PROTECTION AND REPAIR OF AUSTRALIA'S SHELLFISH REEFS – SOUTHERN QUEENSLAND REPORT

DIGSFISH SERVICES

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PROTECTION AND REPAIR OF AUSTRALIA'S SHELLFISH REEFS – SOUTHERN QUEENSLAND REPORT

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10.1 Executive summary

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 (F. Pteriidae). The main locations where shellfish reefs occurred included 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 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).

European exploitation of shellfish resources in Southern Queensland began immediately following the first settlement at Redcliffe in 1824 (Smith 1981). Between 1824 to 1863 was a period of little or no government regulation of the rock oyster (*S. glomerata*) fishery (Smith 1981). Prior to 1863, most exploitation of rock oysters 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 pound 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, taste better, 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 1860's and 1870's 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).

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 the 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).

History shows that the dredge sections were the first to experience production declines from the late 1880's, however production of the intertidal banks has also declined over time to less than $1/10^{th}$ 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), however, suggestions that infection by "mudworms introduced from New Zealand" killed large numbers of oysters resulting in extinction of subtidal oyster reefs along Australias 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 (Figure A, Diggles 2013).

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 Figure B). However, in the case of *S. glomerata*, given the current problems with QX disease, utilization 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;

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

Figure A. 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).

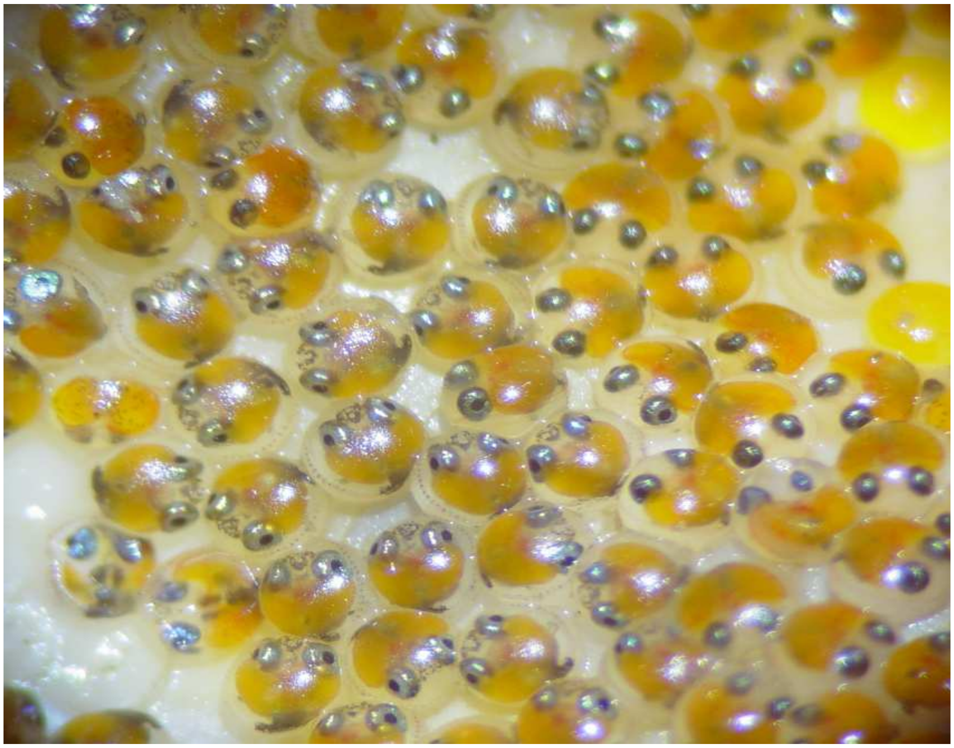

Figure B. Thousands of fish eggs were deposited onto new shellfish reef material deposited into Pumicestone Passage, but only in subtidal areas.

10.2 Presumed Extent

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. Archaeological evidence from Aboriginal middens suggests that the Aboriginal subsistence economy in the coastal region was based mainly on marine resource harvesting for thousands of years, with shellfish dominating midden remains (Ulm 2002, Ross et al. 2015). Smith (1981) in his historical account of the oyster fishery noted that the first official European report providing details of the shellfish resources of Moreton Bay dates back to June 1822. At that time, William L. Edwardson in command of H.M. Cutter *Snapper* reported "*From this point (Skirmish Point, Bribie Island) to the south part of the bay, a distance of about 30 miles by 22 miles, the whole is composed of sand ridges and deep holes interspersed with mangrove islands, and these again surrounded for miles by mud flats and oyster or muscle (sic) bed*" (Smith 1981). Based on studies of the contents of Aboriginal middens in the region (e.g. Ross et al. 2015), the species of shellfish being described by Edwardson in 1822 were the Sydney rock oyster (*Saccostrea glomerata*), hairy mussels (*Trichomya hirsuta*) and possibly pearl oysters (F. Pteriidae, including round toothed pearl shell *Isognomon ephippium*, the akoya pearl oyster *Pinctada imbricata*, and *P. albina sugillata*), all of which are known to be biogenic reef forming organisms.

Figures 1 and 2 outline the presumed extent of the biogenic reef forming shellfish resources of Southern Queensland after stabilization at roughly the current sea level during the late Holocene Period (around 2000 years before present). Also indicated are the main locations of Aboriginal midden sites containing oyster shells that are currently known to archaeologists. The location of the vast majority of midden sites closely correlates with the areas where abundant shellfish resources were reported by early Europeans. Investigations by early European oyster fishers in the 1860's found that subtidal shellfish reefs ("dredge sections") often occurred in deeper channels adjacent to the areas where intertidal "bank" oysters were abundant (Fison 1884, 1889, Smith 1981).

In Southern Queensland the locations where the largest numbers of shellfish reefs were historically observed and documented by Europeans were inside the sheltered embayments of Moreton Bay and the Great Sandy Straits (Figures 1, 2). Heading northwards from the QLD/NSW border, the major concentrations of subtidal *S. glomerata* reefs were found in the Southport Broadwater (Dredge Sections 1-3), and also in Dredge Section 4 near the Couran bank areas eastwards of the mouth of the Coomera River (Fison 1884, 1889, Smith 1981). Dredge Section 4 was reportedly one of the most prolific sections (Fison 1884) until the breakthrough of the coastal bar at Jumpinpin in the late 1890s, which allowed nutrient poor oceanic water into that part of the waterway after a long period of closure (McCauley and Tomlinson 2006). The opening of Jumpinpin reportedly resulted in scouring of oyster banks through increased tidal action, and reduced shellfish productivity in some adjacent areas (Smith 1981, Lergessner 2006). The next major concentrations of subtidal *S. glomerata* reef occurred in Dredge Sections 9 and 10 between Russell Island and Stradbroke Island. Fison (1884) reported on this section as follows: "*From Mr Rutledge's statement – he having been employed dredging there for the past 2 years, it appears that the bottom of both Nos 9 and 10 is composed of rocks and sand, and his dredge bought up thousands of very young dead oyster shells, which proved how thick the spat must have been in this section. When he first went there he sometimes took as many as 40 bags per week and at that time 7 boats were dredging. This was kept up for nine months, and then the obtaining of oysters became more difficult,* *since which time four boats have been continuously dredging in all parts of the section, without any apparent diminution of the yield. His opinion is that the natural surroundings are so favourable to the growth of spat that, without constant dredging, young oysters would become too thick and die. Either spat must be very prolific, or fish do not cause much destruction in this section*".

Further to the north, reefs of *S. glomerata* were found near Amity on the inside of North Stradbroke Island, in the lower reaches of the Brisbane River, around the foreshore at Redcliffe, and throughout Deception Bay (Figure 1). However, perhaps the largest quantities of oysters in Moreton Bay were found inside Bribie Island in Pumicestone Passage, where *Saccostrea glomerata* was reported to occur both intertidally and subtidally in oyster reefs down to around 4 meters below the low tide mark (Lergessner 2006) in benthic reefs that were up to 1.2-1.5 metres thick (Fison 1884). A Mr Alexander Archer described a trip to Pumicestone Passage in 1862 as follows: "*the water teems with fish, great and small and as for the oysters, I never saw anything like it. This day we saw something like a reef of rock about 3 feet out of the water and 300 yards long. On pulling up to see what it was, we found it to be a huge and apparently solid bed of oysters, large enough to load several large ships*". (Lergessner 2006).

Fison (1884) reported that the dredge sections in Pumicestone Passage "*were eagerly competed for*", and that Dredge Section 31 "*which includes Ningi Creek, has been continuously cultivated…., and for the last 6 months 350 bags have been forwarded to market from it. Number 32 has also given good returns, but in No. 33* (which is opposite Donnybrook, around 8 km north of Ningi Creek) *thousands of bags of oysters have been taken, they being in some places 4 ft and 5 ft deep* (Fison 1884).

Further north, dredge sections for subtidal *S. glomerata* reefs were also opened up in the Maroochy and Noosa Rivers (Fison 1884), as well as in Tin Can Bay and the Great Sandy Straits (Figure 2) where it was noted that *S. glomerata* spat grew abundantly on rocks within the intertidal zone and also on the bottom of the channels (Brown 2000). In the late nineteenth century, while inspecting the Great Sandy Straits, forester Jules Tardent described "*the astronomical quantity of seed-oysters, stretching for miles, which has to be seen to be believed*" (Brown 2000). Only one dredge section was operating in the Great Sandy Straits region in the 19th century, that being held by the Leftwich family in the Susan River, a tributary of the lower Mary River (Fison 1889). However, in 1902 G.H. Clarke discovered dredge oysters in other parts of the Great Sandy Straits, after which it was promptly divided into an additional twenty-six dredge sections (Smith 1981). Further to the north, significant quantities of oysters were reported in estuaries and around rocky headlands up as far north as Gladstone Harbour as well as in The Narrows between outer Curtis Island and the mainland, as well as Rodds Harbour in Keppel Bay (Fison 1889, Figure 2).

Figure 1. The grey shaded areas represent the presumed extent of the biogenic reef forming shellfish resources of South East Queensland prior to European settlement. The black squares indicate the main locations of Aboriginal midden sites containing oyster shells that are currently known to archaeologists. Numbers denote dredge sections mentioned in the text.

Figure 2. The grey shaded areas represent the presumed extent of the biogenic reef forming shellfish resources of Southern Queensland (north of Bribie Island) prior to European settlement. The black squares indicate the main locations of Aboriginal midden sites containing oyster shells that are currently known to archaeologists.

10.3 Indigenous Use

Archaeological evidence indicates that Aboriginal people have lived in Moreton Bay for at least 20,000 years (Neal and Stock 1986, Ross et al. 2015), and evidence from middens at Wallen Wallen Creek on the west coast of North Stradbroke Island suggests that harvesting of marine resources, particularly shellfish, was the dominant subsistence activity for much of that time (Neal and Stock, 1986, 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 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). While variable taphonomic processes of decay may act to increase the relative proportion of mollusc shells in older middens compared to other less robust artifacts such as fish bone (Ulm and Vale 2006), based on the sheer volume of mollusc shell material in middens it is clear that shellfish were a very significant resource for coastal Aboriginal people in Southern Queensland that was developed and exploited in a sustainable manner for thousands of years prior to European settlement. As noted previously, the shell middens tend to be located close to areas where shellfish were abundant, however radiocarbon dating suggests there is a trend whereby older middens tend to be further inland away from the present coastline, suggesting these were deposited during periods of higher seal level over 2000 years before present (Ulm and Reid 2000, Ulm and Vale 2006).

10.4 Early Settlement

European exploitation of shellfish resources in Southern Queensland began immediately following the first white settlement in Queensland at Redcliffe in 1824 (Smith 1981, Diggles 2013). In Moreton Bay, the period of early European settlement from 1824 up to the 1863 Oyster Act was a period of little or no government regulation of the rock oyster (*S. glomerata*) fishery with no licensing, or control in any form, resulting in over-exploitation of many of the more accessible oyster banks in Moreton Bay during this time (Smith 1981). In such cases the oysters were harvested by individuals helping themselves where, when and how they chose, often assisted by local Aborigines who were paid by the number of sacks they filled (Smith 1981). Aboriginals also made a thriving trade of oysters and other seafood with early settlers throughout the 1800's, but particularly before the 1870s (Kerkhove 2013). As they were more accessible, bank oysters growing in the inter-tidal zone were exploited long before the oyster reefs growing below low water were discovered in the mid 1860's (Smith 1981).

In the early years of European settlement in Moreton Bay between 1824 and 1863, most exploitation of rock oysters was not for food but for the production of lime to make the mortar used in the construction of the houses and buildings of early Brisbane (Smith 1981). The oysters were gathered, 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". Schooner loads were carted away and burnt at Toorbul Point and the Caboolture River in the northern bay and Lamb and Russell Islands in the southern bay (Smith 1981). Another easy source of shell was found in Aboriginal middens, which were considered ideal and thus heavily mined as they were predominantly oyster deposits that could be shovelled into heaps or into lime kilns with firewood to burn (Smith 1981).

10.5 The Harvest Years

Smith (1981) described the evolution towards an "officially regulated" rock oyster harvest industry in Southern Queensland as follows: "*Early in August 1863 the attention of the Queensland Government was drawn to the wasteful practice of lime burning and to the general unprotected condition of the beds of Moreton Bay. A Bill for the protection of oysters was introduced in the Legislative Council and given assent on 22 September 1863 in the Legislative Assembly. lt had been hurried through without much consideration because of the imminent close of the session. The main provisions of the Oyster Act were to provide for a fine of up to 10 pounds or imprisonment for up to three months as penalties for the burning of live oysters for lime*." Licenses were also introduced with a 5 pound fee for a permit to lay down oysters on defined oyster beds. These provisions applied only to Moreton Bay but could be extended to other areas (Smith 1981).

The harvest industry gained momentum when subtidal reefs of "dredge oysters" (also *S. glomerata*) were first discovered in Pumicestone Passage, and shortly afterwards in the Southport Broadwater in the mid 1860s (Smith 1981). Dredge oysters were claimed to grow faster, taste better, obtained higher prices, and were collected using a dredging basket operated from a boat. The dredges had various designs but usually were square or triangular frames about 1.5 m. wide with a mesh basket of wire rings or tarred cotton (Smith 1981). In contrast, bank oystering involved collection of oysters obtained from the inter-tidal zone. The oysters were picked by hand off sand banks, mangrove roots or oyster reefs with little or no attempt made at artificial cultivation apart from breaking up the clumps and redistributing them into the lower tidal zone to assist growth. Some oystermen later experimented with rocks, tiles, dead shell and sticks as alternative substrate to collect spat (Smith 1981).

The rock oyster industry in Moreton Bay developed and expanded throughout the 1860's and 1870's, but as concerns over sustainability arose this was accompanied by increased regulation in the form of limiting entry to the fishery which was then followed by a revised Oyster Act in 1874 (Smith 1981). The new Act allowed the Government to sell (by auction) 7 year leases to run dredge sections and annual licenses to allow use of oyster banks. By 1884 Moreton Bay was divided into 164 bank sections (Fison 1884) and 39 dredge sections which encompassed waters 2 ft below the low tide mark (Smith 1981). By 1886 there were 178 oyster banks licensed in Moreton Bay over an area of slightly more than 5000 acres, with an average of around 30 acres (12 hectares) per bank, while in the Great Sandy Straits there were 13 large bank licenses totaling around 1800 acres, averaging around 138.5 acres (56 hectares) per bank (Smith 1981). A revised Oyster Act in 1886 provided more protection by prohibiting removal to interstate of oysters less than 5 cm and increasing the duration of dredge section leases to 14 years. By this time the industry in Moreton Bay was intensifying further by enhancing oyster banks and dredge sections with *S. glomerata* spat collected from the Great Sandy Straits, Keppel Bay and Rodds Harbour, after which they would be ongrown for 12 to 18 months in Moreton Bay prior to sale (Smith 1981).

By the late 1880s the rock oyster industry in Southern Queensland was nearing its production peak, which was achieved in 1891 at a production of 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 the 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 (see Section 10.6). 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).

Indeed, history shows that the dredge sections were the first to experience production declines in the late 1880's, however throughout the 20th century production of the intertidal banks has also declined precipitously, to less than 1/10th of their 1891 peak by 1980 (Smith 1981), despite technological improvements such as use of intertidal rack and tray culture methods. The next section discusses the likely causes of those declines.

10.6 Ecological Decline

The peak of production for the rock oyster industry in Southern Queensland was in 1891, after which it declined to less than 10% of its former peak (Smith 1981), and has not recovered since (Diggles 2013). Many authors have studied the decline and all agree that it was not due to one single problem, but a combination of events. Potential contributors to the decline include overfishing, disease and declining water quality, however there is some conflict in the literature as to the extent of the respective roles of each of these events (Smith 1981, Kirby 2004, Ogburn et al. 2007, Diggles 2013).

Outbreaks of "mudworm disease" were the main reason why oystering for *S. glomerata* in subtidal dredge sections was abandoned firstly in Moreton Bay, then eventually throughout Southern Queensland (Smith 1981). In Moreton Bay the process of abandoning subtidal dredge sections started around 1889 (Fison 1889) and accelerated into the early 20th century. Nevertheless, the number of dredge sections leased actually increased from 1889 until the peak of 64 in 1904, but this was mostly due to new discovery of subtidal oyster reefs in Great Sandy Strait in the period of 1902-04 (Smith 1981). Review of historical literature leaves little doubt that infection by spionid polychaete mudworms (*Polydora* spp., *Dipolydora* spp., *Boccardia* spp. and others) is why subtidal oystering was abandoned (Smith 1981, Ogburn et al. 2007, Diggles 2013), and this is logical considering that oysters were being sold for food and mudworm blisters can make oysters unmarketable (Nell 2001). However, suggestions by some authors that infection by "mudworms introduced from New Zealand" killed large numbers of oysters, decimating subtidal oyster reefs along Australias east coast resulting in their failure to recover (Ogburn et al. 2007) are not supported by current scientific knowledge of the taxonomy of mudworms, or the epidemiology of mudworm infections of bivalve molluscs (Read 2010, Diggles 2013).

Certainly, high mortality rates of *S. glomerata* were sometimes reported from subtidal dredge sections during post-flood periods after 1893 (e.g. 82.5% mortality of dredge section oysters in February 1898, with 96.5% prevalence of mudworm in surviving oysters, see Brisbane Courier 1898). However, in hindsight there was little if any diagnostic evidence presented which could be used to ascertain the cause of death in such instances. Modern scientific knowledge of oyster diseases has repeatedly shown acute mass mortalities in wild bivalve populations are almost invariably due to physical processes such as prolonged hyposalinity, smothering by silt, and/or infection by highly pathogenic viral or protozoan disease agents, rather than infections of the shell by mudworms (Diggles 2013). Instead, the latter tend mainly to stunt growth, reducing survival only under exceptional circumstances in captivity in intensive aquaculture, or when shells are weakened, thereby facilitating predation (Royer et al. 2006, 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 much more likely to blame highly visible shell dwelling polychaetes for any mortalities, rather than unknown microscopic protozoans. Indeed, in hindsight it is much more likely that acute post-flood mass mortalities such as those reported in the Brisbane Courier (1898) were instead due to either prolonged hyposalinity, smothering of oyster beds with silt, and/or infection by then unknown diseases such as QX disease caused by the endemic paramyxean protozoan *Marteilia sydneyi* (see Wolf 1972, 1979, Perkins and Wolf 1976), which today is known to cause mass mortalities of *S. glomerata* after flood events (see Diggles 2013).

In Southern Queensland, there is a striking correlation between the onset of problems with productivity of subtidal *S. glomerata* reefs and the unprecedented sedimentation bought into coastal estuaries during flooding experienced during the La-Nina period of 1887-1893 (Diggles 2013). Since 1840, European land use practices resulted in large-scale clearing of the Moreton Bay catchment for agriculture and urban development, a process that has continued to accelerate with the regions rapidly increasing population (Diggles 2013). Coral cores from the Great Barrier Reef show that it took less than 30 years of European land use in the Burdekin River catchment (1840-1870) to clear enough land to generate a 5-10 fold increase in sediment loading in river run-off during drought breaking floods (McCulloch et al. 2003). However, further south the Brisbane River did not have a major flood between 1870 and 1887, so the flood of 1887 was probably the first to introduce an unprecedented amount of sediment and nutrients into the Moreton Bay ecosystem, as was remarked upon by those living in Moreton Bay at the time (Diggles 2013). The first problems with the subtidal dredge sections that were being reseeded with *S. glomerata* at the time were subsequently noted when time came to harvest them a couple of years later in 1889, when it was remarked that artificially cultivating previously productive dredge sections had become "*a waste of time and money*" (Fison 1889).

While fishing of the subtidal reefs was certainly intensive, there is historic evidence that prolific recruitment of new oyster spat occurred in subtidal dredge sections up until at least 1887, replenishing them within 1-3 years (Fison 1889). Indeed, Fison (1889) noted a 'wonderful fall of spat' occurred after the 1887 flood, despite silt from the flood smothering oyster banks in the southern sections of Moreton Bay (The Queenslander 1906, Diggles 2013). However, the 1887 flood was quickly followed by more major floods in 1889/1890 and the *La-Nina* event culminated in the multiple 8 + meter flood events in 1893 (Diggles 2013). In Pumicestone Passage and Moreton Bay, Diggles (2013) used epidemiological principles to suggest that these multiple flood events appear to have introduced enough sediment and nutrients into the previously sand-dominated, nutrient limited system to trigger a regime shift, which manifested firstly through smothering of subtidal *S. glomerata* beds, followed by unprecedented outbreaks of mudworm infection in the recovering subtidal beds due to increased organic enrichment and sedimentation (which stimulate settlement by mudworm larvae, see Sebesvari et al. 2006). Diggles (2013) also points out that introduction of large amounts of fine sediments into these ecosystems would have increased the geographic range of benthic mud-dwelling polychaetes such as *Nephtys australiensis*, which is a putative alternate host of *Martelia sydneyi*, the causative agent of QX disease in *S. glomerata* (see Adlard and Nolan 2015). Because of this, it is possible that some of the early epizootics observed in *S.*

glomerata in Moreton Bay after the late 1880's were due to QX disease (Diggles 2013). This is because in waterways adjacent to anthropogenically modified catchments, *M. sydneyi* infection pressure appears to have increased substantially compared with pre- European baselines. As this parasite is endemic, a plausible explanation for this is that environmental change has favoured range expansion and proliferation of its alternative host(s), as well as reduced the immunocompetence of oysters through reductions in water quality (Butt and Raftos 2007, 2008, Diggles 2013, Carrasco et al. in press).

Ogburn et al. (2007) stated that '*Sedimentation and nutrient loading, may have contributed to a decline in subtidal oyster reefs, but not their complete disappearance and failure to recover.*' However, larval settlement is a critical bottleneck in the life history of bivalve molluscs, and survival of oyster larvae is highest on sediment free, hard substrates (Diggles 2013). Oyster larvae have evolved over time to respond to a variety of physical and chemical settlement cues that are emitted by adult conspecifics, and/or particular bacterial biofilms (Tamburri et al. 2008). In organically enriched environments with high quantities of resuspended sediment, algal turfs form on all hard subtidal surfaces (McEwan et al. 1998). This biofilm traps sediment and detritus, making the surface unsuitable for settlement and/or post-settlement survival of oyster spat (Tamburri et al. 2008; B.K. Diggles pers. obs., Figures 3, 4). Because of this, a combination of sedimentation, sediment resuspension and nutrient loading that generates sediment laden algal turfs over hard surfaces appears sufficient to cause multigenerational recruitment failure for oyster spat that settle in subtidal areas (Diggles 2013). Indeed, such a process explains the existence of mushroom shaped oyster clumps in Pumicestone Passage (Figure 3), which form when the lowest oysters that die first during QX epizootics (and not due to mudworm) are not replaced by new recruits (Diggles 2013). It has been calculated that around 96% of the historically available vertical zonation suitable for *S. glomerata* settlement and survival in Pumicestone Passage has been lost in this way over the past 125 years (Diggles 2013). These processes are also evident in other parts of Moreton Bay and Southern Queensland, for example in Gladstone Harbour, the Broadwater and the Nerang River (Diggles, personal observations), where a similar upwards compression of the zone suitable for *S. glomerata* recruitment and survival into the upper intertidal region is evident (Figure 4).

Hence while some authors consider overfishing was the major cause of decline of subtidal oyster reefs in eastern Australia (Kirby 2004, Beck et al. 2011), in Moreton Bay and Pumicestone Passage, Diggles (2013) suggests there is little evidence that overfishing alone was primarily responsible for the ecological extinction of subtidal *S. glomerata* reefs. Instead, 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 (which may have originally been restricted only to muddy areas in the middle and upper reaches of local estuaries), to proliferate over a much wider area including Moreton Bay proper, where the majority of oysters occurred (Diggles 2013). This has resulted in functional extinction of subtidal *S. glomerata* reefs and substantial reductions in the productivity of intertidal bank oysters (Figures 5, 6).

Figure 3. 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).

Figure 4. In the lower Nerang River, a similar upwards compression of the intertidal zone suitable for *S. glomerata* recruitment and survival is evident, due to formation of algal turfs that trap sediment on hard surfaces, preventing settlement of oyster spat.

Figure 5. Intertidal bank containing *S. glomerata* clumps, Toorbul Point circa 1906 (from Diggles 2013, Photo from John Oxley Library)..

Figure 6. Same location as Figure 6 over 100 years later in July 2011. There are a very high number of dead oysters, and a lack of oyster recruitment. Abundant algal growth has trapped a significant amount of sediment, giving the rocks a dirty appearance. From Diggles (2013).

10.7 Current Extent and Condition

Today, subtidal oyster reefs are functionally extinct in Pumicestone Passage (Diggles 2013), throughout most (if not all) of Southern Queensland as well as many other estuaries along Australia's east coast (Beck et al. 2011). Around 96% of vertical zonation of oysters has been lost in Pumicestone Passage over the last 125 years, due to the ecological processes discussed in Section 10.6 (Diggles 2013). While significant numbers of *S. glomerata* are still evident in intertidal areas in most suitable estuarine habitats in Southern Queensland (Figures 1, 2), in many places affected by anthropogenic catchment development they are increasingly being compressed upwards into a much narrower habitable zone in the upper intertidal region (Figures 3, 4). Little is known regarding the status of the less well studied species of reef forming shellfish such as hairy mussels and pearl oysters, but based on observations in Pumicestone Passage and interviews with fishers who have lived in the region for over 80 years, significant declines of both these species have also occurred compared to historical baselines (B.K. Diggles, unpublished observations).

Recent studies of the health status of wild and cultured *S. glomerata* in Moreton Bay have revealed high prevalences of a variety of disease agents, including QX, disseminating hemocytic neoplasia, a *Steinhausia*-like infection, a branchial rickettsia-like organism, digenean flukes encysted in the gonadal tissue, and gill responses to an unknown toxin (Green et al. 2008, Dang et al. 2013, Diggles 2013). The cause of mortalities of *S. glomerata* in the Pimpama River in 2008 (during a dry year) was attributed to disseminating hemocytic neoplasia (Green et al. 2008), while in a wet year (2010-2011) QX was the main cause of death of oysters held in the same river (Dang et al. 2013) as well as elsewhere in Moreton Bay (Diggles 2013). Little to nothing is known of the health status of other reef forming shellfish such as hairy mussels and pearl oysters, however it is known that mud arcs (*Anadara trapezia*) in western Moreton Bay in particular are infected with the shellfish pathogen *Perkinsus* spp. (including both *P. olseni* and *P. chesapeaki*) at high prevalences (Dang et al. 2015).

10.8 Opportunities for Repair

Subtidal reefs of filter feeding shellfish are “the lungs” of healthy estuaries, providing food and habitat for fish and crustaceans, filtration of water, carbon sequestration, nutrient cycling (including uptake of nitrogen), bentho-pelagic coupling and other “ecosystem engineering” services (Beck et al. 2011). Because of this, restoration of shellfish reefs is a critical component of the estuarine rehabilitation process as they help improve water quality, provide fisheries habitat and increase fisheries productivity. Without oyster reefs, our estuaries become extremely vulnerable to algal blooms and domination by the microbial/algal loop.

Preliminary small scale scientific trials have discovered much potential for restoration of subtidal shellfish reefs in Pumicestone Passage (B.K. Diggles, unpublished data). Substantial recruitment of *S. glomerata* (Figure 7), small fish and invertebrates (grapsid crabs, juvenile *Scylla serrata*) occurred on clean spat collecting substrates (oyster shell, concrete, bricks) placed in intertidal and subtidal areas. Clumps of 1000’s of fish eggs were also observed, but only in oyster shells taken from subtidal collectors (Figure 8).

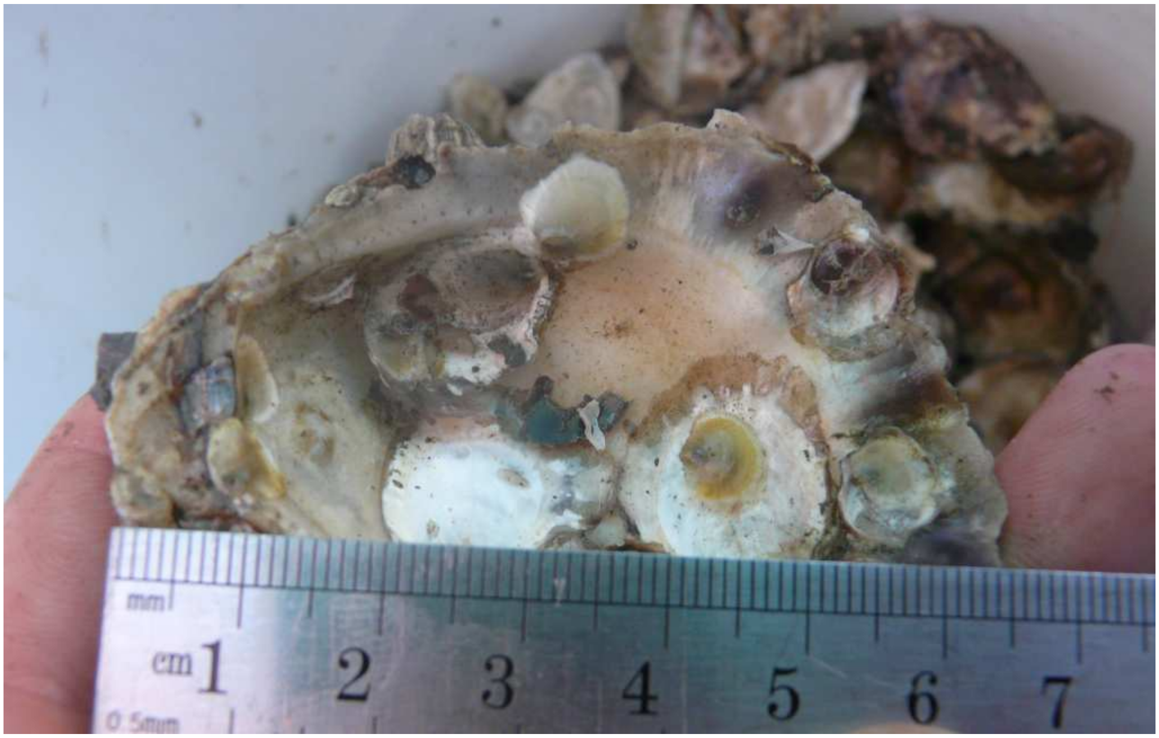

Figure 7. Clean substrate placed in subtidal areas of Pumicestone Passage at the right time of year attracted large numbers of newly settled *S. glomerata* spat from the plankton.

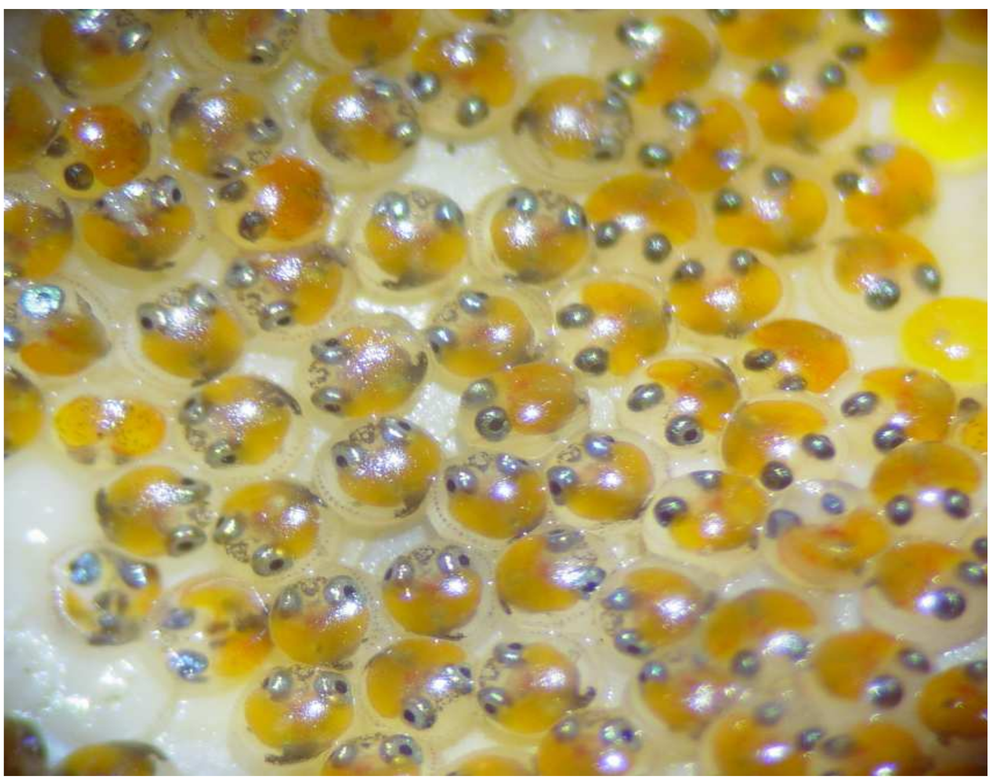

Figure 8. Thousands of fish eggs were deposited onto new shellfish reef material deposited into Pumicestone Passage, but only in subtidal areas.

These preliminary trials also found that invertebrates such as crabs were 4 to 5 times more abundant in oyster shells held in subtidal collectors compared to intertidal collectors. These experiments not only provide data to assist development of proof of concept for restoration of subtidal shellfish reefs in Southern Queensland, but they also suggest improvements in fish and invertebrate biomass upwards of 500-1000% (or more) could be expected if subtidal shellfish reefs could be restored in Southern Queensland on a large scale. This would be a result similar to previous shellfish reef restoration projects conducted overseas such as oyster reefs in the United States (Peterson et al. 2003, Kroeger 2012) and mussel reefs in New Zealand (McLeod et al. 2013).

Direct economic benefits that are likely to accrue from conducting shellfish reef restoration projects are mainly in the area of increased fisheries productivity through improvements in habitat (increased area of biogenic and hard reef) and water quality (Creighton et al. 2015). The latter has also been shown overseas to generate significant improvements in other ecosystem services (e.g. improved water clarity from shellfish feeding results in seagrass regeneration due to improved light penetration). In the longer term indirect economic benefits through increased fishing and wildlife associated tourism may also accrue. Shellfish reefs are also proven to be useful for control of coastal erosion, which may provide substantial benefits in avoided damage to coastal properties in the future if sea level rise due to warming climate continues at the present rate. Indeed, even if the economic benefits of avoided damages to property are ignored, economic analyses done in the USA suggest oyster reef restoration projects provide excellent return on investment (ROI) ratios of 2.3 or more (Kroeger 2012).

10.9 Protecting and Managing Shellfish Reefs

Aboriginal people were living in coastal areas of Southern Queensland for thousands of years prior to European settlement. They practised a marine economy, in accordance with traditional Aboriginal Law (Moreton and Ross, 2011), including farming of rock oysters (Ross 1996). The pristine condition of shellfish resources in Southern Queensland at the time of European settlement is proof that Traditional Owners practiced sustainable exploitation of shellfish resources, which speaks volumes for the stewardship and resource management abilities of the Traditional Owners of the region.

But time moves on, and today coastal regions of Southern Queensland are amongst the fastest growing human population centres in Australia. This rapid and unprecedented growth has had massive impacts on coastal resources in the region, with subtidal shellfish reefs being one of the earliest casualties of this development as evidenced by the 1891 peak in rock oyster production (Section 10.6). Examination of this decline using epidemiological principles suggests that sedimentation, eutrophication and declining water quality have modulated recruitment and disease processes resulting in what we currently see today with functional extinction of shellfish reefs in Southern Queensland (Diggles 2013, Section 10.7). An important step towards managing, protecting and restoring shellfish reefs in Southern Queensland to regain their important and much needed ecosystem services 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 ecosystem changes over the past 125 years, natural recruitment has been interrupted and the subtidal shellfish reefs in the region can no longer restore themselves by natural processes. Active intervention is required if shellfish reefs are to be restored in Southern Queensland, but encouragingly small scale trials have shown that it is possible to begin the reef restoration process if shellfish recruitment can be kick started again in subtidal areas (Section 10.8).

Given that natural recruitment in subtidal areas is constrained at present by adverse environmental conditions, perhaps the most important management arrangement that needs to be recognized, if restoration efforts are to go ahead, is that restored subtidal shellfish populations would need to be "no take". To realize the full value of their ecosystem services, shellfish in restored subtidal shellfish reefs should not be harvested for human consumption, but would be restored into the ecosystem solely for environmental remediation and as fish habitat (i.e. "natural artificial reefs").

10.10 Action Plan

- Identify priority areas in Southern Queensland for repair. Based on historical records, one priority area would be Pumicestone Passage, as it was one of the areas with historically highest densities of subtidal shellfish reefs. Pumicestone Passage is also situated close to the Bribie Island Aquaculture Centre (if artificial enhancement is required) and is managed as a recreational only fishing area, which would easily be adapted to fulfil requirements for no-take of subtidal oysters. See www.restorepumicestonepassage.org for more details.
- Other priority areas shortlisted for repair would include the Southport Broadwater, north and east of Russell Island in Southern Moreton Bay, Maroochy River and Noosa River, the Great Sand Straits and the Narrows north of Gladstone Harbour.
- At the first chosen (most favourable) priority area, liase with the indigenous community, fishing groups and other stakeholders, government authorities and the wider community to identify suitable sites for restoration and obtain permissions to conduct research trials at the most suitable sites. Criteria for site selection processes should include literature review of location of historic shellfish reefs, conduct underwater surveys to identify suitable areas of hard bottom in water >2-3 meters deep at low tide to ensure no disruption of navigation while maximizing survival of the target shellfish species (this will also make it difficult for the public to destock reefs).
- Obtain sufficient funding to undertake a rigorous scientific approach to the trials.
- Determine current extent of oyster recruitment at different levels above and below the low tide mark using standardized spat collection methods, and conduct baseline surveys of fish and shellfish population species composition, biodiversity, biomass and disease status at the chosen site(s).
- Commence restoration trials. Examine several different methods of shellfish reef construction (different materials, structure/relief/water depth, regularly maintained or set and forget). If natural shellfish recruitment is still effective subtidally, provision of clean spat settlement materials at the correct time of year may be all that is required to begin regenerating reefs. However, if natural recruitment is absent hatchery reared spat (QX resistant in the case of Sydney rock oysters) may be needed to rapidly build up subtidal shellfish reef formations into 3 dimensional reef structures.
- Conduct scientific monitoring of shellfish growth, survival, diseases, water quality (clarity, nutrient assimilation etc.) and fisheries productivity (fish numbers, catch rates, seagrass coverage) to quantitate the effectiveness of the restoration process. Also conduct scientific monitoring in the laboratory and field to quantitate carbon and nitrogen uptake to provide data upon which to develop environmental offset models.

- If the concept can be proven on a small scale by establishment of functional subtidal shellfish reefs in the study area which are accompanied by improvements in fisheries production or water quality, these data can then be used to justify and inform estuary restoration efforts at larger scales in the other priority areas and then ultimately throughout Southern Queensland, potentially using funding derived in part from developers using environmental offset models.

10.11 Concluding Comments

Loss of shellfish reefs represents a significant loss of ecosystem services to the estuaries and bays of Southern Queensland. These environmental losses have been accompanied by substantial social and economic losses that have been related to declines in inshore oyster and fisheries productivity over the past 125 years. But what is not widely recognized is the full extent of the devastating loss of cultural heritage that has been experienced by the Traditional Owners of Southern Queensland. Restoration of shellfish reefs therefore 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 the following 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

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