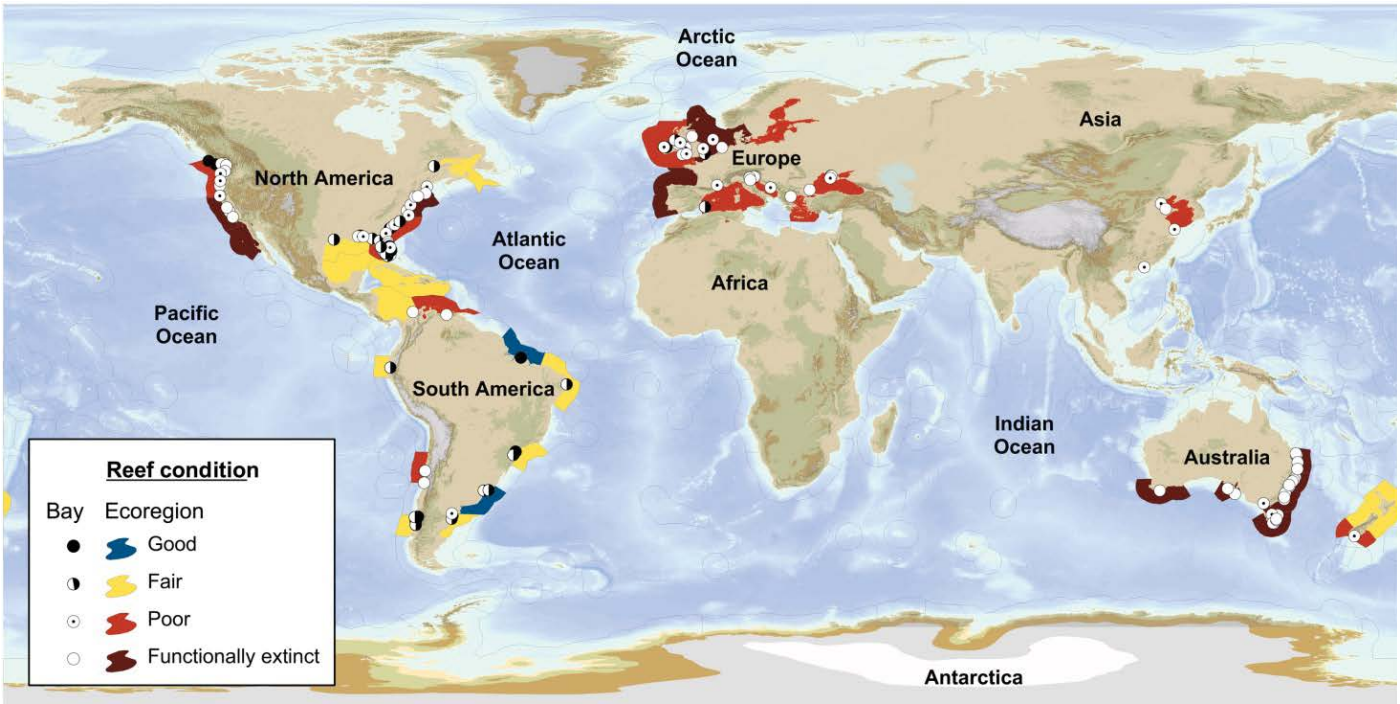

Figure 1. The global condition of oyster populations, with condition ratings based on the current abundance divided by the historical abundance of oyster reefs: < 50% lost (good); 50-89 % lost (fair); 90-99% lost (poor); > 99% lost (functionally extinct; Adapted from Beck et al. 2011).

Shellfish reefs: their role in ensuring a healthy and productive coastal Australia

By Chris Gillies

The Nature Conservancy, Carlton, Victoria.

2.1 Types of shellfish reefs

Oysters and mussels are considered ecosystem engineers (Jones et al. 1994) creating, modifying and maintaining habitat for a range of other species at a system-wide scale (Gutiérrez et al. 2003; ASMFC 2007). When occurring in dense aggregations they form reef structures comprised of both living assemblages and/or dead shell accumulations. Shellfish reefs are created when individuals cement or join, with additional hard surfaces with habitat complexity forming when these are colonised by associated organisms such as other shellfish, bryozoans, barnacles and calcareous polychaetes (Kennedy and Sandford 1999). Shellfish reefs vary in nature from consolidated structures with a high vertical profile (often termed 'reefs') to low profile structures with little differentiation in relief from their surrounds ('aggregations' or 'beds') and also include shell-rich muddy bottoms ('accumulations'; ASMFC 2007; Beck et al. 2009; Todorova et al. 2009). Shellfish reefs have a global distribution, occurring in tropical and temperate waters from intertidal to full subtidal depths, in enclosed waters such as bays and estuaries and on the open coast (Beck et al. 2011).

2.2 Shellfish reef definition

Recent definitions of shellfish reefs are provided by Baggett et al. (2014) and Kasoar et al. (2015). For the purpose of this report and to suit the Australian context, we defined *shellfish reefs* as:

"Intertidal or subtidal three-dimensional habitats formed by oysters and/or mussels at high densities".

Shellfish reefs can vary in appearance depending on the dominant reef-forming species (Plate 3A-H) but they share a number of common attributes:

- They provide habitat for other species by creating a hard substrate with high surface complexity, acting as attachment sites for sessile organisms and refuges for mobile organisms, supporting high levels of species diversity and unique assemblages (Wells 1961; Dame 1979; Coen et al. 1999; ASMFC 2007);
- They accrete dead shell material such that the reef grows in size and mass over time (except where restricted by tidal exposure or when harvested) with decay occurring at varying rates (Powell et al. 2006, Powell and Klinck 2007; Waldbusser et al. 2013);
- They provide food for other organisms, either when consumed directly or through the species assemblages they support (Peterson et al. 2003; ASMFC 2007).

Shellfish reefs can be created by a single shellfish species (e.g. *Saccostrea glomerata*, Plate 3G), or comprised of several reef-building species (for instance where *Pinctada albina sugillata* co-occurs with *Pinna bicolor* Plate 3E)

We define a *shellfish reef system* as:

"An area dominated by interconnected shellfish reefs interspersed with sand, mud, seagrass or rocky reef habitats".

2.3 Australian shellfish reef-forming species

Little information is available on the ecology of Australian shellfish reefs with only Sydney rock oyster (*Saccostrea glomerata*) and the introduced Pacific oyster (*Crassostrea gigas*) studied in some detail (Minchinton and Ross 1999;

Plate 3A. *Crassostrea gigas* (Pacific oyster – introduced) reef at Georges Bay, Tasmania. *C. Gillies*

Mitchell et al. 2000a; Krassoi 2001; Summerhaze et al. 2009; Bishop et al. 2010; Wilkie et al. 2012). Only one study is published describing the ecology of reef-forming mussels (*Mytilus (edulis) galloprovincialis*; Chapman et al. 2005). Most Australian shellfish research focuses on describing life history, feeding, husbandry and disease in cultivated species (e.g. *C. gigas*, *O. angasi* and *S. glomerata*) in support of shellfish aquaculture (Nell 1993; Nell 2001; Saxby 2002; Nell and Perkins 2005).

Over 2000 species of marine bivalves occur within Australian nearshore waters (Lamprell and Whitehead 1992) yet only a handful are considered reef building according to the definition in *Section 2.2*. Below we list those species known to build reefs across multiple locations and at scale:

Crassostrea gigas (Thunberg, 1793) Pacific oyster (introduced)

Primarily an intertidal species with a distribution from Tasmania, Victoria, South Australia and New South Wales. Introduced from Japan in 1947 for aquaculture. Occurs in intertidal to subtidal zones. Aquaculture fishery in Tasmania, South Australia and New South Wales (Plate 3A).

Isognomon ephippium (Linnaeus, 1758) leaf oyster, rounded toothed pearl shell

Primarily an intertidal species with a distribution from New South Wales to Queensland and northern Western Australia. Occurs in association with mudflats, sandy bottoms and hard substrates. No recorded fishery or aquaculture within Australia (Plate 3B).

***Mytilus (edulis)* galloprovincialis** (Lamarck, 1819) bay mussel, blue mussel

An intertidal to subtidal species with a distribution from southwest Western Australia to northern New South Wales. Occurs on hard surfaces and sandy/muddy bottoms. A dredge fishery occurred in Victoria's Port Phillip Bay from 1960s to 1990s (Hamer et al. 2013). Aquaculture current in Tasmania, New South Wales, Victoria, South Australia and Western Australia (Australian Mussel Industry Association 2015; Plate 3C).

Ostrea angasi (Sowerby, 1871) native flat oyster, mud oyster, Port Lincoln oyster

Primarily a subtidal species with a southern distribution from New South Wales to Western Australia including Tasmania. Occurs from low intertidal areas to a depth of 30 meters. *Ostrea angasi* reefs can also form mixed reefs in association with *M. galloprovincialis* and *Pinna bicolour*. Dredge fishery occurred from mid 1800s to mid 1900s in Tasmania, New South Wales, Victoria, South Australia and Western Australia. Aquaculture current or previously attempted in Tasmania, New South Wales, Victoria, South Australia and Western Australia. Small-scale wild harvest fishery still present in Tasmania (Plate 3D).

Pinctada albina sugillata (Reeve, 1857) pearl oyster

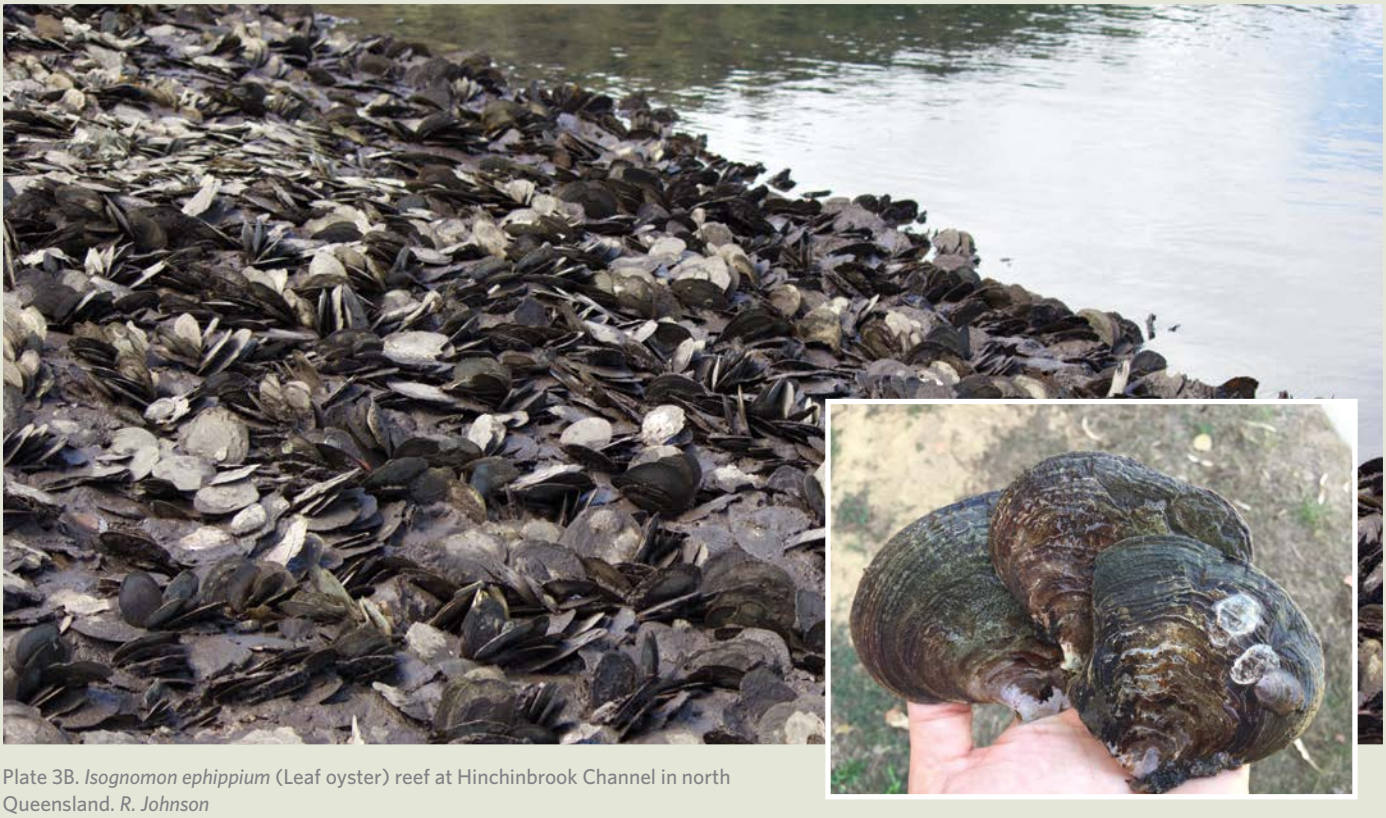

Plate 3B. *Isognomon ephippium* (Leaf oyster) reef at Hinchinbrook Channel in north Queensland. *R. Johnson*

Occurs from Northern Territory to New South Wales and Upper Spencer Gulf, South Australia on hard surfaces in the lower intertidal as well as subtidal zones to depths of at least 50 meters. *P. albina sugillata* forms reefs in Upper Spencer Gulf (Rutherford and Miller 2011) and possibly near Groote Eylandt, Northern Territory (Hynd 1960) and southern Queensland (B. Diggles *pers. comm.*). Can form mixed species reefs with *P. bicolor* in South Australia or *S. glomerata* in Queensland (plate 3E).

Saccostrea cucullata (Born, 1778) coral-rock or milky oyster

Primarily an intertidal species with a distribution extending from Queensland to Northern Territory and Western Australia. Occurs on hard surfaces, including mangroves and dead coral. Often forms mixed reefs with *Saccostrea echinata*, becoming more dominant with increasing shelter (Lewis et al. 2015). Previously formed an important local hand harvest fishery in central and southern Queensland. Current small-scale harvest and aquaculture trials (Beattie 2001; Nell 2001; Plate 3F).

Saccostrea glomerata (Gould 1850) Sydney rock oyster

Primarily an intertidal species with a distribution extending from southern Queensland to northeast Victoria. Occurs in mid to low intertidal areas on hard substrates and can form extensive reefs subtidally. Dredge and hand fishery on the east coast of Australia from early 1800s (Kirby 2004), aquaculture in New South Wales, Queensland and Western Australia (Nell 2001; Plate 3G).

Trichomya hirsuta (Lamarck 1819) hairy mussel

An intertidal and subtidal species with a distribution from South Australia east to Victoria, northern Tasmania, NSW and Queensland. Occurs on hard surfaces, often in bands below oysters (Dakin and Bennett 1987; Plate 3H). It is a prominent component of aboriginal middens along Australia's east coast.

In addition to those species listed above, a number of other bivalve species are known to develop reefs systems or dense aggregations but generally only under unique conditions or single geographies. For instance, the southern hammer oyster (*Malleus malleus meridianis*, Cotton 1930), eroded mussel *Brachidontes erosus* (Lamarck 1819) and razor clam (*Pinna bicolour*, Gmelin 1791) can form dense aggregations but these occur only within a restricted range along the southern temperate coastline including the South Australian gulfs and embayments, including those on the far west coast and Kangaroo Island (Plate 4A). The black lip oyster (*Saccostrea echinata*, Lamarck 1819) can form dense aggregations in Queensland but generally only forms reefs in association with other, reef-forming species such as *Saccostrea cucullata*.

Other aggregating bivalves such as the Mesodesmatidae (surf clams) Cardiidae (cockles) and Donacidae (pipis) and some species of mussels (e.g. *Limnoperna pulex*, *Xenostrobus inconstans*) which can also be considered ecosystem engineers, are largely endobenthic and thus are not considered 'true' reef forming species (according to the definition in Section 2.2). Further research is needed to clarify which species and in what conditions other bivalve species may form reefs, particularly pearl oyster species such as *Pinctada maxima* (gold lipped pearl oyster), *Pinctada margaritifera* (black lipped pearl oyster) and *Pinctada fucata* (Akoya pearl oyster).

Plate 3C. *Mytilus (edulis) galloprovincialis* (blue mussel) reef. Lakes Entrance, Victoria. *P. Hamer*

Plate 3D. *Ostrea angasi (native flat oyster)* reef. Georges Bay, Tasmania. *C. Gillies*

Plate 3E. *Pinctada albina sugillata* (pearl oyster) reef. Upper Spencer Gulf, South Australia. *H. Alleway*

Plate 3F. *Saccostrea cucullata* (milky oyster). Hinchinbrook Channel, Queensland. *I. McLeod*

Plate 3G. *Saccostrea glomerata* (Sydney rock oyster) reef. Port Stephens, New South Wales. *E. Lebrault*

Plate 3H. *Trichomya hirsuta* (hairy mussel) reef with *S. glomerata*. Pumicestone Passage, Queensland. *B. Diggles*

2.4 The ecological, social and economic value of shellfish reefs

Shellfish reefs have value beyond those related directly to the management of species. Recent reviews of their benefits have been conducted by ASMFC (2007); Grabowski and Peterson (2007) and Grabowski et al. (2012). These values include:

Food provision – underpinning livelihoods

The harvest of natural shellfish reefs has supported civilisations for millennia (Mackenzie et al. 1997) and was a stable food source for coastal Aborigines (Bailey 1975) and early colonialists (Kirby 2004; Alleway and Connell 2015). Although the collapse of Australia's wild shellfish fisheries had occurred by the late 1950s (Kirby 2004; Hamer et al. 2013; Alleway and Connell 2015) small commercial wild harvest fisheries for adult oysters and mussels still occur in Tasmania, New South Wales and Queensland for *S. glomerata*, *S. cucullata*, *O. angasi* and *M. galloprovincialis*. In some regions, wild oyster and mussel populations provides benefits for aquaculture because natural spat fall from these populations may reduce or negate the costs of producing shellfish spat in hatcheries (Australian Mussel Industry Association 2015).

With the exception of *I. ephippium* and *T. hirsuta* there were, or are, commercial fisheries and/or aquaculture for all reef-building shellfish species.

Water filtration - improving water quality

Oysters and mussels are suspension feeders, consuming plankton and non-living material from the water column down to a size fraction of ~ 3 µm (Newell 2004). The filtration of suspended matter in the water column by shellfish can cause a reduction in turbidity, improving light penetration and growing conditions for submerged vegetation (Wall et al. 2008), whilst the consumption of phytoplankton releases ammonium as a waste product supporting aquatic vegetation growth (Everett et al. 1995; Newell and Koch 2004). Oyster reefs are also likely to reduce eutrophication through the reduction in phytoplankton and cycling of nutrients, particularly the removal of nitrogen through denitrification (Dame et al. 1984, 1985). Grabowski et al. (2012) estimated the valued of removing nitrogen by oysters from one hectare of oyster reef habitat at USD $1385–$6716 per year in 2011 dollars and the value towards shellfish reefs promoting the recovery, productivity, and maintenance of seagrasses in estuaries between USD $1292 and $2584. Where shellfish reefs are important components of the estuary system, their capacity to filter water can be significant, in many cases filtering the entire volume of the estuary within the residence time of the water (Zu Ermgassen et al. 2012).

Fish production – supporting recreational and commercial fisheries

Shellfish reefs are considered functionally important habitats for many recreationally and commercially targeted fish species and their prey items (Breitburg 1999; Coen et al. 1999). The abundance, biomass and diversity of finfish species can be higher on shellfish reefs than nearby unstructured habitats and they can harbour unique prey species (Lenihan et al. 2001; Grabowski et al. 2005; Scyphers et al. 2011; McLeod et al. 2013). The mechanisms by which shellfish reefs support fish production include: providing refuge from predation and thereby increasing survival (Zimmerman et al. 1989; Posey et al. 1999; Tolley and Volety 2005), by increasing the amount of available prey items augmenting growth (Coen et al. 1999; Peterson et al. 2003; ASMFC 2007; McLeod et al. 2013) or by providing habitat for spawning (typically for gobies and other resident demersal fish (Plate 5) – Tolley and Volety 2005).

In northern New Zealand, mussel (*Perna canaliculus*)

Plate 4A. *Brachidontes erosus* aggregations in Gulf St Vincent, South Australia. *S. Dittmann*

reefs were found to have a distinct assemblage of macroinvertebrates, which had 3.5 times the density, 3.4 times the biomass and 3.5 times the productivity of surrounding areas (McLeod et al. 2013). The macroinvertebrate community was dominated by small crustaceans, which are an important food source for small fishes (0.1-100 g). Indeed, the density of small fishes was 13.7 times higher associated with mussel reefs than in surrounding areas. Peterson et al. (2003) estimated that 10m^2 of shellfish reef on the east coast of the United States produces 2.6kg/yr of fish and large mobile crustaceans for the duration of the reef life. Grabowski et al. (2012) used this data to calculate the value of 1 ha of shellfish reef as $USD 4123 per year in 2011 dollars.

Little information is available to determine the association between Australian shellfish reefs and recreational and commercially important fish species or their prey items. However, oysters and mussels reefs were likely important foraging areas for snapper (*Pagrus auratus*; Hamer et al. 2013) and other estuarine species such as bream (*Acanthopargus* sp.), King George whiting (*Sillaginodes punctatus*), estuary perch (*Macquaria colonorum*), tailor (*Pomatomus saltatrix*) and tarwhine (*Rhabdosargus sarba*) with recreational fishers often detailing anecdotal associations between shellfish reefs and fishing success (author's *pers. obs.*). Further research is required to determine the role that Australian shellfish reefs play in supporting the food chain, fisheries production and fisheries aggregation.

Coastal protection - reducing coastal erosion

Shellfish reefs can act as natural barriers reducing coastal erosion and protecting other habitats such as saltmarshes by baffling waves, reducing water velocity or by increasing sedimentation (Meyer et al. 1997). The use of natural habitats such as shellfish reefs as shoreline protection is termed 'living shorelines' and seen as a preferred option in many cases to traditional 'grey' infrastructure such as seawalls, bulkheads and rip-rap because of its dual capacity to support species, filter water and reduce wave energy (National Research Council 2007). Shellfish reefs reduce rather than deflect energy unlike hardened seawalls, which can further erode coastal habitat located at the end of the hardened structure. The biogenic nature of shellfish reefs means they may be able to keep pace with sea level rise and they have the capacity to naturally rebuild within a few years after storm damage. Grabowski et al. (2012) suggests that their capacity to protect coastlines from eroding is their most valuable trait, estimated between USD $860 - $85,998 (per hectare per year) in 2011 values depending on the coastal environment.

Habitat for other species - supporting biodiversity

Shellfish reefs provide habitat for a number of sessile and motile species including algae, invertebrates such as shrimps, crabs and molluscs and finfish species (Plates 5-7). Shellfish reefs often have high densities and productivities of associated communities of benthic

Plate 4B. Dense aggregations of *Pinna bicolour* in Streaky Bay, South Australia. Whilst not strictly considered reef-forming, they provide habitat for a range of other marine species, including other shellfish. *P. Hunt, Malacological Society of South Australia*.

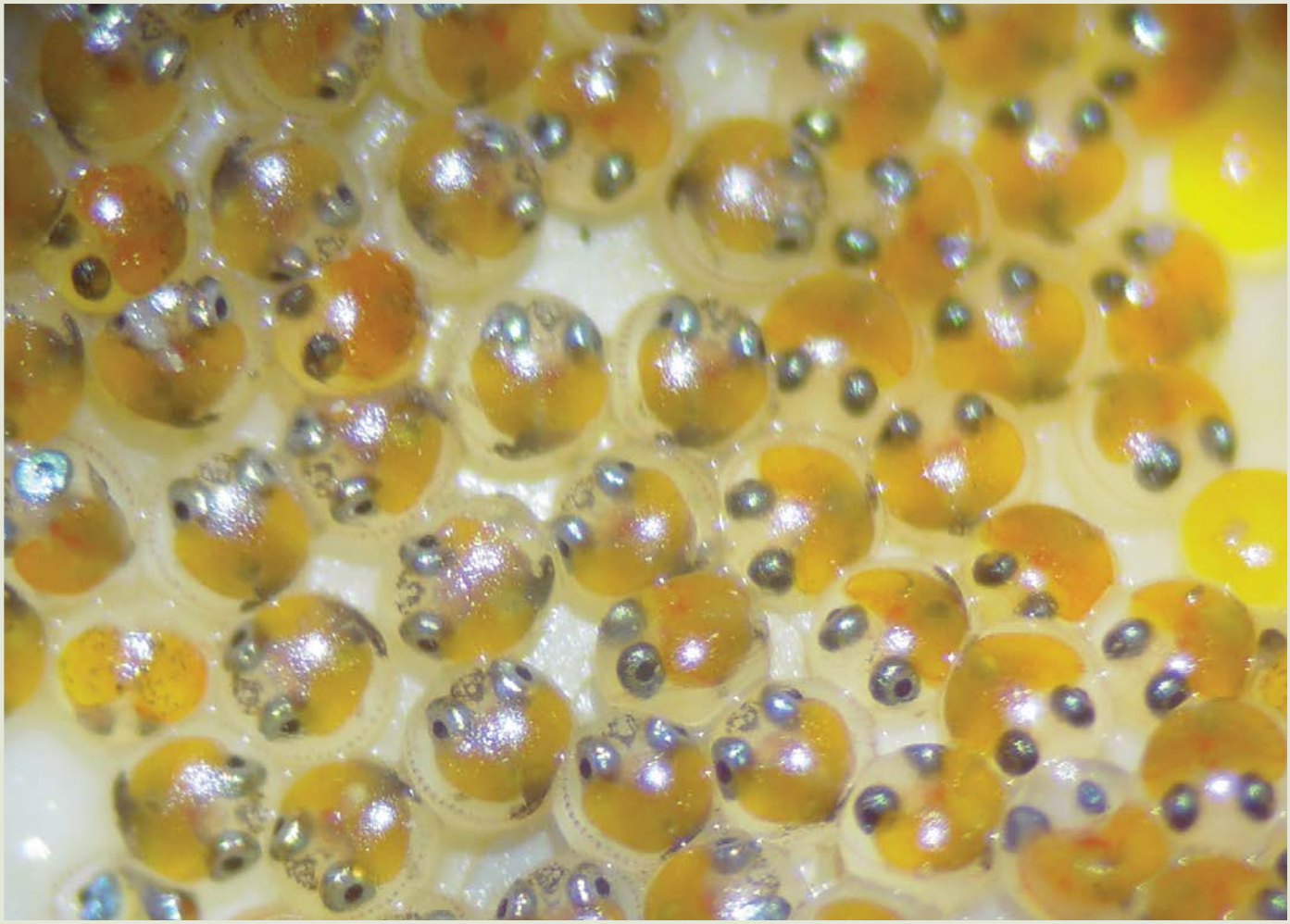

Plate 5. Thousands of fish eggs were deposited onto new shellfish reef material deposited into Pumicestone Passage, but only in subtidal areas. *B. Diggles*

invertebrates because they are structurally complex habitats (e.g. Coull and Wells 1983) with high inputs of detrital organic matter (e.g. Vetter 1995). They may also form egg-laying substrates and nursery habitats for fish and decapod species. Mobile invertebrates inhabiting structurally complex habitats may be less vulnerable to predation than those associated with a more homogeneous structure (Heck and Thoman 1981; Coull and Wells 1983). In addition, shellfish offer a hard surface for algae or sessile invertebrates to attach to. In turn, these algae and sessile invertebrates may offer further habitat and food for mobile invertebrates.

Shellfish directly consume particulate matter or bind unconsumed particles with mucus and deposit these as pseudofaeces, thereby transporting energy from the water column to the benthos (Dame et al. 1984; Dame and Dankers 1988; Asmus and Asmus 1991). This process of bentho-pelagic coupling supports the production of invertebrates and fish species and is an important pathway for energy to move up into the marine foodweb (Rodney and Paynter 2006).

Plate 6. Shellfish reefs provide habitat for a wide range of algae, invertebrate and fish species. *C. Gillies*

Plate 7. An example of mobile invertebrates associated with mussel reefs. *R. Taylor*

Shellfish reefs of the Great Barrier Reef region

By Ian McLeod, Agnès Le Port and Marcus Sheaves

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Past extent of shellfish reefs

Historical and archaeological evidence suggests the existence of abundant populations of reef forming shellfish along the Great Barrier Reef (GBR) coasts and estuaries prior to European settlement. The major reef forming species included the milky or coral rock oyster (*Saccostrea cucullata*; formally known as *Crassostrea cucullata* or *C. amasa*), the black-lipped oyster (*Saccostrea echinata*), the Sydney rock oyster (*Saccostrea glomerata*; formally known as *S. commercialis*) and the rounded toothed pearl shell (*Isognomon ephippium*). These species may have formed mixed-species reefs possibly also including hairy mussels (*Trichomya hirsuta*) and pearl oysters (*Pinctada* spp.).

Most historical records refer to 'oysters' and it is mostly unknown what species are being referred to. *Saccostrea cucullata* and *S. echinata* occur in the intertidal or shallow subtidal zone of rocky outcrops or in association with mangroves all along the GBR coastline (Endean 1956a; 1956b; Atlas of Living Australia 2015; Figure 2). Both *S. cucullata* and *S. echinata* favour sheltered and semi-sheltered areas, with *S. echinata* becoming more dominant with increasing shelter (Lewis et al. 2015). Records from the 1950s show that these species were frequently the dominant littoral fauna in this region, covering the rock surface in the intertidal zone with a 'pavement' of oysters (Endean et al 1956a). *Saccostrea glomerata* occurred as far north as Townsville and formed thick reefs in the intertidal and shallow subtidal waters of southern Queensland (Smith 1985). The past abundance and distribution of *I. ephippium* is not available in the literature. However, *I. ephippium* are currently present along the GBR coast (Atlas of Living Australia 2015; Figures 2-3) and form reefs (some 10s of square meters in area) in mangrove creeks in a few known locations (Ian McLeod *pers. obs.*).

Archaeological evidence and Indigenous use

Shellfish have historically been an important food source for Indigenous Australians (Smith 1985; Ulm 2006; Ogburn et al. 2007; Ross et al. 2015). Reef forming shellfish such as oysters and mussels were one of the most important coastal food sources for Aboriginal communities in pre-European times (Meehan 1982; Creighton 1984). Shells from reef forming species, especially oysters, made up large amounts of middens in coastal areas of Australia, including along the GBR coast and islands (Rowland 1986, Ulm 2006). For example, on Curtis Island, middens were dominated by shell remains of *S. glomerata* and *T. hirsuta* (Ulm 2006). Two species of oysters (*S. cucullata* and *O. angasi*), pearl shells (*Pictada sp.*), rounded toothed pearl shells (*I. ephippium*), and hairy mussels (*T. hiruta*) have also been found at other midden sites in the southern GBR (Rowland 1986; Barker 1989; Ulm 2006).

Historical records and 'the harvest years'

Historical records of oyster and mussel abundance and fisheries are sparse, and much of the information about early European oyster use is only available from newspaper articles. European exploitation of shellfish resources probably commenced immediately after settlement as these were likely an abundant and easy to harvest food source. Between 1824 and 1863, there was little or no government regulation of oyster fisheries. Queensland's first Oyster Act was proclaimed in 1863 to make wasteful burning of live oysters for lime (for mortar used in construction) illegal and requiring a license fee for oyster culture (Smith 1981). However, it is unknown if similar to more southern regions, oysters from the GBR region were also burned to make lime.

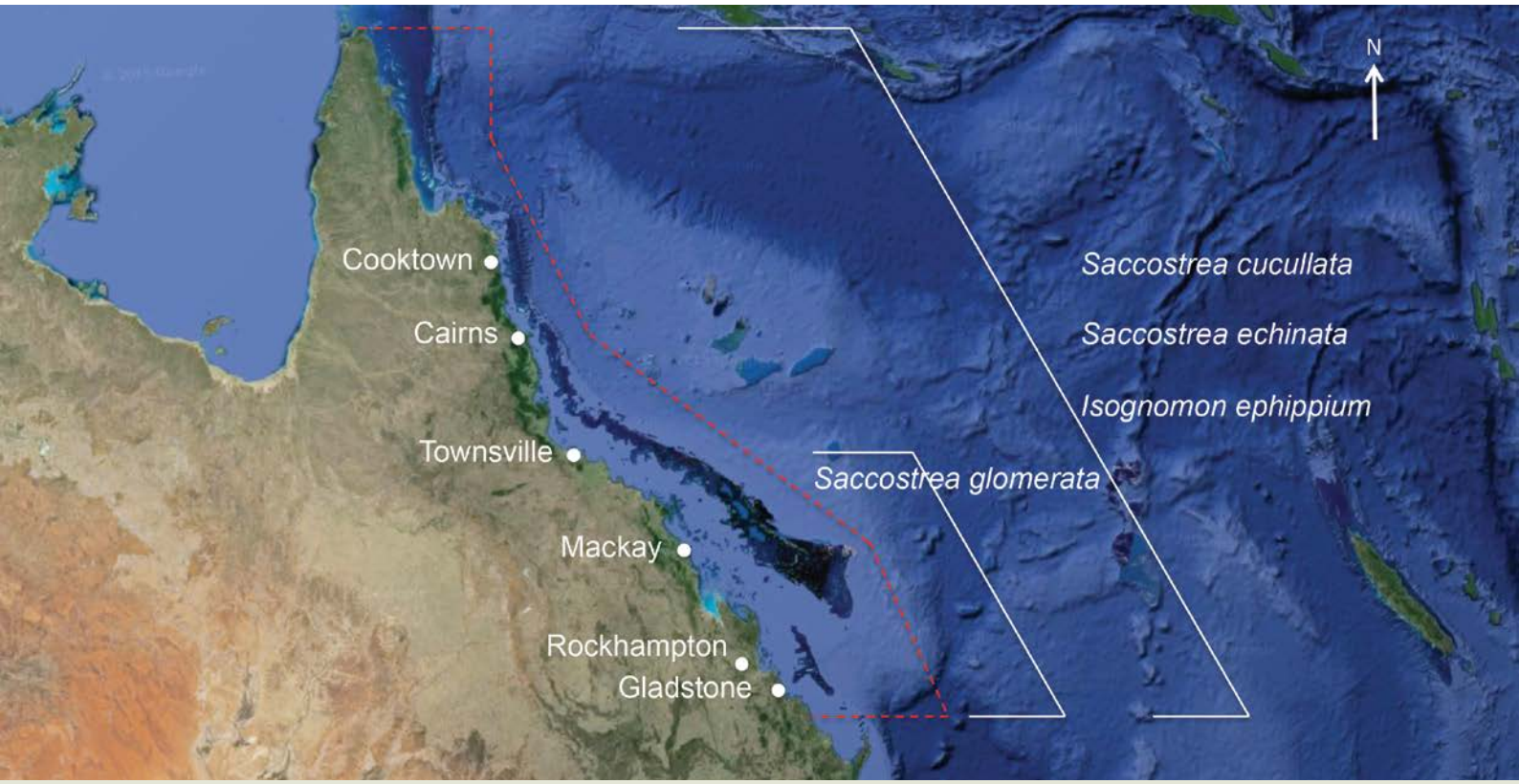

Figure 2. Current ranges of the four main shellfish reef species in the Great Barrier Reef (GBR) region. The dashed red line denotes the GBR World Heritage Area boundary.

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Fison (1889) reported vast quantities of oysters in estuaries and around rocky headlands along the southern GBR coast north to Gladstone Harbour, in The Narrows between outer Curtis Island and the mainland, as well as Rodds Harbour and in Keppel Bay. The species' names were not recorded, but they are presumed to be *S. glomerata*, *S. cucullata* and *S. echinata*. Most of the substantial oyster fishery (*S. glomerata*) in Morton Bay during the peak years from 1870 to 1920 was supported by juvenile oysters brought in from northern regions including Gladstone, Keppel Bay and Rodds Harbour (Anon 1909; Smith 1985). The scale of this fishery is largely unknown, however, in 1904, 20 oyster leases of 30 acres each were marked out in Gladstone Harbour (Anon 1904a, Figure 4).

By 1905, there were oyster leases (likely comprised of *S. cucullata* and *S. echinata*) being worked around Magnetic Island, the entrance to Yellow Gin Creek, Upstart Bay, Rocky Pond Creek, Heath Creek and Edgecombe Bay, but none north of Townsville (Anon 1904b, Figure 4). Between 1920 and 1936, harvesting of *S. cucullata* (and presumably *S. echinata*) from the central Queensland coast was on the increase. This industry supplied a large share of the central and north Queensland market up until 1985 (Smith 1985).

Saccostrea cucullata and *S. echinata* were considered difficult to remove from rocks and were often opened on the oyster banks and bottled for later sale (Smith 1985; Witney et al. 1988). Some of the first quantified information came from the Mackay region in 1945 when four boats were licensed for oyster taking. Fourteen men were engaged, and 2000 bottles of oysters, valued at £400 were harvested (Anon 1945). In 1946, 1,500 sacks of oysters (at 90 kg per sack = around 135 tonnes) worth £4,500 were collected from around the Rockhampton and lesser quantities from Bowen and Mackay (Smith 1985). Most of these oysters were sold locally in north Queensland towns (Smith 1985).

Ecological decline and current extent

Past and current existence and condition of shellfish reefs are poorly recorded making it difficult to quantify change in the GBR region. Subtidal oyster reefs appear to be functionally extinct over their former range along the east coast of Australia (Beck et al. 2011). However, it is unknown if substantial subtidal reefs occurred in the GBR

Figure 3. Locations of *I. ephippium* reefs in the Great Barrier Reef (GBR) region. The dashed red line denotes the GBR region.

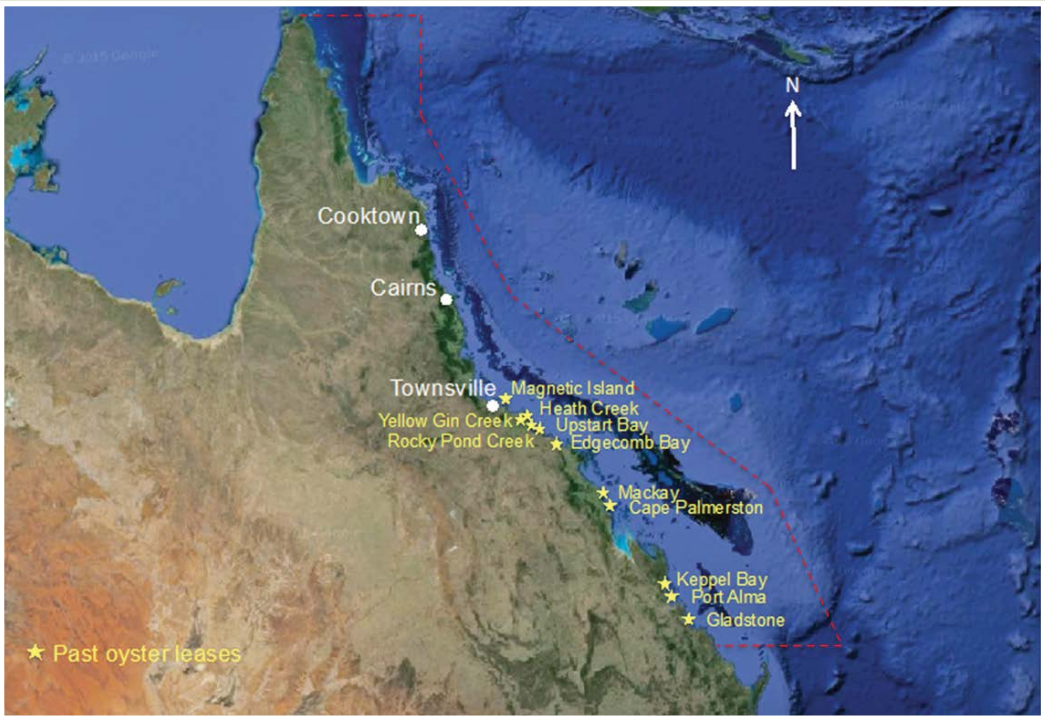

Figure 4. Locations of past oyster leases. The dashed red line denotes the GBR region.

region. The current status of intertidal reefs is also largely unknown. However, historical reports of past abundance and descriptions of declines over the last 110 years suggest that these are also severely reduced.

Dredged oysters in southern Queensland were the first to experience production declines in the late 1880s. The decline was attributed to a combination of factors including overfishing, disease and declining water quality. Outbreaks of "mudworm disease" due to infection by spionid polychaete mudworms were the main reason for abandoning oystering for *S. glomerata* in subtidal dredge sections (Smith 1981). Mudworms have been blamed for causing the extinction of subtidal oyster reefs along the east coast of Australia (Ogburn et al. 2007). However, recent research suggests oyster mortalities were more likely due to prolonged hyposalinity, smothering of oyster reefs with silt and/ or infection by diseases such as QX disease (Diggles 2013).

Interestingly, vast oyster die-offs in oyster leases in Heath Creek and Rocky Pond Creek, south of Ayr in north Queensland were described as early as 1904. These were attributed to smothering by mud after floods (Anon 1904a). Declines in the oyster fishery around the Keppel Islands were described as early as 1923 (Anon 1923), and were attributed to overharvest and destructive fishing practices with locals worried about local extinction. Destructive fishing practices used in the Keppel Islands region included the use of levering or dynamite to remove oyster encrustations off rocks (Colin Creighton *pers. comm.*), and the removal of clumps of live oysters along with the rocks they grew on (Heritage Consulting Australia 2009).

There is still a small-scale handpicking fishery for oysters (presumed to be *S. cucullata* and *S. echinata*) in the GBR region (Nell 2001; Wallin 2011). However, while many oyster leases are still active, many are currently unworked. Despite the large reduction in fishing pressure, the formerly abundant oyster reefs of the GBR region have not recovered suggesting that environmental conditions are no longer suitable or these populations are recruitment-limited.

Immediate opportunities for protection, repair and restoration

The Australian and Queensland Government investment in GBR management is projected to be over AU$2 billion over the coming decade, with a good portion of this going towards catchment management and improved water quality (Anon 2015). These efforts may lead to improved coastal conditions that may allow shellfish reefs to return in some areas. However, active restoration may also be necessary and research efforts will be needed to prioritise the species and locations where restoration efforts will be most successful. We have little information on the ecology and function of shellfish reefs in Australia, and investment is needed for this research to underpin best practice restoration and understand the ecosystem services and environmental benefits of the natural infrastructure created by reef forming shellfish. The current distribution and health of shellfish reefs is also poorly known, and a scoping study mapping these would be a useful first step. Remaining reefs identified could be considered threatened ecosystems and protected. Linking the restoration and recovery of shellfish reefs to ecosystem services (fish production, shoreline protection, water filtration) has proved successful internationally through developing community involvement and government support for large-scale restoration.

There is increasing infrastructure and development along the GBR coastline, with engineered structures existing in nearly every estuary and covering 9.4% of the shoreline (Waltham and Sheaves 2015). There are opportunities for green engineering to increase the natural infrastructure value around existing and future development. For example, shellfish could be reintroduced around hard substrates such as rock walls of wharf pylons, either as environmental offsets associated for new development, or to boost the natural infrastructure values around existing built infrastructure. These shellfish reefs would likely provide environmental services such as water filtration and providing food and possibly nursery grounds for fish. *Isognomon ephippium* currently exist in the GBR's most modified coastal creek, Ross Creek in Townsville (Waltham and Sheaves 2015; Ian McLeod *pers. obs.*; Plate 9). Ross Creek could be a good site for a pilot study to explore these opportunities. We suggest laboratory and field-based experiments to test the possibility of increasing local *I. ephippium* populations and to quantify their ecosystem services (water filtration and providing habitat for macroinvertebrates).

In the GBR region, given their former abundance and the scale of the fishery, investigating the potential for restoration of *S. cucullata* and *S. echinata* reefs could be prioritised. It may also be possible to revitalise this former oyster fishery in a sustainable way, while creating jobs for local and Indigenous communities. Furthermore, given Indigenous Australians' long tradition of management of shellfish resources, there is a great opportunity for Indigenous co-management of future restoration and enhancement projects. Shellfish restoration would likely have the additional benefits of reviving cultural heritage and providing traditional, healthy food, while providing sustainable employment opportunities through the restoration and management process. Both *S. cucullata* and *S. echinata* are currently being cultured at the Darwin Aquaculture Centre as part of the Northern Territory Government's 'Tropical Oyster Program' targeting food security and economic opportunities for Indigenous communities (Herbert 2015). This hatchery could be a source of spat for restoration trials, or the techniques developed could be used to breed and raise locally sourced oysters.

Plate 8. *Isognomon ephippium* reef along the bank of a mangrove creek in the Hinchinbrook Channel. *I. McLeod*

Plate 9. *Isognomon ephippium* growing on a rock bank near the river mouth of the Great Barrier Reef region's most modified coastal creek, Ross Creek in Townsville. This could be an ideal location for enhancement efforts, adding natural infrastructure to built infrastructure to improve ecosystem services and habitat value. *S. Fry, Dry Tropics NQ NRM*

Plate 10. Oysters (presumed to be *Saccostrea cucullata*) growing on a mangrove root along the bank of a mangrove creek in the Hinchinbrook Channel. *I. McLeod*

Plate 11. Oysters (presumed to be *Saccostrea cucullata*) growing on a metal pole along the bank of a mangrove creek in the Hinchinbrook Channel. This suggests that spat are still available and oysters can grow in this area given appropriate settlement surfaces and elevation. *I. McLeod*

Shellfish reefs of South East Queensland

By Ben Diggles

Digsfish Services, Banksia Beach, Queensland.

Past extent of shellfish reefs

Archaeological and historical records indicate the existence of extremely abundant populations of reef-forming shellfish in the coastal bays and estuaries of southern Queensland prior to European settlement. Major reef-forming species included the Sydney rock oyster (*Saccostrea glomerata*), hairy mussels (*Trichomya hirsuta*) and also pearl oysters (Pteriidae). The main locations where shellfish reefs occurred include the Southport Broadwater, Southern and Eastern Moreton Bay, Pumicestone Passage, Maroochy and Noosa Rivers, Tin Can Bay and Great Sandy Straits, and various coastal rivers and headlands north to Gladstone Harbour, The Narrows and Rodds Harbour in Keppel Bay. The location of the vast majority of Aboriginal midden sites closely correlates with the areas where abundant shellfish resources were reported by early Europeans.

Archaeological evidence and Indigenous use

Archaeological evidence from middens indicates that Aboriginal people have lived in Moreton Bay for at least 20,000 years (Neal and Stock 1986, Ross et al. 2015), and that harvesting of shellfish was a very important subsistence activity during that time (Ulm 2002; Ulm and Vale 2006). Historical accounts from early Europeans further support the reliance of coastal Traditional Owners (including Quandamooka, Gubbi Gubbi (Kabi Kabi), Joondoburri, Bailai, Merooni, Taribelang Bunda, Butchala, Yugumbir, Bandjalung and Gooreng Gooreng) on maritime resources (Hall 1982; 1984), including farming and trading of rock oysters (*S. glomerata*) in Moreton Bay (Ross 1996; Kerkhove 2013). In southern Queensland, shellfish including not only *S. glomerata* and *T. hirsuta* but also pearl oysters (*F. Pteriidae*), mud arcs (*Anadara trapezia*), whelks (*Pyrazus ebininus*), eugaries (*Plebidonax deltoides*) and assorted other species of bivalve and gastropod molluscs dominate the contents of middens deposited by Indigenous groups (Ulm 2006; Ross et al. 2015).

Historical records and 'the harvest years'

European exploitation of shellfish resources in southern Queensland began immediately following the first settlement at Redcliffe in 1824 (Smith 1981). Between 1824 to 1863, there was a period of little or no government regulation of the *S. glomerata* fishery (Smith 1981). Prior to 1863, most exploitation of *S. glomerata* was not for food but for production of lime to make mortar for construction of houses and buildings in early Brisbane (Smith 1981). The oysters were piled into heaps or in lime kilns and burnt. Live oysters were preferred by some builders, as they were claimed to give the lime more "body", but Aboriginal middens were also heavily mined for shell (Smith 1981). Queensland's first Oyster Act was proclaimed in 1863 to make wasteful burning of live oysters for lime illegal and requiring a £5 license fee to lay down oyster culture on defined oyster beds (Smith 1981). The industry gained momentum in the mid 1860s when subtidal reefs of "dredge oysters" (also *S. glomerata*) were discovered in deeper channels in Pumicestone Passage, and shortly afterwards in the Southport Broadwater (Fison 1884; 1889; Smith 1981). Dredge oysters were claimed to grow faster and taste better. They obtained higher prices, and were collected using a dredging basket operated from a boat. In contrast, traditional bank oystering involved hand-picking oysters off sand banks, mangrove roots or oyster reefs in the inter-tidal zone. Some oystermen later experimented with rocks, tiles, dead shell and sticks as alternative substrate to collect spat (Smith 1981). The oyster industry expanded throughout the 1860s and 1870s accompanied by increased regulation, firstly by limiting entry to the fishery, then by revision of the Oyster Act in 1874, allowing the Government to auction 7 year leases to run dredge sections and sell annual licenses to allow use of oyster banks (Smith 1981). By 1884 Moreton Bay was divided into 164 bank sections and 39 dredge sections in waters 2 ft below the low tide mark (Fison 1884; Smith 1981). By this time the industry was intensifying further by enhancing oyster banks and dredge sections with oyster spat collected from the Great Sandy Straits, Keppel Bay and Rodds Harbour, after which they would be ongrown for 12-18 months in Moreton Bay prior to sale (Smith 1981).

Plate 12. Decaying mushroom shaped intertidal clumps of *S. glomerata* demonstrate a 96% loss of the historical subtidal and lower intertidal zones suitable for rock oyster recruitment in Pumicestone Passage, Moreton Bay. *From Diggles* (2013)

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The rock oyster industry in southern Queensland peaked in 1891 producing around 21,000 sacks (at 90 kg per sack = around 1890 tonnes; Smith 1981; Lergessner 2006; Diggles 2013). Smith (1981) noted that around 80% of the production at this time was generated by oyster banks, while dredge oysters comprised only about 20% of the harvest after the dredge sections were damaged by the floods of 1887, 1889 and 1890. Even though production dwindled from that time onwards, during the decade 1901-10 the industry reached its peak for the number of men employed, banks and sections leased, and boats licensed (Smith 1981). For example, the total number of dredge sections in Queensland reached an all-time high in 1904 with 64 leased, but from then on there was a gradual decline until the last dredge section in Queensland in the Maroochy River was forfeited in 1947 (Smith 1981).

Ecological decline and current extent

History shows that the dredge sections were the first to experience production declines from the late 1880's with production on the intertidal banks also declining over time to less than 1/10th of their 1891 peak by 1980 (Smith 1981). Many authors have studied the decline and all agree it was due to a combination of events potentially including overfishing, disease and declining water quality. However, there is some disagreement about the extent of the respective roles of these events. Outbreaks of "mudworm disease" due to infection by spionid polychaete mudworms was the main reason why oystering for *S. glomerata* in subtidal dredge sections was abandoned (Smith 1981). This is logical considering that oysters were being sold for food and mudworm blisters can make oysters unmarketable (Nell 2001). Suggestions that infection by "mudworms introduced from New Zealand" killed large numbers of oysters resulting in extinction of subtidal oyster reefs along Australia's east coast (Ogburn et al. 2007) are not supported by current scientific knowledge

of the taxonomy of mudworms, nor the epidemiology of mudworm infections or other oyster diseases (Sebesvari et al. 2006; Read 2010; Diggles 2013). Indeed, in hindsight it is much more likely that acute post-flood mass mortalities were due to either prolonged hyposalinity, smothering of oyster beds with silt, and/or infection by then unknown diseases such as QX disease. QX is caused by the endemic paramyxean protozoan *Marteilia sydneyi* (see Wolf 1972; 1979, Perkins and Wolf 1976), which has mud-dwelling polychaetes such as *Nephtys australiensis* as a putative alternate host (Adlard and Nolan 2015) and today is known to cause mass mortalities of *S. glomerata* after flood events (see Diggles 2013). But back in the late 1800's and early 1900's, oyster farmers and scientists knew little about disease agents of oysters, and hence were more likely to blame highly visible shell dwelling polychaetes for any mortalities, rather than unknown microscopic protozoans. The historical epidemiology of *S. glomerata* diseases suggests the overriding mechanism responsible for the decline of oyster populations in Pumicestone Passage and Moreton Bay is one of declining water quality over the last 125 years, causing multigenerational recruitment failure as well as forcing disease processes by modulating the host/ pathogen relationship and allowing what were once innocuous endemic disease agents like QX to proliferate over a much wider area (Diggles 2013). Today, subtidal oyster reefs are functionally extinct in Pumicestone Passage (Diggles 2013), and throughout most (if not all) of Southern Queensland (Beck et al. 2011). Indeed, around 96% of vertical zonation of oysters has been lost in Pumicestone Passage over the last 125 years, due to these ecological processes associated with catchment development (Plate12; Diggles 2013).

Immediate opportunities for protection, repair and restoration

An important component of management and restoration efforts for shellfish reefs in southern Queensland is therefore improvement of inshore water quality by reducing influx of sediment, nutrients and other pollutants from both point and non-point sources. However, because of the extent of the environmental changes over the past 125 years, the subtidal shellfish reefs in the region can no longer restore themselves by natural recruitment, and active intervention is required if shellfish reefs are to be restored in southern Queensland. Research will therefore be required not only to prioritise the locations where restoration is most likely to be successful, but also to determine the most cost effective methods for restoration of functional shellfish reefs. Restoration of shellfish reefs in some areas and with some bivalve species may be possible with ecosystem manipulation using natural spatfalls and preliminary research trials are underway to examine the potential for this in the Noosa River and Pumicestone Passage, with encouraging early results (www.restorepumicestonepassage.org, and Plates 12 and 13). For *S. glomerata*, given the current problems with QX disease, utilisation of artificial enhancement methods using hatchery reared QX-resistant oysters may be necessary, at least in the initial stages, if functional, self-sustaining subtidal *S. glomerata* reefs are to be restored into southern Queensland estuaries over the longer term.

What is certain is that restoration of shellfish reefs in southern Queensland represents a significant opportunity to renew the cultural links of Traditional Owners to their lands. There is no better way of communicating the importance of this process than heeding this statement made by the Traditional Owners in the Pumicestone Region of Moreton Bay:

What is certain is that restoration of shellfish reefs in southern Queensland represents a significant opportunity to renew the cultural links of Traditional Owners to their lands. There is no better way of communicating the importance of this process than heeding this statement made by the Traditional Owners in the Pumicestone Region of Moreton Bay:

> ***As Aboriginal Traditional Owners it is important for us to recognise our history and continued connection to Country through the maintenance of our past, present and future. We acknowledge and pay respect to our Ancestors who continue to exist in our Country and guide us in our decisions as the current custodians of our water, sea, land and culture. We pay respect to our Elders in helping and guiding us.***
>
> ***Our Vision is to unite and address the issues of degradation to our traditional Country and the continuing erosion of the values of our cultural heritage sites and landscapes. Our Vision is to restore shellfish reefs to Pumicestone Passage and Moreton Bay.***
>
> ***We welcome the opportunity to work with our non-indigenous brothers and sisters who are making a valuable contribution to caring for Country. Our first priority, as Our Vision is implemented, is to reach out to all people in South East Queensland and to involve all who are interested in our Country and our culture to play a more active role in caring for our part of the Earth. The Earth is our Mother. As she is healed we will also be healed.***
>
> ***Fred Palin,***
> ***Joondoburri Elder***
> ***Kabi Kabi First Nation Traditional Owners Claim Group***

Plate 13. Shellfish reef bar formed by *S. glomerata*. *B. Diggles*

Shellfish reefs of New South Wales

By Kylie Russell and Emma Lebrault

Fisheries NSW, NSW Department of Primary Industries, Port Stephens, NSW.

Past extent of shellfish reefs

The two most abundant native oysters of New South Wales (NSW), the Sydney rock oyster (*Saccostrea glomerata*) and the flat oyster (*Ostrea angasi*), are well adapted to a mild climate and were historically found almost everywhere along the coast where suitable substrate occurred, with the exception of Intermittently Closed and Open Lakes and Lagoons (ICOLLS).

Archaeological records and Indigenous use

Shell middens dating back at least 6,000 years (Stockton 1977) prove that oysters have been a valuable food resource for Aboriginal people. However, it appears that the Aboriginal impact on oyster populations was relatively benign and some tribes may have even returned shell to the water to provide substrate for new spat (Plate 14).

Historical records and 'the harvest years'

During Captain Cook's first voyage of exploration in Australia in 1770, he reported abundant oyster resources in Port Jackson and Broken Bay, and the largest flat oysters he had ever seen in Botany Bay (Attenbrow 2010). When Europeans returned in 1788 to establish a colony, they began to harvest oysters heavily for food and also for burning for lime production as part of the manufacture of cement. Oysters were harvested in an unsustainable way across NSW for many decades through both hand collection and dredging. Dredging also removed hard substrate and contributed to increased siltation in waterways potentially leading to larval recruitment failure. The heavy, unregulated exploitation of oysters in many NSW estuaries during the 1850s–1870s resulted in drastic declines in estuarine oyster populations, with reports from the 1860s indicating a need to restore oyster beds, particularly around population centres such as Sydney.

The first implementation of regulations by the Government was the *Oyster-beds Act* in 1868, which encouraged the establishment of oyster fisheries by introducing a licensing system and prohibiting the burning of live oysters for lime. In 1876, following an audit of NSW estuaries, the Oyster Culture Commission was organised to discuss the best modes of cultivation and how to improve and maintain the natural oyster beds, and to suggest legislation to manage these objectives (Oyster Culture Commission 1877). In 1884 the *Oyster Fisheries Act* instituted a system of leases that were rented by the oyster farmers. This Act also established the Public Oyster Reserves, which were foreshore areas set aside for public access to oyster resources.

Ecological decline and current extent

The first major biological threat to oysters in NSW was 'mudworm disease', reported in Sydney rock oysters in the Hunter River around 1882 (Quinan 1884; Plate 15). Mudworm disease was caused by several species of parasitic spionid polychaete worms, major mudworm outbreaks occurred in several NSW estuaries, such as the Hawkesbury, Clarence and Tweed rivers, between 1886 and 1889. It is thought that natural beds of subtidal oysters in NSW estuaries and Queensland have never recovered. There is ongoing debate as to the source of the mudworm infestations, with some citing introductions from imported New Zealand oysters (Ogburn 2011), while others suggesting an endemic source, potentially facilitated by changes in other environmental parameters such as water quality and sedimentation (Read 2010; Walker 2011; Diggles 2013). In the early 1900s, practices of commercial cultivation with stick and tray culture began to take place, partially in response to mudworm problems. The oysters were placed in the intertidal zone so that they would dry out for long enough each day (a minimum two hours per tidal cycle) to kill off any settling mudworm. This practice continues today.

The two other principal diseases that have been recorded in native oysters include winter mortality (cause unverified)

Plate 14. Men collecting oysters on a mangrove flat in Port Macquarie, NSW. *T. Dick*

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and Queensland Unknown (QX) disease (involving the protozoan parasite *Marteilia sydneyi*). Winter mortality typically affects sites in the more saline regions nearer the ocean, in estuaries south of Port Stephens. QX disease typically occurs in the upper reaches of estuaries north of the Georges River. In terms of successful restoration, these pests and diseases present challenges in addition to a variety of other ecological, environmental, financial and logistical risks that need consideration.

The spread of diseases may be a symptom rather than the cause of oyster declines. Human population growth and development have increased in coastal catchments throughout NSW, leading to poorer water quality in estuaries. Increasing urbanisation has brought increased levels of nutrients and chemicals (including pesticides, herbicides and anti-fouling compounds) into estuarine systems, thereby contributing to the decline of oyster populations. Also, the clearing of catchments has increased sedimentation, causing smothering of oyster reefs. The sediment covers rocks and other hard substrates, while nutrient loading promotes growth of algae over these surfaces, leading to the inability of new recruits to settle.

In NSW, small oyster populations still exist in most bays and estuaries but at very low densities compared to the pre-European period. Despite the years since very heavy levels of harvesting, natural oyster beds have shown few signs of recovery.

On top of the difficulty in assessing the extent of the historical population with precision, there is a lack of knowledge about the current status of natural oyster populations. A project recently initiated by

Plate 15. Map of the Hunter River, 1871

NSW Department of Primary Industries (NSW DPI) is mapping some of the remaining intertidal reefs using aerial photography, and particularly looking at historical aquaculture sites, which themselves were often positioned on or near natural oyster beds. This mapping will assess the extent of intertidal reefs around key locations in NSW estuaries via the application of GIS layering, and is due to be completed in late 2015 (Plates 16A-F). The project will identify and define reefs of 'ecologically significant size', and provide a database of locations, species, age and type of reef (natural or man-made). It is a more complicated task, however, to determine the location and extent of oyster reef beds in deeper water.

Immediate opportunities for protection, repair and restoration

To best ensure the long term recovery of oyster reefs in NSW (and across Australia) the causative factors influencing their lack of recruitment to estuaries since the cessation of mass collection and dredging activities must be ascertained. The original stresses were considered to be historical overfishing and destructive fishing, while ongoing problems include pollution, diseases, introduced species and sedimentation.

There are some remaining areas of natural oyster reef in NSW – for example in the Richmond River in northern NSW (Plate 17). Protection of these areas from harvesting or other damage and improving catchment water quality are two actions that are warranted to ensure the reefs long-term viability. Several mechanisms for protection exist under NSW legislation, such as fishing closures and marine protected areas, for protecting reef sites.

Figure 16A. Aerial image of historic shell bed cultivation on existing lease area at Botany Bay NSW

Figure 16B. Historic elevated shell bed cultivation at Georges River NSW

Figure 16C. Historic freestanding rock cultivation at Clyde River NSW

Figure 16D. Linear oyster reef (background) formed over historic oyster cultivation at Moruya River NSW

Figure 16E. Ibis foraging among historic oyster encrusted low oyster posts at Port Stephens NSW

Figure 16F. Aerial image of historic oyster encrusted rock and low oyster post at Port Stephens NSW

As there is a large choice of possible restoration sites in NSW, surveys should be conducted to determine a priority list of suitable conditions for restoration success. Once completed, the NSW DPI project investigating oyster colonisation on and around abandoned or relic oyster leases will provide a database of potential intertidal locations. The reefs in these areas could be expanded and water quality and hydrological conditions studied to inform future works. Research to determine the extent of reef required to be 'environmentally significant' is also being considered. Australian versions of a suitability index and a reef quality index model, originally developed for United States oyster restoration activities, could be used by coastal resource managers as practical decision-support tools for provision of the best mechanism for identifying key restoration sites.

One possible NSW restoration location is near Tahlee in Port Stephens, where long abandoned lease infrastructure has continued to recruit oyster spat and now forms a significant area of intertidal reef. Other examples of possible restoration sites may take advantage of old aquaculture and shipping infrastructure, including historic raised beds and ballast dumps that are now naturally recruiting oyster populations. An important parameter required to ensure a self-sustaining reef is an abundance of new recruits. OceanWatch is currently planning an oyster reef restoration project for 2015-17 in two Sydney locations: Lane Cove River and Botany Bay. The primary aim of these projects is, however, to protect against shoreline erosion.

Another project being undertaken by the University of Western Sydney is trialling oyster restoration at three Sydney coastal lakes. The study is looking at the uptake of nutrients by the oysters, along with the use of created oyster reefs by fish and invertebrates.

Other pragmatic activities for effective reef restoration projects could include:

- Determining biosecurity and cleaning protocols suitable to allow oyster cultch to be collected, cleaned

Plate 17. North Creek, Richmond River, 2015. *P. Dwyer*

and used for oyster restoration purposes;

- Determining and implementing suitable and targeted education programs, along with opportunities, processes and logistics for participating in restoration projects;
- Determining suitable existing, or developing new, bagging materials or methods to allow oyster cultch to be used for oyster restoration purposes;
- Various biological questions with respect to optimising the likelihood of success of reef restoration projects;
- Effective monitoring.

Immediate priorities for oyster reef restoration in NSW include:

- Determining favourable locations, including pros/cons in function of several criteria;
- Finding the most suitable method and substrate for restoration.

In the medium term:

- Raising awareness of the value of oyster reefs among the community;
- Determining and resolving regulatory pathways for issues such as biosecurity, compliance, landholder permission and maintenance requirements, navigation and Marine Park zonings, in order to facilitate projects;
- Planning and funding for long term monitoring of the projects.

Shellfish reefs of Victoria

By Paul Hamer and John Ford

Fisheries Victoria, Department of Economic Development, Jobs, Transport and Resources, Queenscliff, Victoria.

Past extent of shellfish reefs

Victoria has lost vast areas of native flat oyster (*Ostrea angasi*) and blue mussel (*Mytilus edulis galloprovinicialus*) reefs from estuarine, bay and coastal waters since European settlement. These reefs were initially lost primarily due to intensive dredge fishing early in colonial settlement (particularly 1840-1860), which removed both live and dead oysters for food and making lime (Pearson 1990; Hannan and Bennett 2010). Later from the 1960s to 1990s an intensive dredge fishery for scallops and mussels caused the destruction of large areas of predominantly mussel reef in Port Phillip Bay, and also removed and/or damaged any recovering oyster reefs. Currently there are no known oyster reefs left in Victoria and mussels are mostly confined to small areas of shallow rocky reefs and man-made structures, with the only known beds or reefs (i.e. large areas growing on sediments) found at a few locations in the Gippsland Lakes.

While removal and destructive fishing practices drove rapid declines, recovery of reefs over-time has been hampered by a host of factors including changes to catchments and resultant poor water quality and sedimentation, pollution impacts and disease of native flat oysters (i.e. *Bonamiasis*), and introduced species that compete with or predate on shellfish. Further, the prolonged absence of settlement substrate for shellfish larvae (i.e. other shellfish and dead shell) has limited recovery potential irrespective of the more recent halting of dredge fishing and improvements in water quality and catchment management practices.

Opportunities now exist for repair and recovery of shellfish reefs in the three major bays and inlets – Port Phillip, Western Port and Corner Inlet. By out-planting adults and/or spat sourced from the growing shellfish aquaculture industry and Victorian Shellfish Hatchery (VSH), providing new settlement substrate in the form of recycled shell, limestone rubble and low profile reef material, and identifying areas of low disease incidence and optimal water quality/food supply, it is possible to re-establish shellfish reefs as a functioning ecological community in Victoria's coastal environment. It is expected that re-establishing shellfish reefs will result in benefits to fisheries production of key species such as snapper, bream and flathead, increased resistance to impacts of nutrient pulses, such as harmful algal blooms, reduced suspended sediments, and enhance biodiversity.

Archaeological records and Indigenous use

Coastal shellfish reefs were an important source of food for indigenous people in coastal Victoria (Godfrey 1989). Mussels were likely to be of most importance to northern and eastern Port Phillip clans, as mussels are the dominant species in Port Phillip Bay middens and there exists historical accounts of Indigenous mussel gathering (Sullivan 1981). Oysters were considered of greater importance around Corner Inlet and some locations in western Port Phillip, and are the dominant species in middens from these areas. With no accounts of subtidal Indigenous oyster fishing, it is assumed that most harvesting occurred in the intertidal and shallow water areas. Hence the extensive subtidal oyster and mussel beds were largely untouched until the arrival of European settlers. Carbon dating of oyster shells from central Port Phillip Bay cores indicates they have been present in the bay since shortly after it was formed (10,000 year ago).

Historical records and 'the harvest years'

At the time of European settlement, reefs of native flat oyster are thought to have covered much of the soft sediment banks and channels in Western Port and Corner Inlet – Nooramunga (Figure 5). Dredge fisheries began in these areas in the early 1840s. The arrival of the Victorian goldrush in the 1850s increased the demand for both food and building materials, and as a consequence the oyster dredge fisheries expanded and were most productive during this decade. It is thought that the Western Port oyster

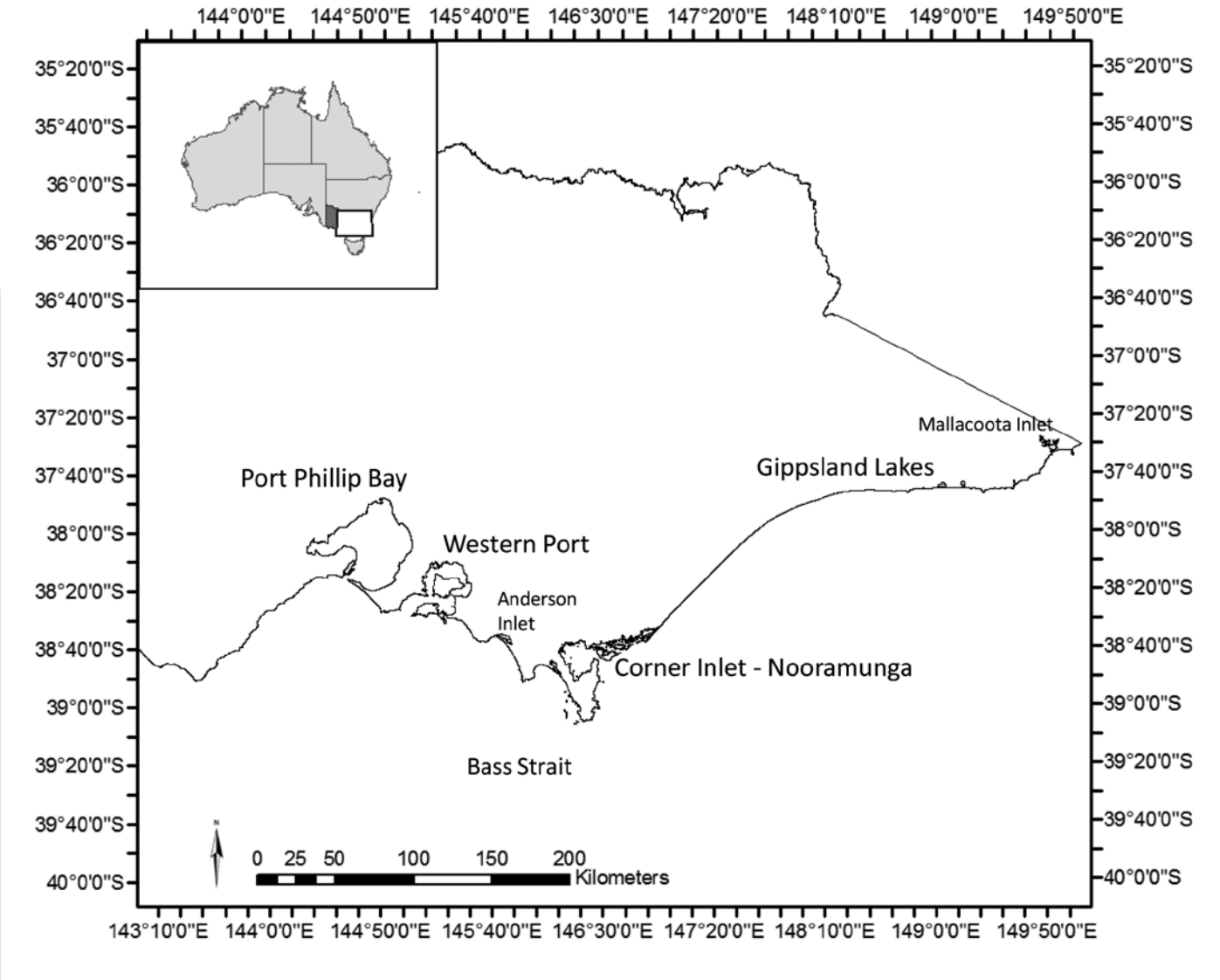

Figure 5. Victorian coast showing the locations of major bays and estuaries with documented historical presence of significant areas of native flat oyster and mussel

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dredge fishery supported at least twenty to twenty-five boats and employed up to 100 people during its peak in the 1850s, with production estimated at around 10 tonnes per week (Hannan and Bennet 2010). The Victorian oyster dredge fleet was estimated at over one hundred boats in 1860, when the Western Port beds collapsed and many of the boats converged on Port Albert to fish Corner Inlet's beds. Production is estimated at £3000 worth of oysters from Port Albert in this year alone (over a million-dollar fishery in today's terms, Plate 18). The 'golden years' of oyster fishing in Victoria from 1842 - 1862 came to an abrupt end when the Port Albert oyster beds collapsed in the early 1860s, with relatively minor levels of fishing occurring until a short revival in the late 1880s.

The revival of the oyster fishing industry in the late 19th century was initiated by the appointment of fisheries consultant William Saville-Kent by the Victorian government in 1887 (Harrison 1996). The Bay fisheries were reopened and numerous unsuccessful attempts at oyster farming occurred in Western Port and Corner Inlet – Nooramunga. After the long period of closure (since 1859) the natural beds in Western Port were re-opened in 1894 and were again productive, sending hundreds of tonnes to market in Melbourne. The revival was short-lived, as the beds were again fished down rapidly. £500 rewards for the discovery of new oyster beds sparked an interest in offshore beds, which were located in 15-24 m of water off Shallow

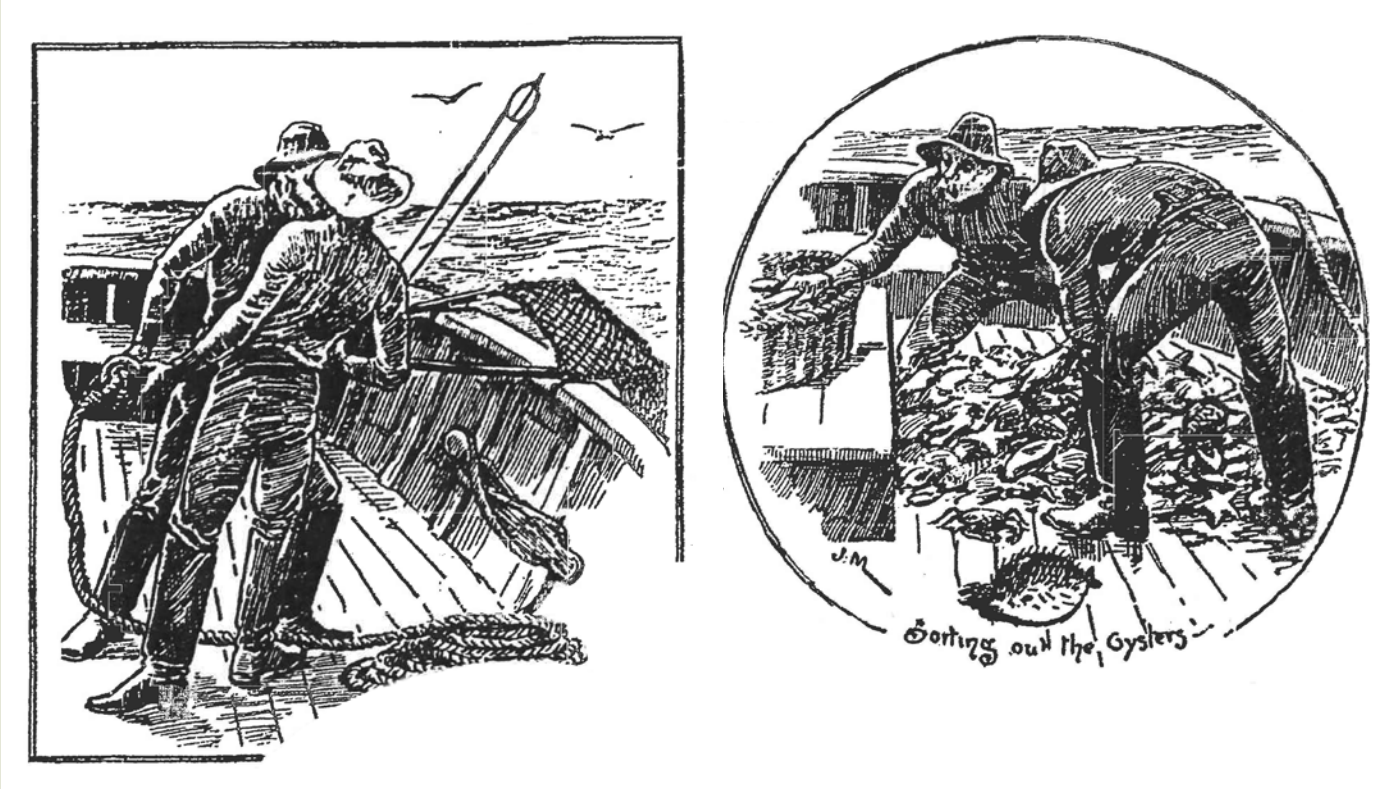

Plate 18. 'Shooting the oyster dredge' and 'sorting out the oysters' from *A visit to the oyster beads near Port Albert* (Vic) published in the Illustrated Australian News, 1891. *Trove*

Inlet and Corner Inlet. These beds, which were mixed with scallops, were quickly depleted and the industry again slumped by the mid-1890s.

The northern and eastern Port Phillip shellfish reefs appear to have been dominated by blue mussels rather than native flat oysters, although the common occurrence of buried oyster shell in this area suggest that oysters were also common. Evidence for the mussel abundance is provided by their dominance in Indigenous shell middens of the region, the lack of references to a major oyster industry in north Port Phillip in the early days after colonisation, and fisheries data from the 20th century showing high mixed species dredge catches dominated by mussels. However, early explorer accounts of oyster reefs on the shore of eastern Port Phillip and the existence of many historical lime burning sites provide evidence for an early oyster dredge industry in Port Phillip Bay, likely centred in the Corio Arm near Geelong. This fishery may have been depleted very early in colonial history, or the oysters were not as prized for eating as the Western Port and Corner Inlet oysters and hence did not warrant mention in the Melbourne newspapers at the time. The amount of oyster shell found in Port Phillip Bay sediments and around its shoreline, including large banks of shell in the Geelong Arm, clearly indicates that oysters were once very abundant in the Bay. It is important to note that before the 1890s there was no official government data collection of Victorian fisheries and hence historical information comes almost solely from newspaper reports. The last notable records on oyster catches was 30 tonnes taken by dredge in the Geelong Arm in the 1960s. Fisheries data from the 20th century show large catches of mussels from 1966 onwards as a consequence of the expansion of the scallop and mussel dredge fishery and growing taste for mussels following southern European migration to Australia. From 1964-1996 at least 11,000 tonnes of blue mussels were removed by the Port Phillip Bay dredge fishery. Oysters are noted as an abundant bycatch species of the mussel and scallop dredge fishery but were mostly discarded due to lack of marketability. It is probable that the extensive scallop and mussel dredging between 1966 and 1996 created an environment unfavourable to both mussels and oysters by removing shell material and reducing substrate complexity.

Shellfish reefs were also present in the smaller Victorian estuaries, most notably the Gippsland Lakes and Mallacoota Inlet. The Gippsland Lakes had large areas of mussel-dominated reefs near the entrance which supported a dive mussel fishery from 1985-2009 that harvested a total of 550 tonnes of mussels. Large mussel reefs can still be found in the entrance region of the Gippsland Lakes. Little is known of the shellfish community before the permanent opening of the Lakes in 1880s, but it is likely to have fluctuated significantly between freshwater and saltwater periods. Evidence of historical mussel and oyster presence at Mallacoota Inlet comes from middens and early historical accounts, but no fishery information is available.

Ecological decline and current extent

The decline of the shellfish reefs of Victoria was driven predominantly by overfishing in the 1840s-1860s for flat oysters, and during the mid-late 20th century for mussels and scallops in Port Phillip. Along with direct removal of adult shellfish, repeated dredging removed, broke up or buried shell material. This likely altered the substrate suitability for shellfish by reducing complexity and removing hard surfaces for spat settlement. Assisting the decline and preventing their natural recovery is a collection of anthropogenic and natural factors. Poor water quality as a result of catchment clearance, urbanisation of the coast and industrial pollution has hampered the recovery of natural shellfish reefs. Without the shellfish reefs to bind and trap sediments, sedimentation/re-suspension continues to bury any shell material and settlement substrates. These factors, while not directly lethal, limit spat settlement and survival and may induce stress on adults and increase susceptibility to disease such as *Bonamia* in flat oysters. This disease is present in both Port Phillip and Western Port, and is linked to oyster reef declines in the Point Wilson area of the Geelong Arm in 1991. Any repair work must therefore seek to minimise the impact of all these factors, as they appear to act synergistically in limiting recovery.

The current extent of shellfish reefs in Victoria is poorly documented and no dedicated surveys have been carried out. There are no known living oyster reefs in Victoria, although exposed beds of mainly dead shell are present in the Geelong Arm of Port Phillip. Mussel beds on soft sediment still exist in the Gippsland Lakes, but are confined to artificial structure and shallow rocky reefs in Port Phillip, Corner Inlet and Western Port. Importantly however, oysters and mussels are still present over most of their historic range. Isolated individuals and small clumps remain in soft sediment communities in Port Phillip and Corner Inlet, albeit very sparsely distributed. Opportunities therefore exist in these environments for returning them to a dominant habitat-forming species.

Immediate opportunities for protection, repair and restoration

Opportunities for the repair of subtidal mixed mussel and oyster reefs exist in Port Phillip Bay, and for shallow oyster reefs in Western Port and Corner Inlet. In all cases repair requires three main steps:

1. Identifying areas that will likely be successful (water quality, food, disease);

2. Sourcing spat and adult shellfish from farms and hatcheries (wild populations are too small) and;

3. Creating new settlement substrates from recycled shell or hard concrete/limestone materials.

Given the logistical requirements and costs involved in developing and implementing methodologies for repair, Port Phillip Bay makes the most economic sense to begin repair works because of the local availability of mussels from the bay's mussel aquaculture industry and flat oyster spat from the VSH in southern Port Phillip Bay. Port Phillip Bay is also the centre of marine recreational fishing in Victoria and has a large community interest from the surrounding population centres of Melbourne and Geelong. This is important to establishing volunteer support and funding base for repair activities. A current project partnering The Nature Conservancy, Fisheries Victoria, Albert Park Yachting and Angling Club and Melbourne University is aiming to develop methodology for subtidal mixed shellfish reef (flat oyster and blue mussel) creation in Port Phillip.

Shellfish reefs of Tasmania

By Christine Crawford

Institute of Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania.

Archaeological records and Indigenous use

Native oysters were an important item in the diet of Aboriginal Tasmanians for many thousands of years as evidenced by the numerous middens around the state containing oyster and mussel shells (Figures 6 and 7). Coastal areas were a foci of economic exploitation (Lourandos 1968), and the oldest middens on the east coast have been dated as c. 6,000-8,700 BP, which corresponds to the approximate age of the present coastline.

Two major types of middens have been distinguished by shell composition and habitat on the east and south eastern coasts of Tasmania, each reflecting the economically obtainable mollusc populations in the immediate vicinity (Lourandos 1968). Bay estuarine type middens dominate from Great Oyster Bay south and are comprised of native oyster and/or mussel shells which occur in differing rations depending on the structure of the nearby shell populations. Open coastal rocky platform middens occur north of Great Oyster Bay and are associated with mollusc populations on exposed rock platform habitats. The dominant mollusc shells are abalone and turbo; oyster shells are present but in reduced numbers compared to middens further south. However, there are many middens that have not been surveyed and are currently being eroded by rising sea levels.

Figure 6. (B) Photograph of a midden at Little Swanport, which covers approx. 32 ha with shells 2-3 m deep. It has been carbon dated to 4,500 years and some 7.2 billion oysters have been deposited. *C Crawford*

Historical records and 'the harvest years'

Records from the first European settlers show that native *Ostrea angasi* oysters were extremely abundant and regularly harvested in many estuaries around Tasmania. The native oyster fishery was very important in the early days of European settlement with the beds being fished extensively and indiscriminately. Local consumption was very high, as well as markets interstate and in Europe, which produced significant export income. In one of the peak years of the *O. angasi* oyster fishery in Tasmania in the 1860's, over 22 million oysters were recorded as being brought to market from five relatively small estuaries in south eastern Tasmania. Additionally, smaller oysters and shells were burnt into lime for building, or used as foundation for roads.

Ecological decline and current extent

This keystone habitat was extirpated in Tasmanian waters in less than a century of largely unregulated fishing using metal dredges that broke up the reef structure and captured all shell sizes. The decline of the native oyster fishery and attempts to protect and restock native beds in the latter half of the nineteenth century have been documented in various Government and Parliamentary Reports. Signs of a declining

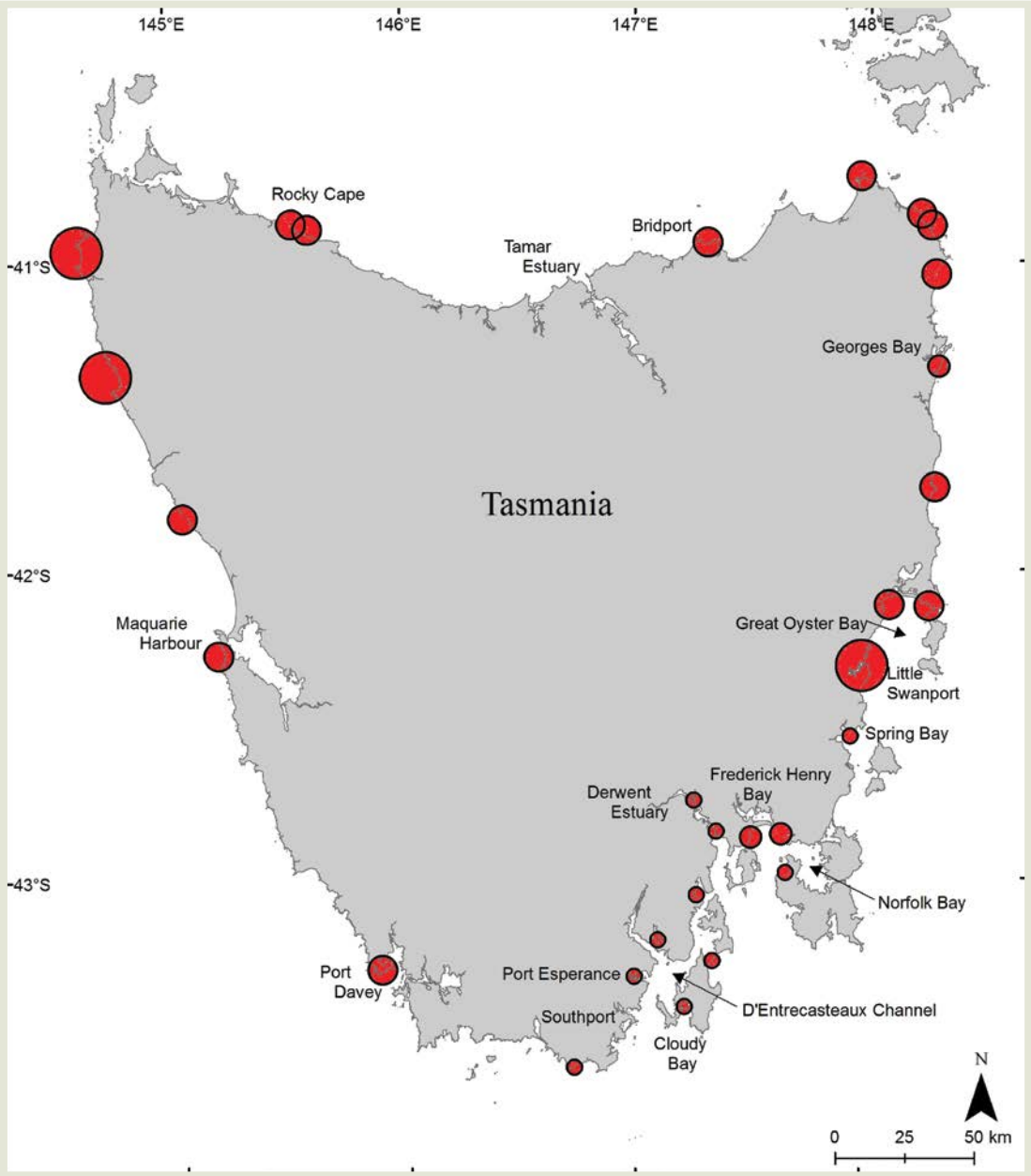

Figure 7. (A) Map of Tasmania showing the aboriginal middens that have been surveyed around the coastline. The size of the circle corresponds to the size of the midden. Modified from Lourandos (1968).

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fishery were already evident by the 1850s and an 'Act for the Improvement and Regulation of the Oyster Fisheries in Van Diemen's Land' (subsequently called Tasmania) was passed in 1853. By the late 1860's the industry was deteriorating and by the early 1880's the fishery was almost negligible. Evidence given at the 1878 Select Committee hearings indicated that in the recent past there had been 16-17 double-handed boats dredging in an area of 100-150 acres in Spring Bay, whereas now there were none.

The Report of the Commissioners (1883) suggested that the decline in the *O. angasi* oyster fishery was because of deterioration of the native beds due to overfishing, mussel encroachment, disease and inclement weather. The colonisation and clearing of the land for settlement and agriculture also led to increased silt loads in the rivers and bays which is implicated in killing many beds. However overfishing is likely to have been a major factor in the population decline.

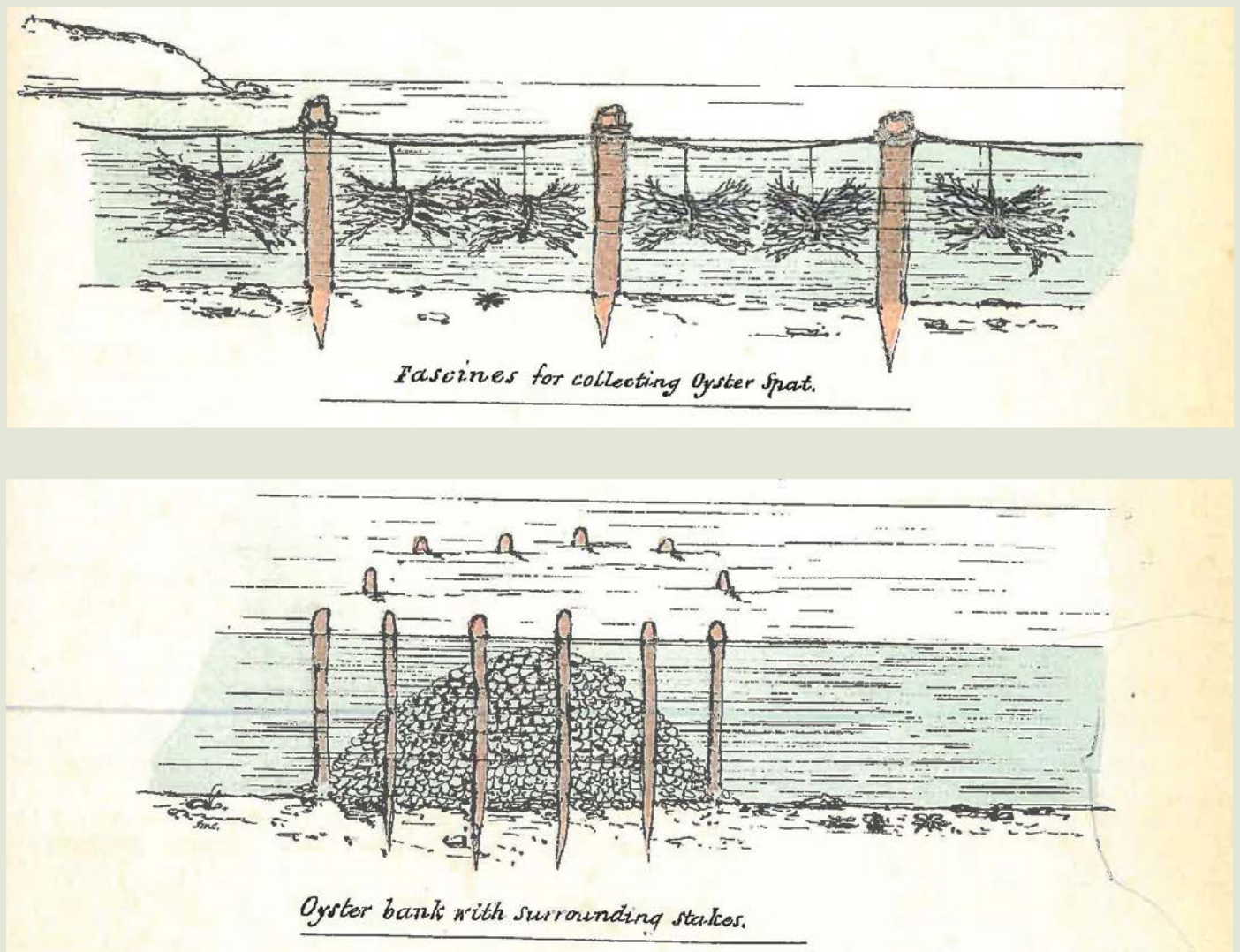

Plate 19. Copies of diagrams by Saville-Kent on methods to collect wild oyster spat (top) and to establish an artificial oyster reef above the seabed (bottom); Inspector of Fisheries Report 1884.

In 1885, with the decline of the wild harvest, biologist William Saville-Kent, the first Superintendent and Inspector of Fisheries in Tasmania, set up government reserves with the aim of establishing broodstock and reseeding the natural beds (Saville-Kent 1893). Saville-Kent expended much effort developing techniques to improve how and where the spat were collected (see Plate 19) and by 1887 there were 33 established oyster farms around Tasmania (Sumner 1972). Broodstock oysters were laid on the seabed and various types of collectors for catching spat were placed around the farm. However, after Saville-Kent left Tasmania in 1888, enthusiasm for oyster reseeding rapidly declined and the project was abandoned.

The native oyster beds were destroyed and have not been re-established in Tasmania, with the exception of the low-profile *O. angasi* reef habitat at Georges Bay on the east coast of Tasmania (Plate 20). The population was estimated at 24 million oysters in 1991 (Mitchell et al. 2000b). Limited wild harvest of market-sized oysters from these beds occurred in the 1990's, leading to the allocation of two commercial licences by the Tasmanian Government in 2007, with area restrictions, hand harvest only, minimum size limit, catch limit (TAC) of 10% of the total biomass and regular stock assessments (DPIW 2007). However, in recent years the annual harvest has been much lower than the TAC because of weak market demands.

Immediate opportunities for protection, repair and restoration

A key priority is to maintain the healthy reefs in Georges Bay because they are the only known remaining reef habitat for this species in its entire distribution from Western Australia to New South Wales and around Tasmania. These reefs provide a unique opportunity to collect quantitative information on the ecosystem services provided by these reefs, including shoreline protection, increased habitat and biodiversity, and capacity to improve water quality. These data could also be used to develop economic accounts of the costs and benefits of restoring native oyster reefs in southern Australia. Investigating why these reefs have prevailed in Georges Bay will also be important to restoration efforts in other areas where *O. angasi* oyster reefs have not survived.

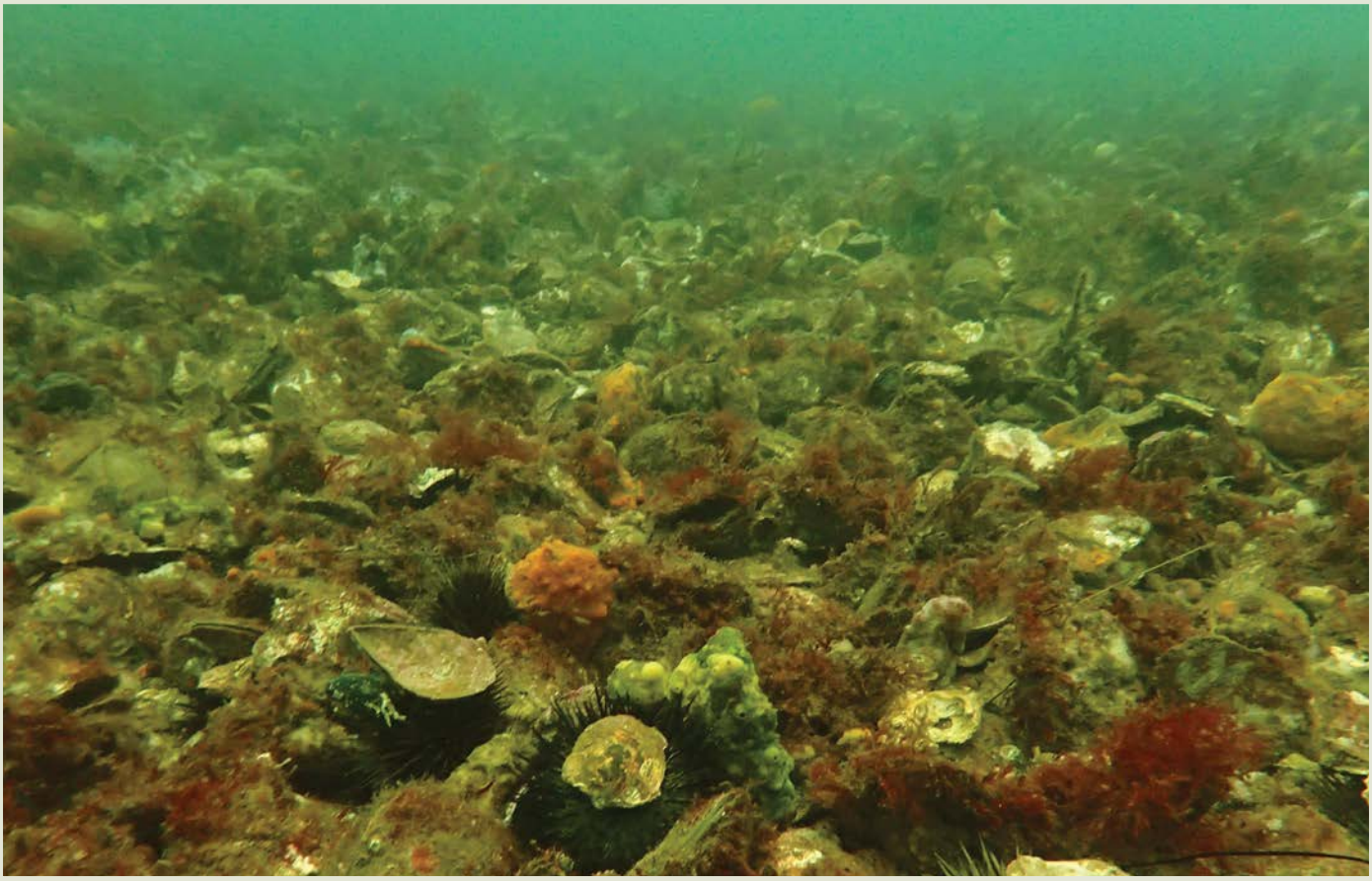

Plate 20. Native oyster low-profile reef in Georges Bay, Tasmania. *C. Gillies*

As significant recruiting was observed in these reefs in the latest stock assessment in 2013, they also present a special opportunity to investigate methods for re-establishment and expansion of *O. angasi* reefs in an area that is clearly suited to growing these oysters. A priority is to gain a better understanding of the extent of natural shellfish reefs to assist both Tasmania and the national shellfish restoration community develop restoration reference sites, criteria for restoration and to determine the ecological, social and economic value of shellfish reefs.

Ostrea angasi oysters have previously been fished in very remote and difficult to access regions in south western Tasmania, where middens dense with *O. angasi* shells occur. Consequently, it is possible that remnant oyster reef habitat still exists in these isolated estuaries; similarly on the Bass Strait Islands. A priority is to survey these areas for *O. angasi* reef habitat.

Of note is that this previously dominant reef habitat which has largely disappeared from Tasmanian waters, has also been erased from the memories of the Tasmanian community. Support from the general public to restore *O. angasi* reefs will require education on the important role these reefs played in the structure and function of estuaries, and on the substantial benefits to be gained from their re-establishment. Similarly, the community need to be made aware of the significance of the only known remaining reef habitat in Georges Bay and the urgency of managing and protecting this unique habitat to ensure its long term survival.

Shellfish reefs of South Australia

By Heidi Alleway

Primary Industries and Regions South Australia, Adelaide, South Australia.

Past extent of shellfish reefs

Although progress has been made toward understanding the past distribution and extent of shellfish reefs in South Australia, through the reconstruction of a historical baseline for the flat oyster, *Ostrea angasi*, and European exploitation of this species (Alleway and Connell 2015), a 'pre-European' baseline has not been identified. Furthermore, Indigenous use of reef forming shellfish species is not well understood and a record of ecological change that spans timescales commensurate with the occurrence of oyster reefs (i.e. tens of thousands of years) is not available. Evaluating ecological change across successive times scales using multiple sources of data enables an accurate picture of change, due to natural versus human mediated pressures, to be created. Furthermore, the implications of the eradication of habitats that have persisted through geological time due to human activity, such as shellfish reefs, should not be underestimated. The scale of such a loss is evidence of the need for restoration.

Palaeoecological records

The presence of not only shellfish species, but also shellfish reefs including those formed by *O. angasi*, has been recorded through geological surveys. Pufahl and James (2006) documented Late Pliocence oyster reefs in the Murray Basin, South Australia in the expression known as the 'Norwest Bend Formation'. Oyster 'buildups' were recorded just north of Walker Flat through to just west of Barmera, along with accumulations of other bivalve species and the presence of shellfish mixed with bryozoans, brachiopods, gastropods, and sponges. From these surveys, Pufahl and James (2006) interpreted three styles of oyster deposits within the Norwest Bend Formation: 1. bioherms, 2. biostromes, and 3, subaqueous dunes. These formations were generally observed to be monospecific, formed almost entirely of the oyster *O. angasi*.

Archaeological records and Indigenous use

The exploitation of shellfish species through Indigenous use has been recorded and may be more extensive, with an earlier onset than perceived (Erlandson and Rick 2010). Aboriginal consumption of shellfish in South Australia has been recorded, including the patterned use of a range of resources based on seasonal occupation of areas, as well as longer-term changes in consumer behaviour (e.g. Luebbers 1978). However, in comparison to European exploitation of *O. angasi*, which formed the basis of the state's first formal commercial fishery, Aboriginal consumption of this species may not have been extensive. Exploitation occurred and *O. angasi* have been identified within Aboriginal middens (e.g. Luebbers 1978; Radford and Campbell 1982). However, exploration of a number of Aboriginal middens have also indicated preferences for the consumption of rock species, such as gastropods, and a notable absence of nearshore subtidal species, such as scallops and razorfish (*Pinna bicolor*; Campbell 1979). In his journal of travels across southern Australia Edward Eyre commented on the variation with which Aboriginal use of oysters occurred:

"Many drays might easily be loaded, one after the other, from these oyster beds (Streaky Bay, far west coast, South Australia). The natives of the district do not appear to eat them, for I never could find a single shell at any of their encampments. It is difficult to account for the taste or prejudice of the native, which guides him in his selection or rejection of particular kinds of food. What is eaten readily by the natives in one part of Australia is left untouched by them in another, thus the oyster is eaten at Sydney, and I believe King George's Sound, but not at Streaky Bay" (Eyre 1845).

Patterns of Indigenous use might have reflected consumption of shellfish species that were comparatively easier to forage (Campbell 1979). It might also have reflected a tendency for avoiding subtidal foraging, which would limit exploitation of *O. angasi* and oyster reefs formed by this species. Patterns of Indigenous use of shellfish species, including the cultural connectivity of Indigenous communities to these species and shellfish reefs, warrant

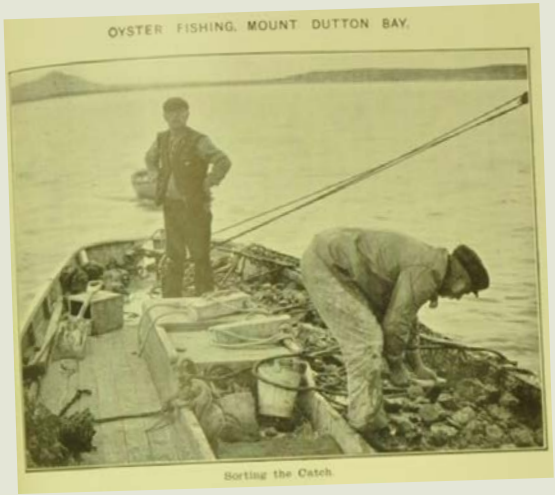

Plate 21. 'Oyster fishing' using dredge equipment from sailing cutters dragged over reefs, whereby all material was bought on board, with live oysters then separated from 'cultch' (limestone and coral; Randall 1911; Randall 1912)

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greater exploration and attention in collaboration with Aboriginal communities.

Historical records and 'the harvest years'

Historical fisheries records including correspondence, reports and diaries of the Inspector of Fisheries, and later annual reports of the Fisheries and Game Department of South Australia provide data regarding the commercial exploitation of *O. angasi* following European colonisation. These reports have been documented by Alleway and Connell (2015); critically, this work identified that the past distribution of commercial fishing and oyster reefs formed by this species were far more extensive than previously thought. Oysters reefs have been lost across more than 1,500 km of the state's coastline.

A factor contributing to the 'forgotten' characterisation of the state's coastline by oyster reefs and the scale of the commercial fishery, which once supported more than 30 sailing cutters that travelled across the state as a fleet, was the early onset of fishing and their overexploitation. Fishing began with the arrival of European settlers and fisheries legislation was first introduced in 1853, with further regulations formed in 1873 and 1885.

The following timeline reflects the 'rise and fall' of South Australia's commercial fishery for the flat oyster *O. angasi* (data reprinted from Alleway and Connell 2015):

1836	Colonisation of South Australia
1853	First introduction of legislation, to permit the "laying down" of oysters where beds did not occur
1873	Legislation to "prevent the wanton destruction of oysters" (fishery closures, minimum size, the deposit of "injurious matter" on a bed)
1881	Appointment of first inspector of oyster fisheries
1885	Legislation to "promote the breeding of oysters and regulate the fishery" (introduction of licensing)
1890	Highest recorded catch of 3,549 bags
1895	Inspector recommended "all further dredging on known deposits must be suspended to enable the beds to be restocked by spawn"
1911	Inspector reported on the failure of the industry, "attributable chiefly to uncontrolled overworking"
1912	Establishment of the first National Oyster Reserve and Nursery
1932	First wastewater treatment system built in Adelaide
1944	No men engaged full time in oyster fishing
1970	*Crassostrea gigas* aquaculture begun

Ecological decline and current extent

Continued review of historical records has reiterated that overexploitation, through the overworking of 'beds' and the dredge equipment used to harvest *O. angasi* was the driver of their decline, although multiple, synergistic impacts such as declines in water quality might have hindered their recovery. From the 1900s onwards, the Fisheries and Game Department published various departmental reports. The Annual Reports produced in 1911 and 1912 described specifically the activities of the commercial fishery and documented the practice of what is now known to be one the most highly destructive fishing methods, dredging (Plate 21).

Records indicating an impact from diseases and parasites on *O. angasi*, which has contributed to declines of oysters reefs in other areas (e.g. Ogburn et al. 2007), have not been found. In fact, correspondence between the South Australian and Australian Museum's made comparisons between oyster populations and allude to a perceived resistance of *O. angasi* in South Australia. For example, a letter from H.M. Hale to T.C. Roughley, 21 June 1935, indicated:

"The habit of *O. angasi* of living in water where it is never bared by the tide exposes it to a far greater risk of attack by Polydora, and the fact that you can find no evidence of attacks by the worm seems rather propitious for the success of the growth of the NSW oyster in similar situations. It (polydora) appears to have a less serious effect on *O. angasi* because of the greater readiness with which that species can deposit shelly material. It is not that *O. angasi* is attacked less, but that it is more capable of dealing with the attacks. But from the fact that you can find no evidence of the worm attaching your oysters I should be inclined to assume that it is not virulent in South Australia and that the NSW oysters should stand a good chance of survival in submerged situations."

Ecological declines of *O. angasi* have been significant and the classification of 'functionally extinct' (Beck et al. 2011) in South Australia accurately reflects the current status of the reef habitat that this species once formed. Alongside this decline, there is a growing appreciation of declines in other reef forming bivalves, including the *Malleus* hammer oyster. Hammer oysters can form reef-like aggregations in South Australia, up to 2m high as observed in the upper Spencer Gulf (Shepherd and Edgar 2013). Extensive areas of *Malleus-Pinna* assemblages, previously reported by Shepherd and Sprigg 1976, are now missing from large areas of the Gulf St Vincent, due to the impacts of prawn trawling and declines in the quality of coastal water (Tanner 2005).

Immediate opportunities for protection, repair and restoration

Recovering the historical baseline of past distribution and abundance of oyster reefs formed by *O. angasi*, and the knowledge that oyster reefs have persisted in South Australia over geological time scales, provides justification for the protection of reef forming species and the restoration of shellfish reef habitat. Despite an increasing awareness of the loss that has occurred, the community has only put forward records of remnant reefs; there remains no confirmed records of living oyster reefs in South Australia. Larval entrainment has been reported in a number of locations by growers involved in the oyster aquaculture sector, which combined with the occurrence of remnant reefs could provide the opportunity to invest in repair.

A key location in which both larval entrainment and the presence of remnant reefs is known is the east coast of Yorke Peninsula near Stansbury in the Gulf St Vincent. Stansbury, a small regional community was historically

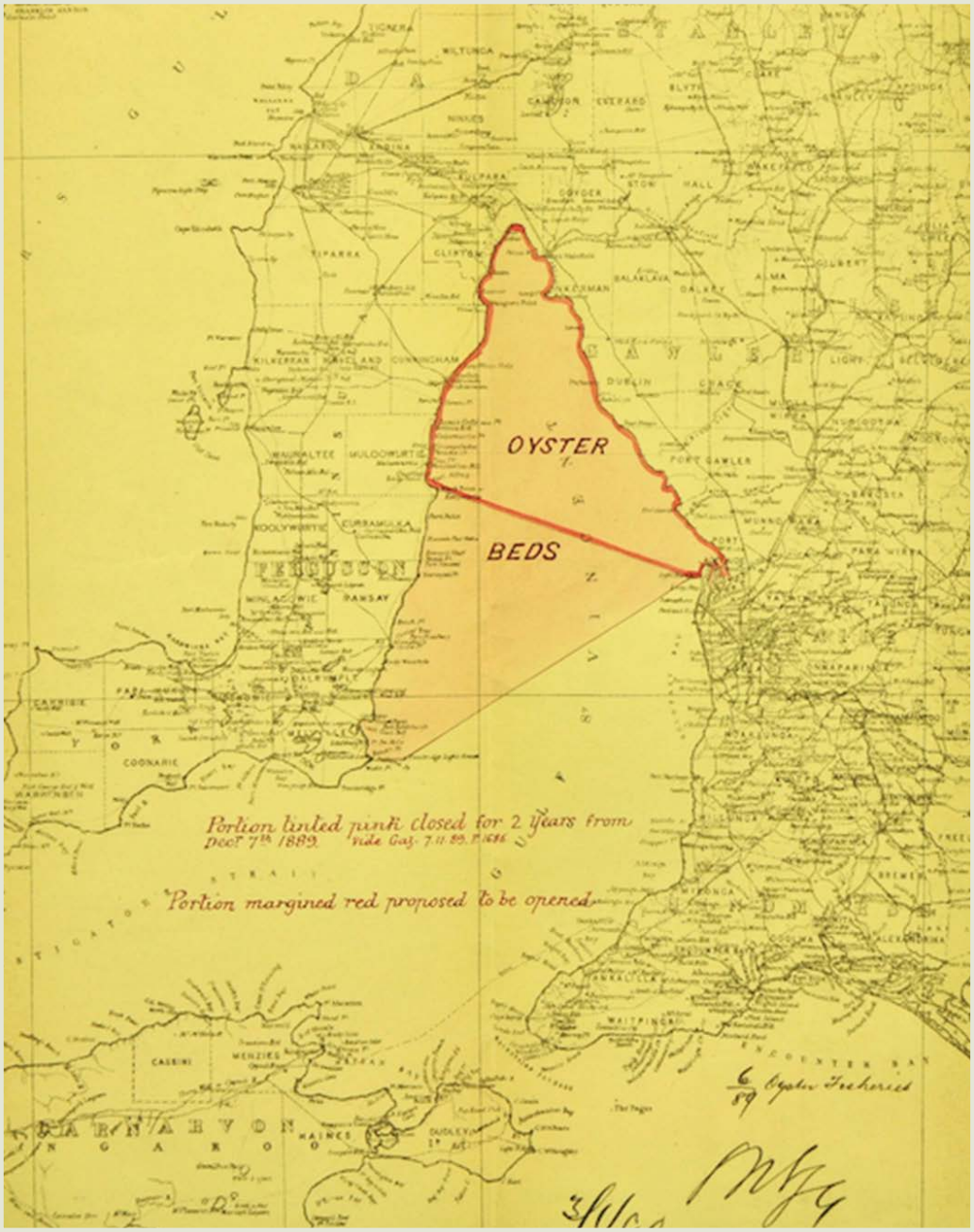

Plate 22. Map of spatial closures for oyster fishing in Gulf St Vincent 1889, proposing one third of the gulf to be closed to dredging with a further third to be opened.

referred to as 'Oyster Town'. In the past, this area supported extensive commercial fishing and a map of 'spatial closures' in 1889, held within the State Records of South Australia, attests to broader distribution of oyster reefs throughout this region (Plate 22).

Investing in restoration in Gulf St Vincent, and specifically the Yorke Peninsula, provides the opportunity to implement on-ground works through a collaborative, community driven approach. This area has an important aquaculture industry for the Pacific oyster, *Crassostrea gigas*, which would act as a test case for works in collaboration with this sector. It is also an area of high recreational fishing activity, adjacent to areas of spatial management including fisheries closures and marine parks. Improving opportunities for recreational fishing, and regional communities that place high economic value on this activity and associated tourism, is an objective of the South Australian Government. This objective is being developed through the habitat enhancement initiative. Shellfish reef restoration is the central premise of this program.

Shellfish reefs of Western Australia

By Bryn Warnock and Peter Cook

Centre of Excellence in Natural Resource Management, University of Western Australia, Albany, Western Australia.

Ostrea angasi have been recorded in many estuaries and bays along the southern and lower west coasts of Western Australia. The present population size is unknown for any estuary within this range, with no oyster specific census completed in over 50 years. Commercial fisheries were known to have existed in at least three estuaries in Western Australia: Princess Royal Harbour, Taylor's Inlet and Oyster Harbour. It is likely that smaller fisheries existed in the large estuaries to the West of Albany, including Wilson and Nornalup Inlets. The *O. angasi* fisheries in Princess Royal Harbour and Oyster Harbour had largely collapsed by 1880, 54 years after the settlement of Albany.

Overfishing and the loss of hard substrate due to the fishing methods employed are the mostly likely causes of their initial decline and poor recovery. Subsequent changes in water quality, sedimentation and the presence of *Bonamia* may have also hindered recovery. Remnant stocks of *O. angasi* are known to be present within Oyster Harbour, with anecdotal evidence of three-dimensional reefs.

Past extent of shellfish reefs

In the Albany region it is likely that extensive beds of *O. angasi* were present in Oyster Harbour, Princess Royal Harbour and Taylor's Inlet. The scale of these beds is unknown; however it is known that acres of beds were present in Princess Royal Harbour, with larger populations present in Oyster Harbour (Saville-Kent 1893). More broadly, *O. angasi* populations were known to exist in Wilson, Irwin and Nornalup Inlets. Figure 8 illustrates the locations where *O. angasi* shells have been found, either alive or dead, extending this distribution considerably.

Other systems such as the Hardy Inlet and Swan River system are known to have supported large populations of *O. angasi* historically (Brearley and Hodgkin 2005). However, changes to their hydrology and geomorphology thousands of year ago likely lead to the collapse of those populations (Brearley and Hodgkin 2005).

Archaeological records and Indigenous use

Based on the writings of early settlers and explorers, it seems unlikely that *O. angasi* made up a significant component of the normal diet of Aboriginal people in the southwest of Western Australia, at least in the period leading up to settlement (Nind 1831, Grey 1841). In fact, it has been reported that while some shellfish were eaten, *O. angasi* was considered poisonous and was thus taboo (Young 1997). This tradition was altered after colonisation, with Nind (1831) reporting that some local Aborigines around the Albany settlement began eating oysters after cooking them on a fire. The view that oysters were not heavily exploited by southwest Aboriginal people is supported by a general lack of large shell middens throughout the region (Dortch et al. 1984). The weathered nature of the coastline coupled with substantial modification post-settlement, may however, have removed some key evidence (Dortch et al. 1984).

Historical records and 'the harvest years'

Early explorers of the South West found *O. angasi* in plentiful supply, to the extent that Vancouver ran his vessel aground on a bank of Oysters while attempting to leave Oyster Harbour in 1791 (Vancouver 1798, Baudin 1809). Making light of the situation, Vancouver and his men "sumptuously regaled" upon the oysters and named the estuary Oyster Harbour in commemoration (Vancouver 1798). Baudin also found Flat Oysters in Oyster Harbour, remarking on their large size (Baudin 1809).

A substantial oyster dredge fishery existed from the mid 1800's until approximately 1880 in the Albany area (Oyster Harbour, Princess Royal Harbour and possibly King George Sound), forming the basis of a 'lucrative shellfish trade' with passing steamers as well as supplying the local market (Saville-Kent 1893; 1894, also see Plate 23).

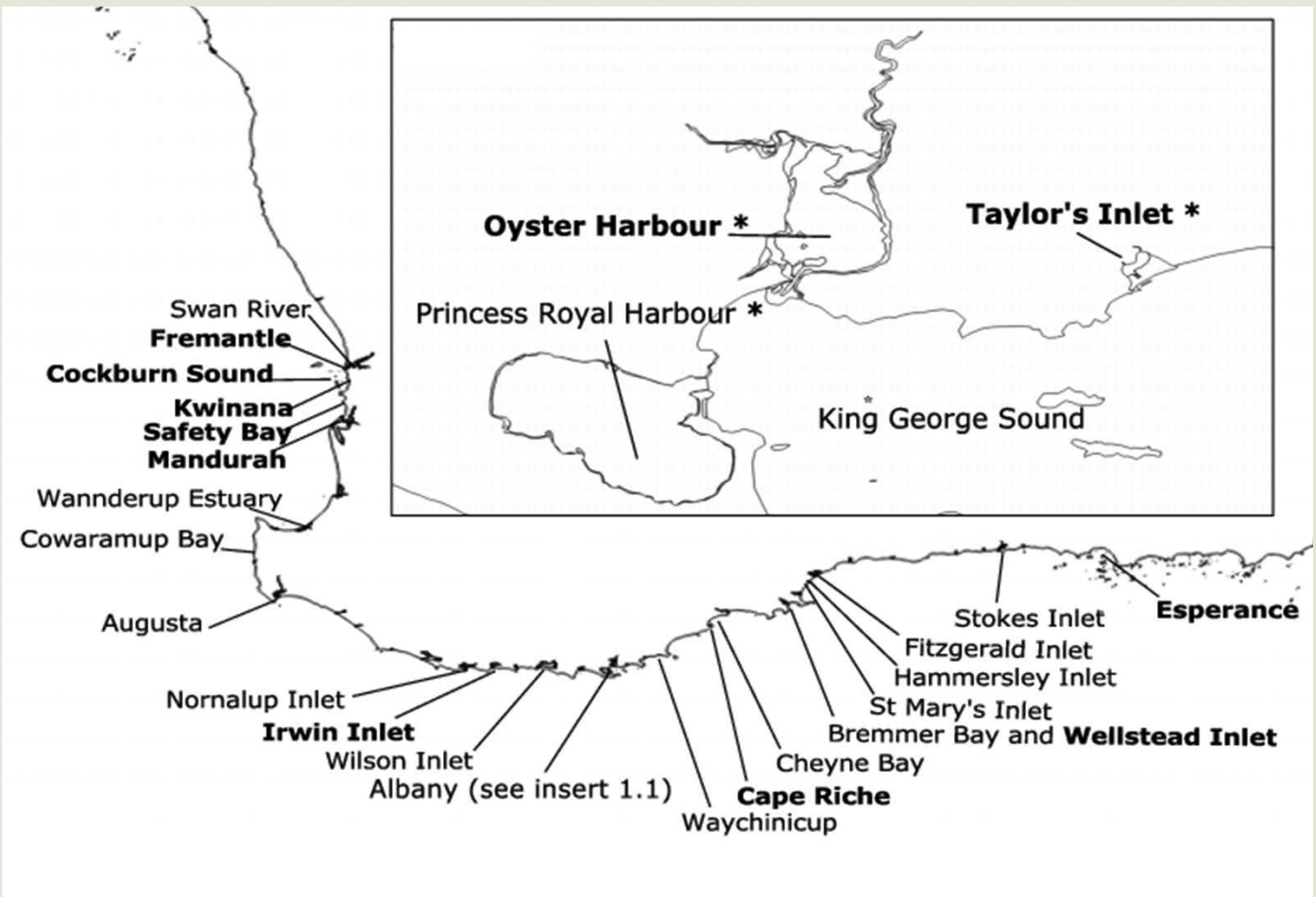

Figure 8: Locations of samples taken by the WA Museum. Areas where at least one sample was identified as probably live at time of collection are market in bold. Those areas where commercial fisheries were known to exist are marked with an *.

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Evidently the colonial government had concerns about the sustainability of the *O. angasi* fishery as early as 1881. In this year the *Oyster Fisheries Act 1881* was passed for the purpose of "...the protection of Oysters and encouragement of Oyster Fisheries". Despite the presence of this act, no catch records were found and hence a quantitative evaluation of the size of the stock or trade could not be made.

In an effort to 'resuscitate' the oyster fishery, the commissioner for fisheries at the time, Saville-Kent, made efforts to begin rebuilding the stock within Princess Royal Harbour after his visit in 1893. He noted that floating spat were plentiful within Princess Royal Harbour, evidenced by their rapid settlement on moored vessels and other suitable substrate (Saville-Kent 1893). However, due to the destruction of the beds by dredging, the spat lacked suitable habitat on which to settle (Saville-Kent 1893). Despite an initial report in May 1895 by the Harbourmaster that Saville-Kent's oyster reserve was doing well, by October 1896 the lake had filled with silt and seaweed (Learoyd 1896). This resulted in the smothering of the spat collectors, as well as facilitating the growth of mudworms.

A private venture leased and attempted to cultivate the oyster beds at Taylor's Inlet, 30km East of Albany around 1898 (Gale 1899; Inspector of Fisheries 1906; Piggott 1992). During a visit in 1900, the Chief Inspector for Fisheries found two large beds, with 'great numbers' of *O. angasi*' (Gale 1900). Exceptionally wet winters in 1899 and 1905

led to the deaths of hundreds of thousands of oysters, with causes cited as prolonged exposure to fresh water, an unusually low water level in the inlet due to three separate openings within the same year, and the transportation of sediment (Gale 1899; Inspector of Fisheries 1906; Piggott 1992). The entire venture was abandoned due to complaints from professional fisherman and holidaymakers who disliked the restrictions resulting from the lease (Inspector of Fisheries 1906; Piggott 1992). No further attempts to culture oysters in Taylor's inlet have been made to date, and the status of its current stock is unknown (Piggott 1992).

Ecological decline and current extent

Saville-Kent noted that the fishery was significantly depleted 15 years prior to his 1893 visit, to the extent that he believed the species was on the verge of localised extinction (Saville-Kent 1893). Dredge fishing (also known as haul net fishing in WA) was used as the primary method of harvesting *O. angasi*. The destruction of oyster shell beds was likely to have been sufficient that the recovery by settlement of spat in the formerly fished areas was limited or non-existent due to a lack of hard substrate. Other environmental changes documented in both Princess Royal Harbour and Oyster Harbour may have further hindered the recovery of the oyster. Most notable among these changes is the widespread loss of seagrass from both estuaries, and the corresponding increase in macro-algae coverage (Brearley and Hodgkin 2005). The loss of seagrass beds is often associated with destabilisation of the sea floor and increased siltation (Campagne et al. 2015) – both of which are likely to have negatively impacted on the quantity and quality of available hard substrate necessary for *O. angasi* bed development. Extensive clearing has occurred within the catchment area of Oyster Harbour, resulting in an increase in sedimentation within the lower reaches of the King and Kalgan Rivers, as well as Oyster Harbour (Hodgkin and Clark 1990). The presence and impact of pathogens on natural populations of *O. angasi* in the southwest is undocumented. However, the presence of *Bonamia* and the experience of the Ocean Food's venture in culturing *O. angasi* indicate that this may also be a contributing factor to the poor recovery of the species.

The paucity of robust census data for *O. angasi* throughout the southwest makes the formation of a qualitative evaluation of the current status of the stock impossible. However based on the available information, it is evident that present stocks of *O. angasi* in southwest estuaries are a fraction of their historical levels. This is certainly the case in Oyster and Princess Royal Harbours near Albany. Overfishing appears to have caused the initial decline. Destruction of oyster beds and hard substrate by dredging, coupled with changes in water quality, increases in sedimentation and loss of seagrass are likely to have prevented an effective recovery of the stock once fishing efforts were reduced. The impact of pathogens such as *Bonamia* sp. on remnant natural stocks of *O. angasi* is unclear, though its impact on commercial operations in Oyster Harbour was severe.

Immediate opportunities for protection, repair and restoration

The lack of natural recovery over the century that followed the effective end of the *O. angasi* fishery, indicates that restoration efforts are required if the ecosystem services provided by oyster reefs are to be returned to southwest estuaries. Efforts are underway to restore *O. angasi* reefs in Oyster Harbour, Albany lead by the University of Western Australia, South Coast NRM, The Nature Conservancy and Recfishwest with the purpose of restoring biodiversity and critical fish habitat. Whilst still in its pilot phase, the project hopes to improve opportunities for recreational fishing whilst also strengthening community engagement in coastal management through school, Indigenous and community-based initiatives that support restoration activities. Further assessment of the current extent and suitability of other locations such as Taylors Inlet, Peel-Harvey estuary and the Swan River estuary could also yield suitable locations for shellfish reef restoration.

This year, owing to the unprecedented rainfall over a short space of time, the inlet broke out on three occasions, a very unusual occurrence. It was, therefore, no surprise to me to find hundreds of thousands of oysters dead, owing to two agencies—(1) too much fresh water, and (2) the repeated outbreak of the inlet leaving the oysters on the shoal banks exposed to the sun long enough to kill them before the water made up to its usual level. However, although so many oysters have died, still in the deeper water there is a great quanity remaining, and from my observations, I am inclined to think that in the middle of the inlet there must be large beds of oysters in deep water. Before I can report conclusively and satisfactorily, I should have to equip myself with proper appliances for testing the bottom.

1899 The West Australian, 1 December, Page 3, Columns A and B

British native. Not many years ago a considerable trade was done here in oysters. The P. & O. steamers obtained large supplies, and considerable quantities were shipped to Perth and Fremantle and other towns in the colony. Oyster dredging was at one time a very profitable industry, but it was ruined through there being no legislation for the protection of the beds and through the lack of knowledge and perhaps also the reckless vigor of those engaged in the trade. The beds were no longer able to supply the demand about fifteen years ago. Had there, say thirty years ago, been a Mr. Saville-Kent in this colony, measures would have been taken to prevent the destruction of the banks and also to regulate the operations of the oyster collectors and to-day we might have had a trade worth many thousands

1894 The Australian Advertiser, 16 May, Pages 2-3, Columns G and A

From the old settlers we find that even about fifteen or twenty years ago many thousands of oysters were sent to Perth and Fremantle and sold to the P. and O. steamers. The oysters were found chiefly in Oyster Harbor and at Nannerup. We cannot find that any effort was made at cultivating the oyster in order to maintain the supply. The oysters were found in their natural state and were hauled out of the water and sold. The banks were dredged until where thousands of oysters had grown, none were to be found. It seems a very great pity that a trade so profitable and a trade too that without much trouble could have been developed to an enormous extent was allowed to go to ruin. Hundreds of thousands of oysters were obtained here, and there is no reason whatever why a supply equal to the demand of this colony, and also of Adelaide and Melbourne should not come from Albany. That, at any rate, is the opinion of Mr. Saville-Kent than whom there is no greater authority on the subject. Can we not realize without any

1893 The Australian Advertiser, 22 December, Page 3, Column A

Plate 23: Excerpts taken from newspaper articles written in the 1890s – a period during which *O. angasi* was the focus of considerable attention from colonial governments in Western Australia.

Repairing Australia's shellfish reefs

By Chris Gillies

The Nature Conservancy, Carlton, Victoria.

10.1 Objectives of shellfish reef restoration

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (Society for Ecological Restoration 2004). The term 'restoration' is used interchangeably and is synonymous with rehabilitation, remediation and re-creation but implies an active intervention to a predefined endpoint (but not necessarily to an original, pristine state, see Elliott et al. 2007). The term restoration is also used simultaneously to describe both the *process* of undertaking repair and the *outcome* of repair works (Society for Ecological Restoration 2004).

The overarching goals for restoring shellfish reefs vary according to the proponents of the restoration but they include:

- **Restoration for the intrinsic value of restoring a degraded or functionally extinct ecological community or as habitat for other critically threatened species (e.g. migratory shorebird foraging habitat);**
- **Restoration for the purpose of restoring commercial or recreational shellfish fisheries;**
- **Restoration for the purpose of restoring ecosystem services (attributes) associated with shellfish reefs such as water filtration, fish production and coastal protection.**

Restoration of shellfish reefs is most advanced in the United States, where restoration efforts have occurred for over 20 years. The precise number of reefs under restoration is unknown but is likely to be in the thousands. For example, over 250 restored shellfish reefs have been documented for the northern Gulf of Mexico alone (La Peyre et al. 2014). A number of guidebooks and restoration manuals (e.g. Brumbaugh et al. 2006; Baggett et al. 2014) have been developed as a result of this work, strengthened by long-term support from national government agencies such as the National Oceanic and Atmospheric Administration (NOAA).

10.2 Likelihood of recovery and risks associated with restoration

The location, morphology and extent of shellfish reefs are influenced by a range of complex interactions between physical, environmental and biological attributes such as salinity, predation and disease, and hence, these factors need to be considered in the planning, design and construction of reefs (Table 2). Consideration also needs to be given as to whether historic locations, which once supported shellfish reefs, can be restored or if physical changes have occurred within the catchment, such that the system can no longer support quantities of shellfish, prevents re-establishment or their reintroduction is undesirable. For instance, the reintroduction of shellfish reefs may increase pathways for disease transfer into regions that may be nominally disease free, increased accessibility for public shellfish harvest may increase risks to human health associated with consuming contaminated shellfish or genetic diversity within a region may decrease if reefs are seeded with broodstock collected from a single source.

The process for deciding if and where to restore shellfish reefs should therefore include an assessment of the risks associated with both success and failure. Habitat suitability models can be developed to support managers in choosing sites that support long-term growth and survival of shellfish reef and aid in determining the cost versus benefit of recovering shellfish reefs (e.g. Pollack et al. 2012). Consultation with key stakeholders such as shellfish growers, recreational fishers and Indigenous groups can also aid in determining the most suitable sites for restoration.

The risk of failure is likely to be higher in early projects when factors relating to survival and long-term viability of reefs are unknown, until a sufficient body of knowledge is gained which can help guide subsequent efforts. Incorporating active research into restoration projects, using pilot projects to decipher best methods for scaling-up and planning for adaptation are likely to reduce the risk of failure in early efforts. Establishing a national restoration database to encapsulate and share critical information on

TABLE 2. ATTRIBUTES THAT GOVERN THE LOCATION, COMPOSITION, STRUCTURE AND ECOLOGICAL FUNCTION OF SHELLFISH REEFS THAT REQUIRE CONSIDERATION DURING PLANNING, DESIGN AND CONSTRUCTION OF RESTORATION WORKS.

Environmental attribute	Local (site based) or regional influence
Salinity	*Local*
Substrate availability	*Local*
Predation	Local
Reproductive supply	Local and Regional
Disease	Regional
Sedimentation	Local
Stratification and hypoxia	Local
Current/water flow	Local
Genetic diversity	Regional
Prolonged aerial exposure	Local

what works and why, strengthening practitioner networks and partnering with experienced groups can also help improve the likelihood of long term success.

10.3 Beneficiaries of shellfish reef restoration

Restoring or sustaining the viability of Australia's shellfish reefs will ultimately benefit the Australian public and future generations through healthier and functioning marine habitats. Several stakeholder groups, however, can strongly identify with the direct benefits of restoring shellfish reefs and their ecosystem services. These include:

- **Recreational and commercial fishers** and associated service providers (e.g. tackle shops, bait suppliers, accommodation): through increased recreational fishing opportunities as a result of habitat enhancement and fish production for recreationally and commercially important fish species;
- **Indigenous Australians:** through the recovery of important Indigenous food sources and cultural practices;
- **Coastal property-owners, local governments and foreshore managers:** through the reduction of coastal erosion and improvements in natural storm defences. Shellfish reefs can reduce wave energy and therefore help protect coastlines from eroding and/or reduce maintenance costs associated with hardened coastal defences such as seawalls;
- **Catchment managers, water managers and regulators:** shellfish reefs can capture sediments and filter considerable quantities of water, removing seston from the water column down to ~ 3 µm. Shellfish reefs also recycle nutrients such as nitrogen which can limit phytoplankton growth and reduce the risk of harmful algal blooms;
- **State and Federal Governments:** by helping to meet domestic and international obligations for the protection and sustainable management of wetland habitats e.g. *Environment Protection and Biodiversity Conservation Act 1999* (Cth) and international agreements such as

Examples from the United States demonstrate that where significant financial resources have been invested in shellfish reef restoration, coastal communities directly benefit through the creation of new jobs and increased economic stimulus as a result of planning, construction works and monitoring associated with large-scale shellfish restoration projects (Meadows et al. 2010; Edwards et al. 2013) (Plate 24).

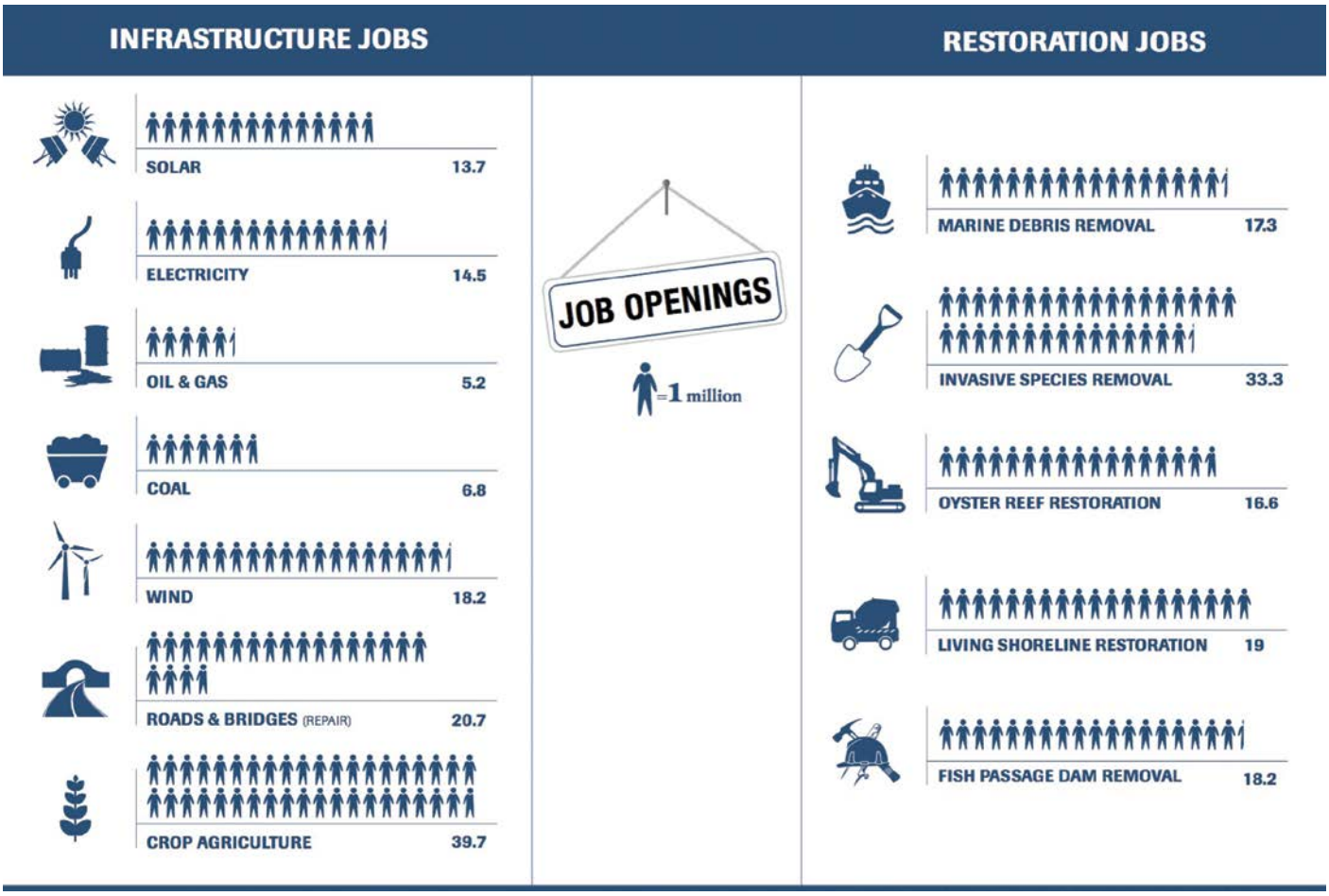

Plate 24. Average number of job openings for oyster reef restoration in the United States compared to other grey and natural infrastructure projects. Adapted from Edwards et al. (2013)

the Ramsar Convention on Wetlands of International Importance and bilateral migratory bird agreements with Japan (JAMBA), China (CAMBA) and the Republic of Korea (ROKAMBA). *Note:* Shellfish reefs have been classified as a wetland habitat type by the Ramsar Convention on Wetlands since 2012 (Kasoar et al. 2015);

- **Research and education industries:** The limited scientific knowledge on the ecology and function of Australian shellfish reefs allows for new research and education opportunities in the study of natural reefs and monitoring and evaluation of restored reefs. The knowledge and skills gained in the study of best practice restoration and coastal management could be applied internationally;
- **Diving and snorkelling tourism:** The re-creation of subtidal shellfish habitat (e.g. *O. angasi*) and the associated faunal assemblages are likely to create a number of new diving and snorkelling opportunities.

Examples from the United States demonstrate that where significant financial resources have been invested in shellfish reef restoration, coastal communities directly benefit through the creation of new jobs and increased economic stimulus as a result of planning, construction works and monitoring associated with large-scale shellfish restoration projects (Meadows et al. 2010; Edwards et al. 2013) (Plate 24). For instance, for every AUD $1.25 million (in 2015 dollars) invested in shellfish reef restoration, on average, 17 jobs are created which is comparable to other coastal industries such as roads and bridges and energy generation, and is higher than for oil and gas (Edwards et al. 2013).

These benefits include:

- **Jobs and/or economic benefits directly connected to the production of shellfish.** Where natural shellfish recruitment is limited, shellfish hatcheries are required to produce large quantities of shellfish spat to re-seed restored oyster reefs. Adult shellfish can be purchased from growers to supplement recruitment and shell cultch obtained from growers can be used as a substrate for shellfish attachment;
- **Jobs in relation to the transportation and logistics of reef construction materials.** Reef substrate materials such as limestone and shell cultch need to be transported from quarries/aquaculture farms to the restoration site(s);
- **Jobs in relation to the construction and deployment of**

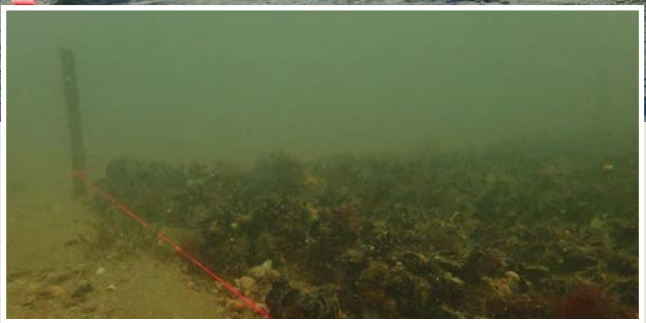

Plate 25. Blue mussels (*M. galloprovincialis*) being deployed by shellfish growers in the Port Phillip Bay Shellfish Reef Restoration Project (above). Newly laid mussel reef (right). *C. Gillies*

shellfish reefs. Construction jobs are required to deploy substrate to the seafloor following engineered design briefs. Such jobs include: plant equipment operators, barge/vessel operators and crew, marine surveyors and commercial divers;

- **Jobs in relation to the engineering, design, and monitoring of shellfish reef restoration projects.** Large-scale restoration requires co-designed reefs amongst ecologists and engineers to ensure risk of structural failure is minimised. Ecologists are required to ensure ecological function is restored and to support monitoring and evaluation. Project managers are required to oversee all phases of the project planning, design, implementation and evaluation;
- **Jobs in relation to community engagement, education and school involvement.** Many shellfish restoration projects provide opportunities for community involvement and engagement. Jobs are required to coordinate and plan community participation events, citizen science activities and school engagement.

10.4 Australian reef restoration efforts

Efforts are underway to restore shellfish reefs in Australia, with pilot projects currently initiated in regions with developed coastlines and with bays or estuaries requiring environmental repair (Plate 25). These pioneer projects have focused on restoring either the native flat oyster (*O. angasi*), Sydney rock oyster (*S. glomerata*) or blue mussels (*M. galloprovincialis*). Typical restoration methods used include using hatchery-produced oyster spat and seeding these onto a range of different substrate types (e.g. limestone, concrete, oyster cultch, scallop cultch) deployed to different sediments (e.g. sand, mud, old oyster reef). Objectives of these early efforts include determining oyster growth and survival, assessing predation rates, and optimising reef design, construction and deployment with medium-term goals including the re-establishment of self-sustaining breeding populations.

These early projects will be critical for building momentum within the broader restoration community and can support the development of new projects by documenting, monitoring and sharing what does and does not work in the Australian context, and why (Gillies et al. 2015). Building on

TABLE 3. DESIGN CONSIDERATIONS FOR SHELLFISH REEF RESTORATION. PROJECTS ALSO NEED TO ENCOMPASS ENVIRONMENTAL CONDITIONS SUITABLE FOR OYSTER GROWTH AND SURVIVAL (SEE TABLE 2)

Restoration attribute	Environmental/Biological attribute
Substrate type and density	Niche diversity, physical complexity, attachment suitability, predation
Substrate height	Predator/disease control, smothering, survival
Substrate construction	Reef integrity, structural failure
Broodstock density	Predation, survival
Broodstock size	Predation, survival
Broodstock source	Genetic 'bottlenecking', reproductive success, disease resistance
Shellfish no-take areas or shellfish sanctuaries	Illegal fishing/over harvesting
No anchor areas	Structural integrity
Local site characteristics (e.g. sub-embayment)	Improved retainment of brood stock
Location to other structured habitats (e.g. saltmarsh, seagrass)	Improved connectivity/biodiversity
Location to other shellfish reefs	Improved retainment of broodstock, reproductive success
Enclosures	Predator control

early successes will also likely engender a conservation and protection ethos for those reefs in the more undeveloped coastal regions of Australia.

10.5 Building on international experience

Much can be learnt from the experiences of shellfish reef restoration internationally, particularly from efforts in the United States where shellfish reef restoration has occurred for over 20 years. Given the skills and capacity of Australian marine scientists and experience of institutions such as Landcare to manage long-term, large-scale restoration programs on land, Australia is well placed to rapidly apply the experience of international restoration projects and adapt those to suit Australian reef building species and environmental conditions.

In order to build on overseas experiences, the Australian research and restoration community will require capacity and resources to:

- Promote the exchange of knowledge and skills between academic, government and community institutions engaged in shellfish reef restoration;
- Establish partnerships with organisations that can support knowledge exchange and provide capacity building in Australian researchers and restoration practitioners; and
- Investment in initial restoration projects, communication materials and training programs.

These activities could be applied through existing networks, conferences and workshops hosted by groups such as: National Estuaries Network, Australian Marine Science Association, Society for Ecological Restoration Australasia and the Australian Coastal Society.

10.6 Restoration methods

The design and monitoring of shellfish reef restoration have been reviewed by Brumbaugh et al. (2006) and Baggett et al. (2014) and are briefly described below.

The location and dimensions of restored reefs are determined based on the environmental suitability for shellfish growth and reproduction (Table 2) and a number of other considerations related to reef design (Table 3). Shellfish reef building species require hard substrates for larval settlement (living or old shells), and so the first stage of restoration requires the deployment of suitable substrate to the seafloor, preferably old shells (cultch) although a variety of other materials are suitable, including limestone, concrete and granite (Schulte et al. 2009). Cultch can be deployed as loose material or contained in mesh bags or engineered structures for a higher vertical profile (often used in shoreline stabilisation projects).

Where broodstock are in low numbers or absent in the system, direct seeding of shellfish may be required. The most common method is to seed shellfish spat directly onto cultch or substrate within a hatchery. Other methods include transplanting shellfish from nearby areas or gluing/placing adult oysters onto deployed substrates. Because the long-term viability and success of shellfish reef restoration is dependent on a range of environmental and physical factors unique to each site (Tables 2 and 3), restoration projects should incorporate a research and monitoring

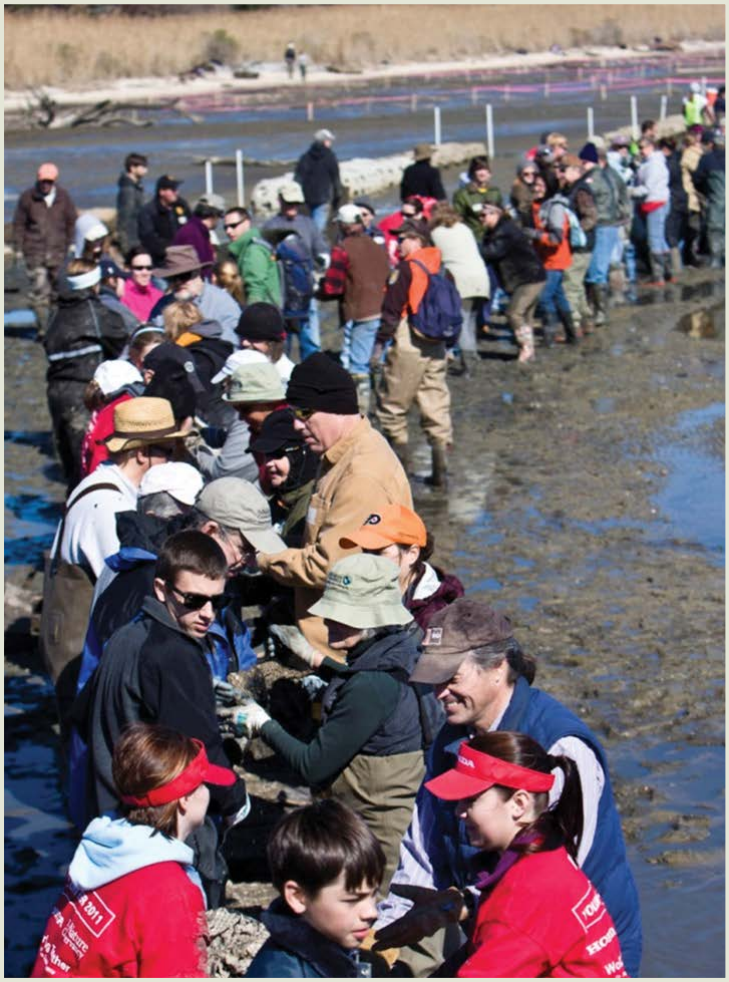

Plate 26. Nearly 400 volunteers construct the first quarter-mile of oyster reef for shoreline protection work. 100-1000: Restore Coastal Alabama project, USA. Similar projects are entirely possible in Australia. © The Nature Conservancy. *E. Nortemann*

Plate 27. Restaurants and oyster bars can engage in restoration activities through shell recycling programs. *C Gillies*

component to guide efforts to scale-up the size and number of reefs in a modular fashion.

10.7 Community engagement

Given the long-term nature of habitat restoration, community support and involvement in the restoration works is critical to overall long-term success and viability. The community, including schools, fishing clubs, restaurants and coastal property-owners can support and participate in shellfish restoration through a number of activities, including:

Reef building

Community members can participate in the construction of shellfish reefs, especially intertidal reefs that use modular construction designs, such as oyster castles or bags of shell cultch (Plate 26).

Shell recycling programs

Shell recycling programs collect discarded oyster shells from restaurants or commercial fish co-ops and stockpile them for later use as oyster reef substrate (Plate 27). Large stocks of shells can also be collected from shellfish aquaculture facilities.

Oyster gardens

Community members can grow oysters in cages from private jetties and piers, which are later returned to the estuary or restoration site, contributing to the reproductive viability of the shellfish population.

Settlement plate deployment and monitoring

Community members can build, deploy and monitor settlement plates to assess shellfish recruitment and reproduction rates before and after restoration works.

Reef monitoring and evaluation activities

Community members can undertake above water, snorkel or dive surveys to assess the viability, assemblage composition and health of restoration works using established citizen science methodologies.

Recommended key actions to support shellfish reef restoration

11.1 Priority areas for investment

Investment in works to repair and re-establish Australia's shellfish reefs is rapidly gaining momentum with projects recently initiated in most states. A national community of practice (Shellfish Reef Restoration Network – www.shellfishrestoration.org.au) has also been newly established to share information and learnings amongst restoration practitioners. The challenge is to ensure that these early projects continue to be successful in order to provide a platform for others to learn from and thereby build the skills and experiences of Australian practitioners. Australia can also integrate knowledge and practice from the wealth of existing international work by seeking to build partnerships with international organisations that have long-term experience in shellfish reef restoration.

To improve marine conservation outcomes, and effectively focus investment and community involvement in shellfish restoration, we identify three immediate priority areas for investment:

1. **Improve community understanding of the value of shellfish reef habitat as a means to increase community support and engagement (including Indigenous involvement) in restoration activities;**
2. **Quantify the ecosystem service benefits and ecology of existing shellfish reefs in order to delineate their ecological, social and economic value and to establish reference sites to guide restoration efforts;**
3. **Invest in the development of early restoration projects to build momentum, expertise and capacity in Australia's marine restoration community.**

In addition to these priority areas we list 12 key actions (Table 4), that we believe if undertaken, will improve Australia's capacity to undertake successful conservation and large-scale shellfish reef restoration. We suggest prioritising research and restoration efforts towards those reef forming species with the highest need, likely conservation value and potential for repair, such as the native flat oyster (*O. angasi*), Sydney rock oyster (*S. glomerata*) and blue mussels (*M. galloprovincialis*).

11.2 Value of partnerships - industry, community and indigenous

Efforts to repair shellfish reefs can be strengthened by forming partnerships and collaborations with similar groups such as the shellfish aquaculture industry, who are likely to have complementary knowledge and experiences that can support restoration efforts, particularly in areas such as shellfish husbandry, disease management and reproduction. As the body of knowledge on the ecology of natural shellfish reefs and methods for their repair grows, this information is equally likely to be of benefit to the shellfish aquaculture industry as a means to improve efficiencies and husbandry practices. Research that seek to address knowledge gaps that are of benefit to both groups may be more attractive to private investors and governments than those that benefit a single sector.

Developing partnerships with the other key coastal stakeholders can be equally important such as recreational and commercial fishers, boaters, community groups and coastal landowners. These partnerships can provide opportunities to garner greater public support for restoration projects, increase funding, recruit volunteers and provide local expertise on restoration projects.

Shellfish reefs were once a major coastal food resource for Indigenous Australians and shellfish reef restoration provides an opportunity to strengthen Indigenous leadership and cultural awareness of traditional ecological knowledge and sustainable Indigenous coastal management. Many of the large Indigenous middens around southern Australia were completely exploited as initial sources of lime for the developing colonies and their size reflected long-term traditional Indigenous use of these shellfish resources. Closer integration and strong partnerships amongst Indigenous groups and the shellfish reef restoration community would help to identify the location and/or historic location of past shellfish middens, support the management of culturally significant sites and establish how best to re-establish Indigenous customary food resources.

Plate 28. Shellfish hatcheries and growers are likely beneficiaries of shellfish reef restoration. Y. Young

11.3 Opportunities for innovation and integrated environmental solutions

Efforts to restore shellfish reefs can be assisted by almost any measure to increase shellfish numbers within an estuary system, when concerns about biosecurity and disease have been considered. Recent innovations in eco-engineering of hardened infrastructure (which seeks to make grey infrastructure such as seawalls more habitable for marine species) have the potential to complement efforts to restore natural reefs when textiles suitable for oyster colonisation are used. Similarly, shellfish reefs as a component of living shorelines can in some circumstances, replace the need for hardened infrastructure altogether (see section 2.4).

Another promising innovation includes the use of shellfish reefs as natural water filters to help offset the impact of effluent derived from fish farms (or indeed effluent from other point sources). This can occur either as an integrated system within the fish pens (e.g. Integrated Multi-Trophic Aquaculture) or as a natural reef system developed within the vicinity of the fish pens. Whilst the potential for Australian shellfish species to act as biological processes of waste nutrient has not yet been fully explored, likely major expansion of the aquaculture industry within coastal waters over the next few years will require innovative, low cost solutions that can support aquaculture sustainability through improvements to water quality and marine habitat.

TABLE 4. RISKS AND RECOMMENDED KEY ACTIONS TO UNDERPIN THE SCALE-UP OF SHELLFISH REEF RESTORATION IN AUSTRALIA

Key risk	Key action
Community fails to support efforts to protect and restore shellfish reef habitat	1. Improve community knowledge and awareness of the value of shellfish reef habitat through the development of communication campaigns and materials
	2. Increase Indigenous engagement in restoration activities by capturing and communicating Indigenous knowledge and stories and invest in programs which support the inclusion of Traditional Ecological Knowledge in shellfish reef restoration
Low public/private sector investment in shellfish reef restoration and conservation	3. Quantify the ecosystem service benefits and ecology of Australian shellfish reefs (including nitrogen cycling, filtration capacity, fish production, shoreline protection and biodiversity) to delineate their ecological, social and economic value and as a means to establish restoration reference sites and benchmarks
	4. Develop the business case to articulate the potential environmental, social and economic return of investment for shellfish reef restoration
Remaining shellfish reefs become extinct	5. Review marine habitat data to determine extent of remaining shellfish reefs, why they still exist and key threats to determine nomination for "threatened ecological community" evaluation processes
	6. Update relevant Commonwealth and State Government agency marine wetland definitions to include shellfish reef habitat
	7. Consider the designation of new Ramsar wetland sites to include shellfish reefs and prioritise the inclusion of shellfish reef habitat surveys when updating the Information Sheet on Ramsar Wetlands (RIS) for existing sites
	8. Undertake a sustainability review of current wild harvest oyster and mussel fisheries to determine level of risk to fisheries collapse
Restoration projects fail to repair ecological structure and function of shellfish reefs	9. Invest in the development of early restoration projects to build momentum, expertise and capacity in Australia's marine restoration community
	10. Promote the exchange of knowledge and develop partnerships with international organisations, governments and universities involved in shellfish reef restoration
	11. Develop routine shellfish health monitoring protocols for restoration to assess disease prevalence and determine disease risk to restoration projects and aquaculture
	12. Undertake an assessment of genetic diversity in existing shellfish populations to determine threat of 'genetic bottlenecks'

Key agencies / parties	Estimated cost[1]	Example delivery mechanism	Priority and timeline
Community leaders with their advocacy networks, governments, researchers, NGOs	$	Websites, brochures, videos, presentations, workshops	Immediate action
Leading Indigenous groups supported by agency resources, NGOs	$$	Indigenous Sea-ranger program, Working on Country program	Immediate action
NGOs, universities and research institutions	$$	NESP *marine biodiversity hub priority*, ARC priority, state environmental research funding schemes	Immediate action
NGOs, governments, Universities and research institutions	$	Socio-economic analysis of shellfish restoration	Immediate action
Commonwealth and State Governments, universities and research institutions	$$	Review of existing estuary habitat data, new habitat mapping	Immediate action
Commonwealth and State Governments	$	Distribution of this report, NESP *marine biodiversity hub* information brief	Immediate action
Commonwealth Government	$	Updated RIS assessments	1-5 year priority
State fishery agencies	$	FRDC review of shellfish fisheries	1-5 year priority
Commonwealth and State Governments, NGOs, NRM and private sector	$$$	*Great Southern Seascapes* program, NRM agencies	Immediate action
Shellfish Reef Restoration network, NGOs, Government science agencies, universities and research institutions	$	Community of practice, international exchanges	1-5 year priority
CSIRO, universities and research institutions	$$	FRDC, NESP marine hub priority, state environmental research funding schemes, ARC	1-5 year priority
Government science agencies, universities and research institutions	$$	FRDC, NESP marine hub priority, state environmental research funding schemes, ARC	*1-5 year priority*

[1] Estimated costs $ = less than $ 500,000; $$ = $500,000 to $1M; $$$ = $2M to $8M

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