The history of benthic change in Pelorus Sound (Te Hoiere), Marlborough

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Executive summary

A review was undertaken of information relating to historic changes to the seabed (benthos) of Pelorus Sound (Te Hoiere). Significant changes appear to have occurred to the benthos of Pelorus Sound, including; loss of extensive intertidal and subtidal green-lipped mussel reefs, loss of biogenic habitats, and contingent changes to sediment structure. Factors most likely to have driven these changes are; over-fishing of shellfish stocks (dredging and hand-picking), contact fishing methods (shellfish dredging and finfish trawling), increased sedimentation from changing land-use over time, and ongoing aquaculture and forestry developments.

On-land, the Pelorus Sound has undergone significant historic deforestation, timber extraction, livestock farming, gold mining, with ongoing effects from land development and forestry. These factors must have contributed significant quantities of sediment to aquatic environments. The lack of innate recovery of biogenic habitats including mussel reefs is likely the result of a combination of habitat change from fishing preventing recruitment of for example juvenile mussels, and decreased water quality and clarity from increased sedimentation compounded by re-suspension of disturbed homogenised sediments laid bare of shellfish. Benthic primary production likely has suffered at the expense of pelagic production. Similar change has occurred in other areas of New Zealand and wild shellfish are in decline globally.

Anecdotal accounts report changes to finfish species abundance and composition, with reductions in numbers of large predators including rig, snapper, and crayfish. As reported elsewhere in New Zealand and overseas, removal of apex predators and engineering species like crayfish and mussels can lead to “trophic-cascade effects”, altering finfish species composition and benthic communities over time. Despite continued growth of mussel farm area granted for farming, there were anecdotal reports of declining mussel farm growth rates and production levels, as compared with early memories. A recent hind-casting analysis however shows that recent production declines and increases could be predicted from particulate-nitrogen estimates derived from environmental and climate data. Some interviewees expressed concern that the health of the Pelorus Sound was at a tipping point.

This review was prompted by concerns about ongoing demand for aquaculture space and its cumulative effects, and also a desire to explore the equivalency of effects from wild extinct mussel reefs versus effects arising from farmed mussels. There is however scant literature devoted to such comparisons probably as a result of the global decline in wild shellfish stocks. Rather, a very recent review of the use of shellfish to mitigate eutrophication from land-based effects was cited. The conjectured differences between wild and farmed shellfish effects stem from the likely disproportionate accumulation of biodeposits (faeces and pseudofaeces), fouling organisms, shell and the shading effects on the benthos from suspended mussel farms. These changes in-turn can affect composition of infauna and nutrient exchange pathways to and from the benthos. However the literature on nitrogen cycling by shellfish provides contrasting results, which varied in orders of magnitude among sites, seasons and growing conditions. Generally, the ability of shellfish to mitigate anthropogenic nitrogen (N) loads in estuaries is best achieved where nutrient loads are relatively low and quality of habitat is abundant, but shellfish aquaculture rarely enhanced denitrification. The international review led to the conclusion that more data was required using a consistent approach to understand the relative benefits and effects of shellfish farms on nutrient dynamics in coastal systems. Other literature reviews examining benthic effects from shellfish aquaculture concur that impacts on infaunal communities beneath mussel farms are limited in magnitude except at sites

suffering poor flushing and high stocking densities. Such growing conditions would however likely negatively affect productive mussel farming.

As there are knowledge gaps in the role of shellfish in nutrient cycling, restoration of mussel reefs would be first required to make valid comparisons in Pelorus Sound. From the lack of innate recovery of mussel reefs after the cessation of dredging, it appears that the system has undergone a regime shift, perhaps created by a bottleneck from the lack of suitable settlement substrata or because the water quality at settlement sites is such that juveniles can no longer survive. This change may have taken decades to occur – a shifting baseline – resulting from an apparent gradual change to seafloor habitats to those dominated by silty sediment that has occurred over decades in Pelorus, such that what exists today does not closely resemble historical benthic communities and sediment composition.

Recommendations:

- Any restoration efforts should explore the benefits of using waste shell to enhance sediment stability, biogenic habitats and mussel stocks.
- To facilitate educating the public and stakeholders about the significance of historic change, a sediment coring study should be undertaken to identify and apportion the land-use changes that have contributed to historical and contemporary sedimentation in Pelorus and to establish a benchmark of the sediment structure and shellfish composition before major impacts occurred.
- Explore the potential to use mussel yield statistics versus modelled yield estimates as an indicator of tipping points or degradation in the system.
- If possible, a hind-casting of early mussel growth rates and production during the first decade of the mussel industry may be useful to compare with early memories suggesting loss of carrying capacity over time.
- While benthic effects from mussel farms are reported to be relatively benign, site selection criteria should maximise water exchange, and seek to protect benthic primary production and functional diversity. Farm management should also seek to optimise stocking densities at low flow sites likely to suffer from high deposition rates to reduce benthic nutrient loading. Such measures should enhance resilience of the benthos and also maximise mussel production potential.
- With the potential for increased sedimentation with predicted effects of climate change, any measures that can be taken to protect and enhance the resilience of the Pelorus should be encouraged, otherwise the rate of degradation related to sedimentation especially, will likely increase.
- To guard against failure to anticipate regime shifts that will have potential negative environmental, social and economic outcomes; managers, scientists and stakeholders would benefit from discussions on the aims of long term monitoring, what to measure, when and how often.

1 Introduction

Marlborough District Council (MDC) has requested a review of available information relating to historical changes to the seabed (benthos) of Pelorus Sound (Te Hoiere). Anecdotal information has arisen during marine farm consenting processes, focus group discussions, and advisory group meetings raising questions about whether ‘shifting-baselines’ have occurred in Pelorus Sound. That is, has gradual change to seafloor habitats occurred over decades, such that what exists today in supposedly unimpacted locations is no longer the same as historical benthic communities and sediment composition? The answer to this question could affect management decisions relating to marine farming and benthic effects. Such debate, in the absence of information, forces the local authority to take a precautionary approach, favouring an anti-development outcome.

Additional questions raised included:

- What were the seafloor habitats in the Pelorus Sound prior to major human-induced impacts?
- How ecologically important and widespread would biogenic habitats including green-lipped mussels have been?
- What ecological functions and roles would biogenic habitats have had?
- How were these habitats impacted over time?
- What prevents them from widespread re-establishment?
- Does the current extent of mussel farms and associated shell deposits- have a broadly equivalent ecological role as benthic habitats to historical green-lipped mussel beds?
- What different cumulative effects do existing mussel farms have at a bay and Sound scale, such that carrying capacity can be determined at these scales?
- If harvested shells were returned to the seabed, where and how should they be re-deposited?
- How would shell deposition affect ecological values of soft sediment habitats?
- What research would be suggested to monitor the effects of shell return, if any?

2 Methods

The approach for this report was to undertake wide ranging searches for historical information relating to marine and land-use changes in Pelorus. To achieve this, search engines; Papers Past (http://paperspast.natlib.govt.nz), Google and NIWA’s library catalogue were used, along with information previously collected for similar exercises in the Nelson region (e.g., Handley and Brown, 2012; Handley, 2006). To address knowledge gaps, interviews were conducted with long-term Marlborough Sounds residents, fishers and aquaculturists. Historic maps of shellfish beds were scanned and geo-rectified in GIS using ArcMap (10.2.1), before digitizing locations or extent of shellfish beds.

3 History of Pelorus Sound

3.1 Geological setting

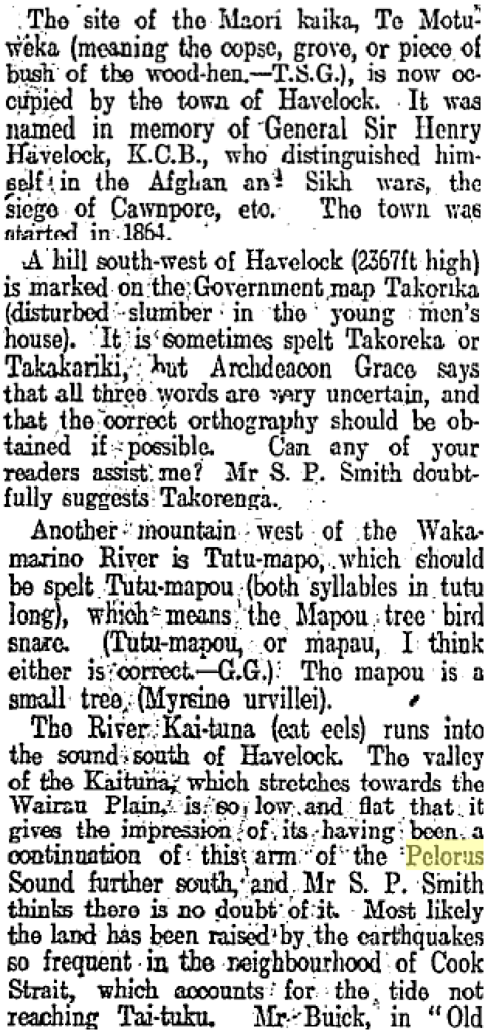
The Marlborough Sounds consist of a series of narrow river valleys that have been submerged by the sea due to sea-level rising some 140 metres higher than during the peak of the last ice age 14,000 years ago, and the subsidence of the Marlborough Sounds area north of the Wairau Fault (Davidson and Wilson, 2011). The rock substrata of the Sounds is composed of metasedimentary rocks that vary in texture, with the lowest being most metamorphosed (Lauder, 1987). The rock type has been described as the Haast or Marlborough Schist Group which are aligned in bands to the northeast. Weathering of weaker mineral bands in the schist produces planes of weakness prone to deep and surficial slippage with sediment detritus of characteristically flat (platy) form. Overlying the schist is a layer of hardened sandstones and siltstones as greywacke and argillite atop the Pelorus Group (Lauder, 1987). Sediments derived from the Pelorus Group are more blocky than platy.

3.2 Land-use change

Māori and European historians recount early occupation of the Marlborough Sounds, including the presence of a race of people that lived in pits high above the beaches, possibly the work of Moriori (Ponder, 1986). Early tribes settling in the Nelson Marlborough region included Rapuwai, Waitaha, Ngāti Wairangi, Hāwea, Ngā Puhi, and Ngāti Māmoe (Ponder, 1986; Walrond, 2012). Accounts by James Cook from 1770 noted that the land was sparsely occupied and "they [Māori] cultivate no parts of the land". Although not reported by Cook, there is evidence that Ngati Mamoe cultivated the shoreline flats (Lauder, 1987). When the first settlers, the Harvey family, sailed and rowed into Clova Bay, Manaroa in 1849, the bush was intact, being dominated by majestic podocarps including kahikatea (*Dacrycarpus dacrydioides*), totara (*Podocarpus totara*), matai (*Prumnopitys taxifolia*) and rimu (*Dacrydium cupressinum*) (Ponder, 1986) with beech (*Nothofagus* sp.) on the steeper land (Lauder, 1987). At altitudes above about 550 m, rimu were rare or absent and the forests comprise mainly mixed beech and kāmahi (*Weinmania racemosa*) with some southern rata (*Metrosideros umbellata*) (Laffan and Daly, 1985).

The human history of the area told by Ponder (1986) recounts the inner Pelorus having been largely abandoned by early Māori inhabitants during conquest raids of north island iwi led by Te Rauparaha from Kāwhia in the north in 1828. The early accounts of the Harvey family support that there were few inhabitants in the area at the outset of European colonisation, and that the land and bush was intact apart from the presence of goats and pigs that had been previously introduced by Cook. The early European settlers first cleared the flattest land available to build dwellings and to start farming cattle for milk and sheep for meat. The abundant shellfish and fish, and wild pigs and goats were an important part of the diet of the early settlers, along with knowledge of edible native vegetation.

Although Picton was an active settlement in 1854, it wasn't until 1860 that Havelock at the head of the Pelorus Sound was established where it became a service centre for nearby gold mining developments and later for milling and shipping of timber.



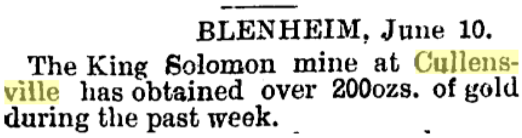
The site of the Maori kaika, Te Motuweka (meaning the copse, grove, or piece of bush of the wood-hen.—T.S.G.), is now occupied by the town of Havelock. It was named in memory of General Sir Henry Havelock, K.C.B., who distinguished himself in the Afghan and Sikh wars, the siege of Cawnpore, etc. The town was started in 1864.

A hill south-west of Havelock (2367ft high) is marked on the Government map Takorika (disturbed slumber in the young men's house). It is sometimes spelt Takoreka or Takakariki, but Archdeacon Grace says that all three words are very uncertain, and that the correct orthography should be obtained if possible. Can any of your readers assist me? Mr S. P. Smith doubtfully suggests Takorenga.

Another mountain west of the Wakamarino River is Tutu-mapo, which should be spelt Tutu-mapou (both syllables in tutu long), which means the Mapou tree bird snare. (Tutu-mapou, or mapau, I think either is correct.—G.G.) The mapou is a small tree (Myrsine urvillei).

The River Kai-tuna (eat eels) runs into the sound south of Havelock. The valley of the Kaituna, which stretches towards the Wairau Plain, is so low and flat that it gives the impression of its having been a continuation of this arm of the Pelorus Sound further south, and Mr S. P. Smith thinks there is no doubt of it. Most likely the land has been raised by the earthquakes so frequent in the neighbourhood of Cook Strait, which accounts for the tide not reaching Tai-tuku. Mr Buick, in "Old [1]

Gold was first discovered in the Wakamarina River that flows into the lower Pelorus in the 1860's with a significant claim developed in 1864 (Ponder, 1986). Gold was also discovered at Mahakipawa in 1888, between Havelock and Linkwater, which supported the town of Cullensville occupied by over 1,000 miners (Lauder, 1987). A section of 2 miles of creek bed at Cullens Creek in the Mahakipawa Arm was worked for a short period but suffered from periodic flooding and associated debris which had to be cleared to continue the workings. The Wakamarina mine likely contributed significant sediment discharge to the upper Pelorus Sound via the lower Pelorus River, migrating down-river over a period of years. Gold prospecting also likely took place at other sites in Pelorus including Nopera and Kenepuru (Handley pers. observ.). Gold-dredging also took place in Mahakipawa Arm:



BLENHEIM, June 10.

The King Solomon mine at Cullensville has obtained over 200ozs. of gold during the past week. [2]

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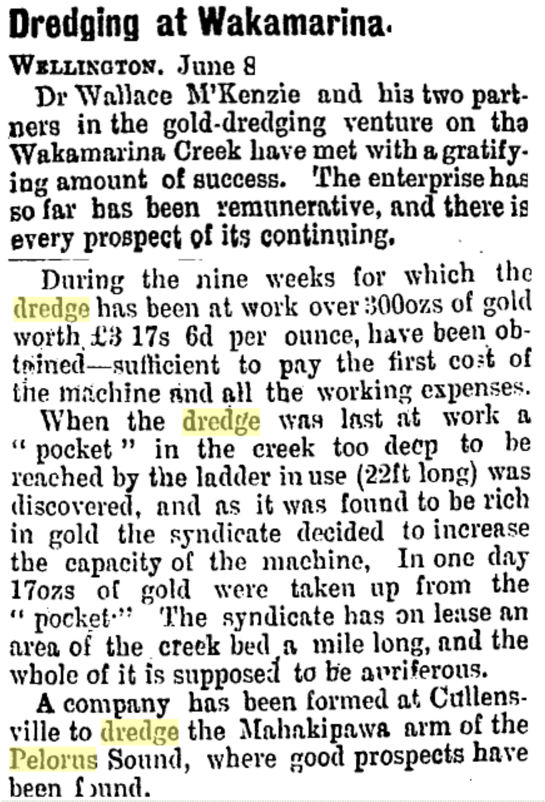
[1] Māori Nomenclature: Otago Daily Times , Issue 15205, 26 July 1911, Page 10

[2] Timaru Herald, Volume LVIII, Issue 1777, 11 June 1895, Page 3



Dredging at Wakamarina.

WELLINGTON. June 8

Dr Wallace M'Kenzie and his two partners in the gold-dredging venture on the Wakamarina Creek have met with a gratifying amount of success. The enterprise has so far has been remunerative, and there is every prospect of its continuing.

During the nine weeks for which the dredge has been at work over 300ozs of gold worth £3 17s 6d per ounce, have been obtained—sufficient to pay the first cost of the machine and all the working expenses. When the dredge was last at work a "pocket" in the creek too deep to be reached by the ladder in use (22ft long) was discovered, and as it was found to be rich in gold the syndicate decided to increase the capacity of the machine. In one day 17ozs of gold were taken up from the "pocket." The syndicate has on lease an area of the creek bed a mile long, and the whole of it is supposed to be auriferous.

A company has been formed at Cullensville to dredge the Mahakipawa arm of the Pelorus Sound, where good prospects have been found.

[3]

Land clearance, including felling and milling of timber was a common part of these early developments. Timber extraction was the usual method of financing the development of pastoral farming (Clarke, 2014). Many timber mills sprang up in Pelorus between 1900 to 1960 with nearly two thirds of the 1,480km^2 native bush catchment of the Marlborough Sounds estimated to have been logged from the flatter lands by 1910 (Bowie, 1963; Laffan and Daly, 1985; Lauder, 1987). The hills were also burned to develop into pasture. Mill sites included Kaituna, Havelock, Nydia Bay, Kenepuru, Grove Arm, Kaiuma, Manaroa, and Tennyson Inlet. The population of the Sounds is thought to have peaked at the turn of the century, with pastoral farming peaking by about 1910. By 1880, the hill slopes up to 100 and 300 m elevation were cleared of bush (Bowie, 1963). After heavy rains, surface slips were common; with more than 30 large slips observed along a 10 km stretch of hillside between Broughton Bay and Portage in Kenepuru in 1930's (Lauder, 1987). From a study of erosion of similar steep slopes in Reefton, a disproportionate sixty percent of the sediment discharged from clear-felled land originated from track surfaces or the loose soil and gravel accumulations which were sidecast onto the steep slopes below forestry tracks during their construction (Lauder, 1987; O'Loughlin et al., 1980). In contrast, the use of fire following bush clearance, created ash and wood debris that filtered the water, encouraging rapid growth of grass, fireweeds and liverwort which restricted sediment transport on lower slopes (O'Loughlin et al., 1980). It is thought that the fertility for pastoral farming initially came from the burning the bush (Clarke, 2014). Soil stratigraphy and composition predisposes the Marlborough Sounds to increased erosion from track construction as the subsoils are more erodible, and the clays more dispersive, than the upper soil layers (McQueen et al., 1985). The range of grain sizes delivered to the coast (from fine to coarse) increased the closer the erosion takes place to the shore, and also the steeper the land adjacent to the coast (Lauder, 1987). By the 1950's the fertility of the land had declined

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[3] Colonist, Volume XLI, Issue 9193, 9 June 1898, Page 3

necessitating the addition of artificial fertilizers to maintain farming productivity, otherwise land was abandoned and left to revert to native bush (Clarke, 2014). Accelerated siltation from the land clearance caused dramatic changes in the sea.

Following land clearance for pastoral farming, it was estimated that 5,000 ha of land has been planted with exotic forest since 1963 - mainly radiata pine (*Pinus radiata*) - with the potential for 40,000 ha of afforestation (Laffan and Daly, 1985). Total nitrogen concentrations in the topsoils of the Marlborough Sounds are low, and critically low below the top 10-20 cm, meaning if the top layer of soil is eroded, then the soil becomes deficient for exotic forest growth (Laffan and Daly, 1985). Similarly phosphorous levels are universally limited. The soils formed from greywacke and schist have moderate nutrient limitations, especially in the upper slopes of the Sounds, and soils formed from serpentine generally have moderate to severe physical and nutrient limitations for growing exotic forest (Laffan and Daly, 1985). A number of factors influence the profitability of forestry in the Marlborough Sounds, including; market forces, isolation and environmental costs. Environmental issues arising from forestry include impacts on water quality, transport and visual landscape issues (MDC, 2008). Although forested catchments generally have lower rates of sediment discharge to the marine environment, forestry can increase erosion of soils during track construction and development, and during harvesting (Davidson et al., 2011). It was estimated that up to 218 tonnes of sediment per square km could be eroded from roadways during logging operations in the Sounds each year (Fahey and Coker, 1992) with sediment discharge increasing as much as five times following logging truck movements over roads consisting of weathered schist (Coker et al., 1993). Sediment in the adjacent waters could climb to 1,000 milligrams per litre compared to background levels of 15-20 milligrams per litre (Fahey and Coker, 1992) where it quickly settles out on the seafloor (Davidson et al., 2011). Increased sediment loading may have profound effects on marine biota (Airoldi and Virgilio, 1998; Cole and Babcock, 1996; Estes et al., 1989; Schiel and Foster, 1986). Recent observations following Easter 2014 storm-related damage from well-managed and well-maintained forestry blocks in the Marlborough Sounds, demonstrated that even under good management, good operators cannot protect the environment from rain storm damage (MDC, 2014b).

3.3 Sedimentation

Once sediment reaches the sea, it is transported, depending on grain size via freshwater inflows, tides and currents. There are complex tidal, estuarine and wind-driven circulation systems in the Pelorus. The mean residence time for the Pelorus channel is approximately 21 days, compared with approximately 6 days in Kenepuru (Gibbs et al., 1991a). Embayments off the side of the main channel tend to flush more readily, as opposed to the longer residence times of embayments that are affected by local circulation patterns that alter tidal circulation. The Pelorus Sound is frequently characterised by stratified estuarine circulation, especially during winter and under high river flow events (Gibbs et al., 1991a). Under high freshwater flows, sediment is transported seaward, whereas under low flows sediment is transported with the ebb and flood tides predominantly landward to the head of the Sounds. Sediment thickness in channel profiles is not considered a useful index of sub-regional sedimentation rates due to the role of hydraulic scour (Lauder, 1987). Pre-human mean sedimentation rates, were estimated at 1.24 mm/yr, in Nydia Bay at 1.17 mm/yr, and in nearby Tennyson Inlet at 1.83 mm/yr (overall mean: 1.41 mm/year, Lauder, 1987). Carter (1976) reported that due to hydrodynamics, the Pelorus acts as a double-ended sediment trap, with sedimentation greatest at the head of the Sounds, and at the entrance where seston (live and dead particulate matter) is delivered from the Cook Strait on flood tides. However, Lauder (1987) cautioned that as the mean sedimentation rate calculated for the inner Pelorus profiles is 0.96 mm/year, which he considered significant, meant that as the sub-bottom (i.e., original river valley) lies close to present sea-level in the inner Sound, it offers limited scope for thick sediment accumulation in the presence of tidal scour. The seabed mud layer follows the sub-bottom profile, suggesting a balance in control between the morphology of the original river valleys and tidal processes of sediment redistribution. Also, the significance of embayment trapping may exceed the importance of Sound-head trapping of fine sediments delivered to the coast. At the head of the Pelorus, there is an extensive shallow delta built by sediment from the Pelorus and Kaituna rivers covering 18 km^2 (Carter, 1976).

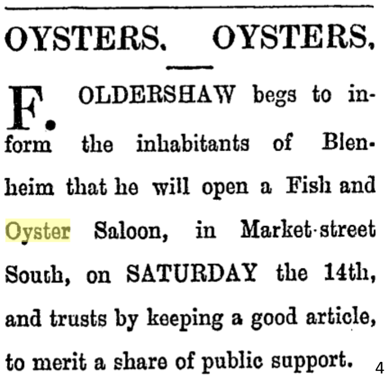
The sediments of Pelorus comprise terrigenous (land-based), biogenic (once living), and indeterminate components (Carter, 1976). Mean shell content in the coarse fraction of offshore samples was 22% and lower (20%) in Pelorus samples. Nearshore shell content of sediments was lower at 10.7% (Lauder, 1987). The fine biogenic component is mostly derived from individual and colonial diatoms, which constitute up to 20-33% of the seston (floating biological detritus) at the entrance of Pelorus indicating higher diatom productivity there (Carter, 1976). The terrigenous and indeterminate components transported in bottom waters are greatest at the head of the Sounds, tapering off rapidly to about a third of the way down the Sound, then tapering more slowly to the entrance. Grain-size evidence shows that Pelorus Sound sites have lower sand contents and Kenepuru Sound sites higher clay contents, but that marginal bays were found to contain a full range of the sediment sizes - sand, silt, and clay.

It has been found that the supply of particulate nitrogen (N) material or seston from Cook Strait differs by season, being driven by climatic factors affecting supply of N off the West Coast (Zeldis et al., 2013). The patterns in seston supply, which comprises important food for invertebrates like greenshell mussels, can be predicted using physical factors. In summer a negative Southern Oscillation Index (SOI), north-north-west winds, and cool sea surface temperature (SST) were correlated with offshore upwelling of nitrate-nitrogen rich water off the entrance to Pelorus Sound which is pushed into Pelorus under NNW winds (Zeldis et al., 2013). As nitrate-nitrogen is a limiting nutrient, this supply stimulates increased growth of phytoplankton and zooplankton (particulate nitrogen production) resulting in greater mussel growth inside Pelorus Sound. In winter however, particulate nitrogen is not related to offshore upwelling, but instead is related to the Pelorus River flow, where the river creates estuarine circulation with the less-dense freshwater flowing over the top and drawing in deeper seawater at the head of the entrance of the Sound (Gibbs et al., 1991b). Vertical stability of the water column can have a major influence on nutrient supply, phytoplankton growth, and light levels, with year to year variability linked to variability of stratification of the water column (Inglis et al., 2000). Therefore, the supply of particulate nitrogen material potentially available as a food source, or destined for deposition to the sediments has the potential to vary seasonally and inter-annually depending on climate driven differences in rainfall in winter, and fluctuations in the SOI affecting wind stress (Zeldis et al., 2013).

3.4 History of Pelorus fishing

3.4.1 Shellfish fisheries and mussel reefs

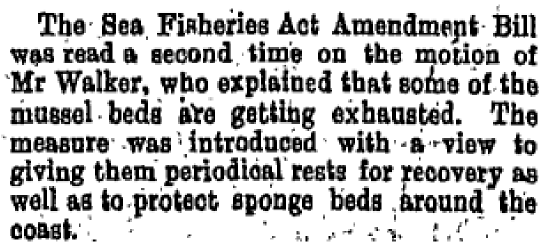
Reports of early fishing in Pelorus are scant. Shellfish including mussels: the green-lipped mussel (*Perna canaliculus*) the blue mussel (*Mytilus galloprovincialis*), fan mussel (Pinnidae), and the horse mussel (*Atrina zelandica*) were an important component of the diet of Māori (Best, 1929; Smith, 2011). Early accounts of shellfish exploitation in Pelorus are rare, but intertidal mussels were likely a first meal for the first European Harvey family on arrival in Crail Bay (Ponder, 1986). Reports of oyster bars in Nelson and Blenheim suggest shellfish sales were part of a thriving local economy from 1859 until over-fishing took its toll by the early 1900’s (Wright 1990).



OYSTERS. OYSTERS.

F. OLDERSHAW begs to inform the inhabitants of Blenheim that he will open a Fish and Oyster Saloon, in Market-street South, on SATURDAY the 14th, and trusts by keeping a good article, to merit a share of public support. [4]

The extent of early shellfish beds can only be conjectured. Early accounts indicate that mussel beds covering soft-sediment and rocky intertidal were present in many harbours throughout New Zealand (Chisholm, 2005; Handley and Brown, 2012; Paul, 2012). Either by necessity or for profit, shellfish were clearly targeted by early settlers, hand-picked from foreshore, or dredged from the seabed. Little is known regarding the structure of the marine environment during European settlement, but there is increasing evidence that overexploitation of fisheries resources was apparent by the turn of the 19th century (Anderson, 2008; Handley and Brown, 2012; Smith et al., 2009). An excerpt from the Nelson Mail (1896) illustrates that mussels were considered over-exploited near the turn of the 20th century in Tasman Bay, Nelson, and that sponge beds were common around the coast, and appeared to be regarded as worthy of protection along with mussels. Because of the associated concern regarding sponge beds, we assume that mussels were being harvested by dredge.



The Sea Fisheries Act Amendment Bill was read a second time on the motion of Mr Walker, who explained that some of the mussel beds are getting exhausted. The measure was introduced with a view to giving them periodical rests for recovery as well as to protect sponge beds around the coast. [5]

Despite this early period of exploitation in Nelson, the first official fisheries records for greenshell mussels was 21 sacks harvested from Tasman/Marlborough in 1958 (Paul, 2012). The first scallop (*Pecten novaelelandiae*) dredging license was issued in 1961 (Dawber, 2004), although Nelson mussel beds appeared to have been exploited before the scallop fishery took precedence. It is unclear whether mussels were a preferred culinary delicacy over scallops in the early days of dredging, or that the scallop beds and their markets developed after the removal of the more abundant and accessible mussels. A preliminary survey of mussel stocks in the Pelorus in 1968-‘69 reported that the Pelorus was first commercially dredged in 1962 by a boat from Havelock (Stead, 1971b). Dredging removed the “crust” of mussels in Kenepuru exposing the underlying mud bottom (Clarke, 2014).

Demand for wild Marlborough mussels came from the Greek population in Australia and the Auckland markets faced with dwindling mussel stocks in the Hauraki Gulf - Firth of Thames (Dawber,

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[4] Marlborough Express, Volume XXVII, Issue 44, 21 February 1891, Page 3

[5] Nelson Evening Mail (1896) Mussel and sponge beds protected. Volume XXX, Issue 156, 3 July, Page 2

2004; Paul, 2012). Similarly, indicating the fragile nature of the Marlborough mussel beds, Stead's (1971b) preliminary survey reported that the commercial sized beds off Skiddaw and Weka Point in Kenepuru Sound already showed signs of depletion (Figure 3-1). Large "old-growth" mussels were also harvested from the outer Pelorus at Forsyth Reef and transported to the North Island via Paremata (Dawber, 2004). Catches from grounds off Skiddaw in 1967 declined, but boats continued to fish at Weka Point. The mussel beds were never thick in the more coarse "dirty" grounds off Skiddaw, but formed a very thick carpet in the upper Kenepuru Grounds, especially in Waitaria Bay (Chris Guard, pers. comm.). By 1968 up to eleven boats were dredging for mussels in Pelorus. Some boats would wait until extreme high tide and fish with their 4 ft dredge so close to shore that their masts would get ensnared in overhanging tree branches. Stead (1971b) commented that conservation of the stock was eventually driven by a fear that "the depletion of the mussel fishery might be detrimental to snapper fishing and thus to the tourist trade." To conserve mussel stocks, in 1968 the area within harbour limits (Tawero Point to Whakamahawahi Point) was closed to dredging, with only hand gathering of mussels permitted apart from during a closed season between 30 November to 1 March. Hand picking produced prolific hauls, with 28 wooden boxes (70-80 lb each) in a single low tide in Waitaria Bay (Chris Guard, pers. comm.). These mussels were never a particularly prized product, and Nelson sales were poor, with the majority being sold in Marlborough via Wairau Fisheries or Tom Reeves Fisheries. Otherwise the mussels were sent to Picton to be shipped to the North Island. Green-lipped and blue mussels were found scattered throughout the inner Pelorus out to Breatrix Bay in the late 1960's (Figure 3-1).

It was in 1968 that the first experiments with mussel farming rafts were undertaken in conjunction with Victoria University in Wellington. A follow-up mussel survey in December 1969 confirmed that most of the areas holding commercial densities of wild mussels in Pelorus had already been dredged and exhibited signs of depletion (Stead, 1971a). The two main areas of dredged mussel beds consisted of mud, broken shell and coral substrate off Skiddaw, and an area of mud bottom north-east of Weka Point in Kenepuru Sound (Stead, 1971b). Mussel distribution was considered patchy, and more dense close inshore. Large mussels often exceeded 70 m^{-2}. A conservative estimate of the area covered by the mussel grounds surveyed by (Stead, 1971b) (and calculated herein), is approximately 350 ha, but this excludes the intertidal distribution recorded on most headlands in the inner Pelorus (Figure 3-1), so an upper estimate could be in the order of 2000 ha. Size distribution of greenshell mussels differed between sites, and from intertertidal to subtidal. All very small mussel recruits (<5 mm) were found amongst adults in intertidal beds on rock substrate, with no <5 mm recruits found on mud, stony, or shell-coral substrate in the subtidal. Stony and mud substrate appeared to hold the largest mussels, and Kenepuru dredged beds had the highest meat to shell ratio. Dredging of the beds was considered by John Greenway of Fisheries Management Division as the equivalent to harrowing a field, with the subsequent collapse of the Pelorus beds, a natural result of such exploitative harvesting (Dawber, 2004). Even though intertidal mussel stocks dwindled, the hand picking of mussels continued well into the 1970's during the early development of mussel farming (Chris Guard, pers. comm.).

The first recorded surveys of scallops in Pelorus were by Mike Bull during his studies as a Doctoral Student at Victoria University between 1973 and 1974. His study had the aim of providing "a contribution to better management of the fishery for this species" (Bull, 1976). Bull described and mapped the preferred habitat, spawning cycle, larval recruitment and growth rates of the scallop mainly from the outer Pelorus Sound area (Bull, 1976, Unpub.) (Figure 3-2). Scallop landing statistics in the early days of the fishery were lumped together with Nelson Bays production, so it is difficult to determine yields from Pelorus (Francis and Paul, 2013). The history of the Nelson/Marlborough scallop fishery was highlighted by a maximum production of 1,000 tonnes meat weight recorded in the 1970's (Francis and Paul, 2013; Handley, 2006). This production subsequently crashed, leading to the closure of the fishery between 1981 and 1982 (Francis and Paul, 2013). In 1983 enhancement trials proved very successful (Arbuckle and Metzger, 2000) leading to large scale reseeding of juvenile scallops caught from larval settlement in mesh spat bags suspended under marine farms, with landings again peaking by the late 1980s. The enhanced fishery was managed by the Challenger Scallop Enhancement Co., and by 1992 the Southern Scallop Fishery was introduced into the Quota Management System (QMS). Under the QMS an Annual Allowable Catch is set for the fishery each year, contingent on a pre-season biomass survey. Reseeding of spat collected in both Tasman and Golden Bays is followed by a two year growing period, and harvesting of scallops in a rotational cycle among nine statistical reporting fishing areas (Arbuckle and Metzger, 2000). The scallop fishery was managed spatially by rotational fishing of sectors annually until 2005/06 when the Tasman Bay stocks declined and enhancement of juvenile stocks also failed. After 2007, commercial harvest of scallops was largely restricted to Golden Bay, west of the exclusion zone, and the Marlborough Sounds (Mitch Campbell, Challenger Scallop Enhancement Co., pers. comm.). There is a great similarity in modern distribution of scallop biomass estimates (Handley, pers. observ, Challenger Unpub. Data, 2013) with historical beds recorded by Bull (Figure 3-2).

Dredge oysters (*Tiostrea chilensis*), whilst present in mussel reefs in Pelorus, were small and rare (Stead 1971b), and did not appear to be targeted by fishers. Like Pelorus, Tunbridge (1962) noted that as much of the seabed in Tasman and Golden Bay is mud, dredge oyster and mussel settlement was probably limiting, and that in order to enhance both fisheries for commercial exploitation "thought could be given to the deposition of a suitable substance on the grounds prior to settlement" (Tunbridge, 1962,Handley, 2006). Similarly, Greenway (1969) stated that dredging of the Hauraki Gulf left an unstable muddy substrate unsuitable for mussel attachment, precluding natural bed regeneration (Paul, 2012). The return of mussel shells or heavier oyster shells was suggested as a mechanism to provide cultch for settlement, because laboratory experiments showed that dredge oyster larvae settle equally on weathered oyster, scallop or mussel shells (Brown, 2011a)., However, there is some doubt as to whether returning shells alone will lead to recovery of mussel beds, as observations from the Firth of Thames (Hauraki Gulf) in 1961 suggested that mussels preferentially attach to other live mussels (conspecific settlement) or recently dead shells, rather than old shells (Paul, 2012; Scott, 1963). Also, mussel spat catching experiments in the Firth of Thames by McLeod (2009) caught very few spat on shells and on hairy spat ropes, although uncertainty around methods could render this work inconclusive[6].

Potentially overlooked, horse mussels (*Atrina zealandica*) dominated most dredge tows in preliminary green-lipped mussel surveys by Stead (1971b).

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[6] Spat ropes were reported as being agitated in fresh water to detach spat (McLeod 2009). The preferred spat counting procedure used by NIWA (N. Davey unpub. data.,) and Buchanan and Babcock (1997) used dilute hypochlorite solution to dislodge the spat from spat ropes.

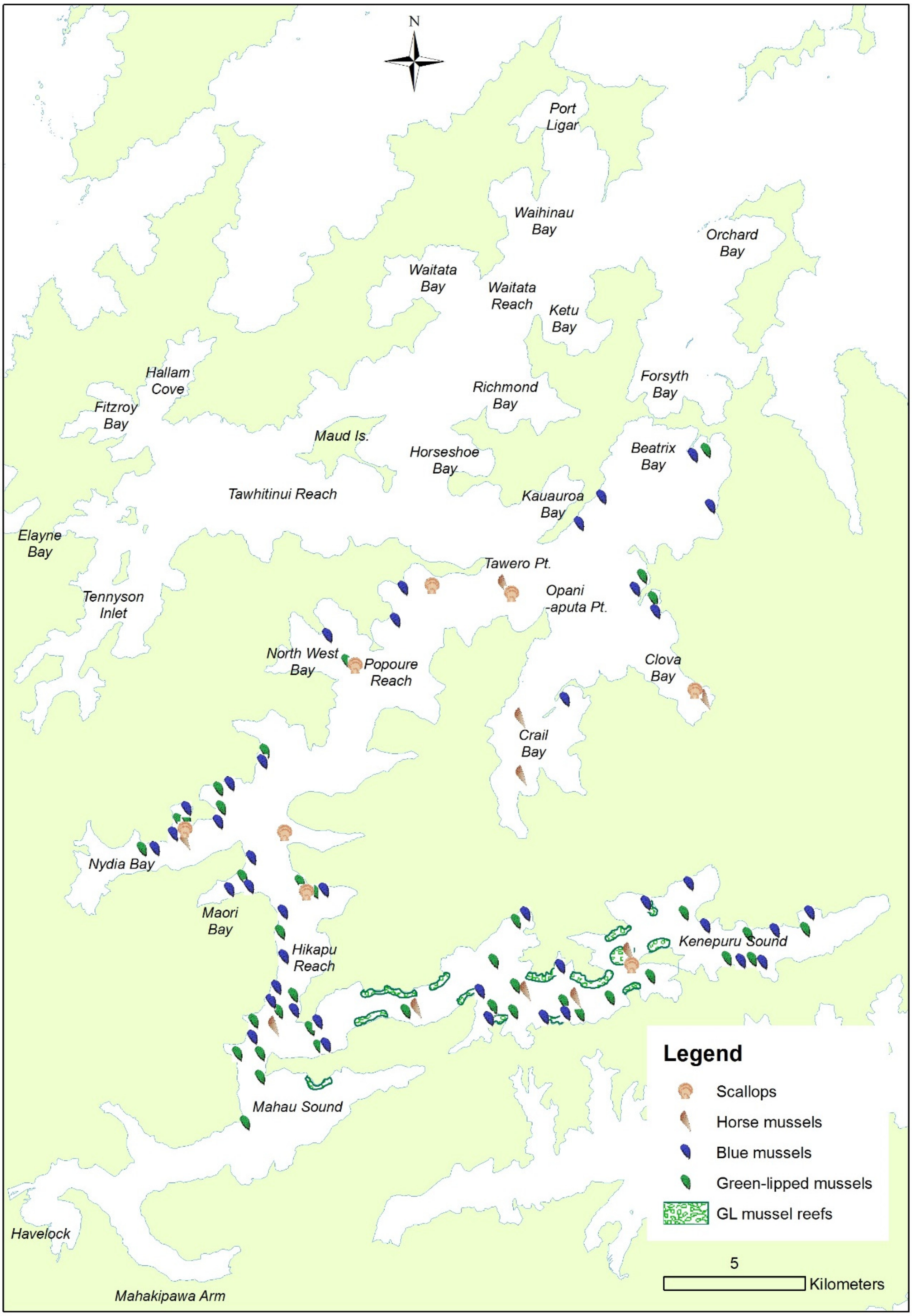
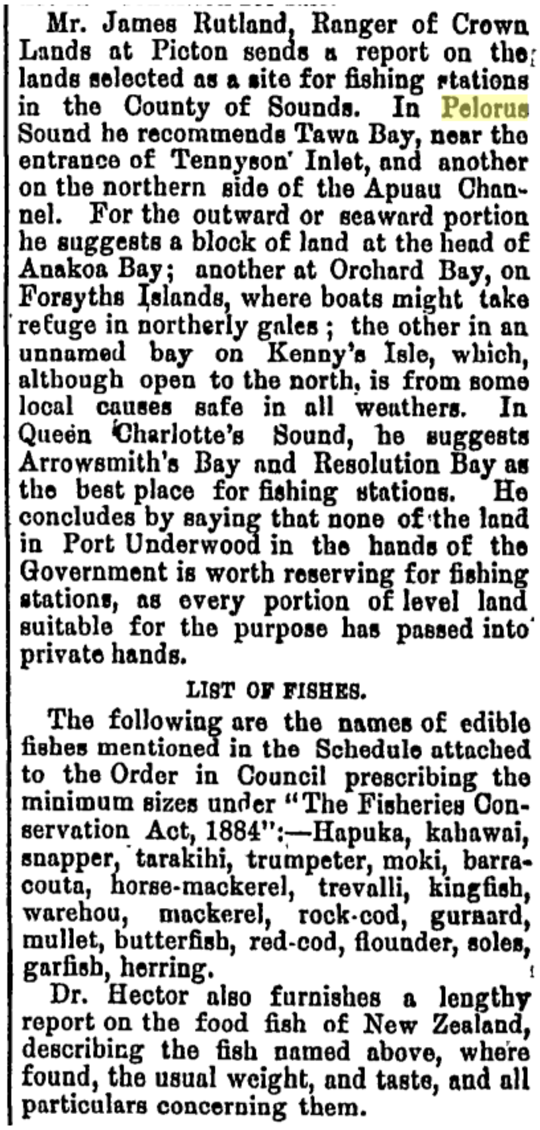


Figure 3-1: Historic shellfish beds from Pelorus Sound (excluding large scallop beds). Sources from: (Stead, 1971a, b) and Davidson et al. (2011). GL = green-lipped.

Figure 3-2: Historic scallop beds in Pelorus Sound. Sources from: Bull (Unpub.); (Stead, 1971a, b)

3.4.2 Finfish fisheries

A great variety of fish have been recorded in the Marlborough Sounds, and early settlers advocated for the establishment of fishing stations to exploit the early abundance:



Mr. James Rutland, Ranger of Crown Lands at Picton sends a report on the lands selected as a site for fishing stations in the County of Sounds. In Pelorus Sound he recommends Tawa Bay, near the entrance of Tennyson' Inlet, and another on the northern side of the Apuau Channel. For the outward or seaward portion he suggests a block of land at the head of Anakoa Bay; another at Orchard Bay, on Forsyths Islands, where boats might take refuge in northerly gales; the other in an unnamed bay on Kenny's Isle, which, although open to the north, is from some local causes safe in all weathers. In Queen Charlotte's Sound, he suggests Arrowsmith's Bay and Resolution Bay as the best place for fishing stations. He concludes by saying that none of the land in Port Underwood in the hands of the Government is worth reserving for fishing stations, as every portion of level land suitable for the purpose has passed into private hands.

LIST OF FISHES.

The following are the names of edible fishes mentioned in the Schedule attached to the Order in Council prescribing the minimum sizes under "The Fisheries Conservation Act, 1884":—Hapuka, kahawai, snapper, tarakihi, trumpeter, moki, barracouta, horse-mackerel, trevalli, kingfish, warehou, mackerel, rock-cod, gurnard, mullet, butterfish, red-cod, flounder, soles, garfish, herring.

Dr. Hector also furnishes a lengthy report on the food fish of New Zealand, describing the fish named above, where found, the usual weight, and taste, and all particulars concerning them. [7]

Species in order of abundance netted at Te Mako estuary, Duncan Bay over a 33 year period (1971-2004) included: kahawai (*Arripis trutta*), warehou (*Seriolella brama*), yellow-eyed mullet (*Aldrichetta forsteri*), yellow-belly flounder (*Rhombosolea leporina*), snapper (*Pagrus auratus*), blue mackerel (*Scomber australasicus*), rig (*Mustelus lenticulatus*), barracouta (*Thyrsites atun*), spotty (*Notolabrus celidotus*), dab or sand flounder (*Rhombosolea plebeia*), grey mullet (*Mugil cephalus*), jack mackerel (*Trachurus novaezelandiae*), blue cod (*Parapercis colias*), trevally (*Pseudocaranx georgianus*), red mullet (*Upeneichthys porosus*), elephant fish (*Callorhynchus milii*), gurnard (*Chelidonichthys kumu*), red cod (*Pseudophycis bachus*), eagle ray (*Myliobatis tenuicaudatus*), red snapper (*Centroberyx affinis*), skipjack tuna (*Katsuwonus pelamis*), carpet shark (*Cephaloseyllium isabella*), spotted stargazer (*Genyagnus monopterygius*), leatherjacket (*Meuschenia scaber*), porcupine fish (*Tragulichthys jaculiferus*), ihi or garfish (*Hyporhamphus ihi*), short-tailed stingray (*Dasyatis brevicaudatus*), and sunfish (*Mola mola*) (Bray and Struick, 2006). Pilchards or sardines (*Sardinops*

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[7] Taranaki Herald, Volume XXXIII, Issue 6798, 3 July 1885, Page 2

neopilchardus) were also recorded in Tennyson Inlet as very abundant in the early days and suitable for bait and canning, and in deeper water groper (hapuku) (*Polyprion oxygeneios*) were also common (Archer, 2010).

Fish populations in Duncan Bay recorded by intertidal netting over a 33 year study have fluctuated over time in relation to season, temperature, rainfall, day/night and moon state (Bray and Struick, 2006). The population variables measured declined between 1971-1986 and 1987-2002 especially in the former period where declines were recorded as 71% decline in weight per fish, 48% length per fish, 70% number of fish caught per tide and 91% decline in weight of fish caught per tide. These declines were thought to be a result of: a large increase in unregulated Foreign Fishing Vessels (FFV) between 1968 (20,000 t) and 1977 (500,000 t); a rapid increase in domestic commercial and recreational fishing and the use of new technology; destruction of nearby benthic communities by trawling and dredging, and; an increase in farmed mussels and wild Pacific oysters (*Crassostrea gigas*) in Pelorus Sound which feed on the plankton base of the food chain (Bray and Struick, 2006). A collapse in the dominant species, rig, from 1971-1974 (58% and 65% of the biyearly percent weight per tide) to no rig present from 1979-80 to 1987-88 was followed by the occasional appearance of rig with a low total weight per tide after 1990. The rig appeared to be replaced by kahawai. Increases in abundance recorded more than once were for short-lived species like flounder and grey mullet.

Bray and Struick (2006) noted that FFV were observed in Tennyson Inlet until 1978 when the Exclusive Economic Zone (EEZ) was declared.

> “In 1978 in Tennyson Inlet, Mr R. Winstanley (P.c.1978) saw three FFV trawlers working near Maud Island and Dr E. Twose (p.c.1978) saw a Japanese purse seiner near Maud Island with a net stretched to Richmond Bay [ca.4 km]. One possible effect of the FFVs was noted by Mr N. Andrews (p.c.) of Tuna Bay, who had fished the area since 1955. He stated that before the early to mid 1970’s you were guaranteed a snapper meal whenever you went fishing, but not thereafter.”

As fish stocks became depleted, not all the pressure on the fish resource of Tennyson Inlet was from FFVs as confirmed by Bray and Struick (2006) and by Chris Guard (pers. comm.) whom recounted of people illegally fishing the area. Anecdotally, illegal practices included trawling at night, fishing in closed areas, the use of dynamite, and nets stretching from Maud Island to the mainland. The deregulation of the inshore fisheries in 1963 led to depletion of inshore fisheries especially between 1965-1975 until recovery in the early 1980s following the introduction of the Quota Management System. The effects of trawling and dredging are thought to have altered benthic habitats:

> “Mr J.H. King-Turner of Canoe Bay, Tennyson Inlet has told us (p.c. 1993) he observed a long term decline in the bottom flora and fauna, including some fish species, of his bay over the previous 30 years. He thought the decline might be due to scallop dredging, bottom trawling, over fishing and the increased number of boats with anti-fouling chemicals on their hulls.” (Bray and Struick, 2006).

At present Danish seining is prohibited in and around the entire Marlborough Sounds (Baxter, 2012). Bottom trawling is prohibited in Queen Charlotte Sound, Tory Channel and inner Pelorus Sound; inside Tawero Point and within Tennyson Inlet and neighbouring Fitzroy Bay and Hallum Cove. Commercial scallop dredging occurs throughout suitable grounds in Waitata Reach down to Maud Island and especially in Ketu Bay. There is relatively little trawling undertaken within the enclosed parts of the Marlborough Sounds (Baxter, 2012). The great majority of effort in the Marlborough

Sounds is in the outer Sounds from eastern D'Urville Island through to Cape Lambert. As fishers want to avoid ensnaring their trawl gear on emergent rocks and reefs, trawling is unlikely to take place on the steeper sloping bottoms found closer to shore or along the sides of the main channels, thus fishing which is generally located a reasonable distance offshore where the bottom begins to shelve out (Baxter, 2012).

3.5 Biogenic[8] habitats in Pelorus

The first published shellfish surveys were carried out by (Stead, 1971a, b) over the summer of 1968-'69 using a shellfish dredge. He reported finding broken shell and "coral" offshore from Skiddaw in the lower Kenepuru consisting of several hundred square yards 45 to 90 metres in ca. 10 m depth. This habitat was commercially dredged for green-lipped mussels. Densities of large mussels in the intertidal exceeded 70 m^{-2} on some exposed rocky headlands in Kenepuru and Nikau Bay, but also occurred individually or in clusters along cobble and boulder-strewn beaches. It is unclear what the "coral" habitat reported by Stead (1971b) was, but it is likely that it may have been formed by rodolith beds. Rodoliths are calcified red coralline algae that can form large beds, like those that still occur in Picnic Bay, in the outer Pelorus (Davidson et al., 2011) and off Rock Point, Catherine Cove, D'Urville Island (Handley pers. observ). Rodoliths or maerl are thought to be important in providing complex three dimensional structures and habitat for other invertebrates and fishes, and are vulnerable to shellfish dredging (Hall-Spencer and Moore, 2000). Today, intertidal blue mussels are relatively common covering up to 80% cover in Queen Charlotte Sound when measured as part of Ferry Wake monitoring, whereas in Pelorus green lipped mussels are almost absent intertidally and blue mussels only achieve as little as 10% cover at some sites (Rob Davidson, pers. comm.). Pacific oysters (*Crassostrea gigas*) also invaded the inner Pelorus after being first recorded in the Marlborough Sounds in 1979 (Jenkins & Meredyth-Young, 1979, Jenkins 1979). Pacific oysters became abundant in Kenepuru Sound during the 1970-'80's on stony beaches and rock outcrops, but recently have declined and appear restricted to soft sediment intertidal habitat where they likely cannot be easily predated by oyster borers (*Haustrum* sp.) (J. Jenkins, pers. comm., Handley, pers. observ.).

Other biogenic habitats have been noted in the Pelorus including the headlands of Tapapa Point, Tawero Point and Kauauroa Bay which contain habitat forming bryozoans, sponges, ascidians, horse mussels and hydroids fed by strong tidal currents (Davidson et al., 2011). Horse mussel beds are also found in Clova Bay and in the Bay between Ellie Bay and Wet Inlet in Crail Bay, and a tiny sea pen species *Virgularia gracillima* is found in Little Nikau Bay (Davidson et al., 2011). Horse mussels (*Atrina zelandiae*) appeared relatively common in Pelorus around the time of early mussel fishing (Stead, 1971b). Large surface dwelling shellfish like horse mussels have been described as important ecosystem engineers as they provide settlement surfaces for other species, filter large amounts of water sequestering sediment and nutrients, and modifying neighbouring macrofaunal communities (Hewitt et al., 2002; Norkko et al., 2001, 2006) (Figure 3-3).

Although seagrass beds may be patchily distributed in the smaller estuaries and bays of Pelorus, for example in Duncan Bay (Bray and Struick, 2006), extensive seagrass beds are now only present in the well flushed areas of the lower Havelock estuary between Cullen Point and Shag Point (Stevens and Robertson, 2014). At Havelock, saltmarsh extent, consisting mostly of rushlands (95%), has been reduced by 15% since 1999 largely from historic estuary drainage (Lauder, 1987), the removal of ca.50 ha of introduced *Spartina*, reclamation and channelization with ongoing activities such as that

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[8] Produced from living organisms or biological processes

in the upper tidal reaches between the Pelorus River channels where drainage and infilling is apparent (Stevens and Robertson, 2014).

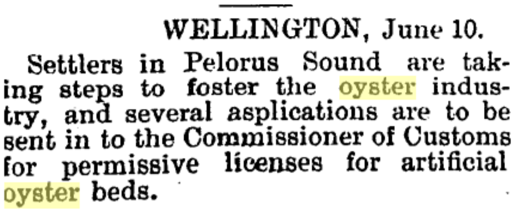
Figure 3-3: Shellfish provide settlement surfaces: A a dredge oyster growing red algae, **B** a scallop with benthic diatom film atop, **C**: a horse mussel encrusted with sponge, coralline algae, and being grazed by an 11-arm starfish and a kina, **D** green-lipped mussels encrusted with tube worms.

In Environmental Protection Agency (EPA) hearing evidence related to finfish farm developments in the Marlborough Sounds, Baxter (2012, Department of Conservation) considered that the value or significance of muddy habitats/communities should not be based solely on matters such as abundance/quantity, diversity or productivity, rather they form part of the natural biotic patterns which occur alongshore and offshore, and are also important in terms of forming or shaping the natural character of the coastal marine environment. Examples of areas in Pelorus with high indigenous biological diversity (biodiversity) include a rodolith bed, a horse mussel bed, a red algae bed, elephant fish spawning areas, and certain estuaries, subtidal reefs and high current habitats. Four significant stretches of coastline not habited by large numbers of mussel farms include: Tennyson Inlet (47 km of coast); western Nydia Bay – Wilson Bay (apart from three mussel farms on the northern side of Fairy Bay, 51 km of coast); Apuau Channel to Waitata Bay, including Maud Island (apart from three farms approved for sponge and seaweed culture between Treble Tree Point and Reef Point [sponge and seaweed culture has little effect on the seabed], 28 km of coast); and, Richmond Bay–western Forsyth Bay (apart from one mussel farm on the northern side of Richmond Bay, 21 km of coast) (Baxter, 2012). These four areas are the remaining examples of “natural character” in the mid-outer Pelorus where marine alongshore biotic patterns remain largely intact over tens of kilometres.

With the development of scuba diving in the 1960’s, the resulting drastic decline in lobster (*Jasus edwardsii*) appeared to cause kina (*Evichinus chloroticus*) populations to “explode resulting in major habitat changes to the exposed shores of the outer Sounds" (Clarke, 2014). Availability of cheap outboard powered boats later resulted in overfishing of blue cod (Clarke, 2014), presumably having other, unmeasured food-chain effects.

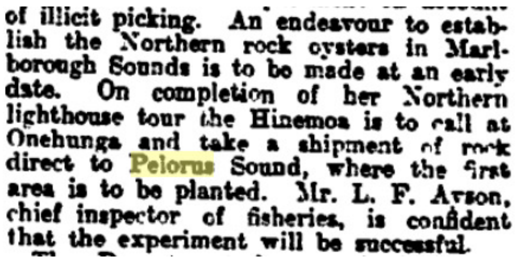
3.6 History of aquaculture in Pelorus

The artificial culture or aquaculture of shellfish has a long history in Pelorus, much longer than formerly realised. The following newspaper accounts depict the introduction of rock oysters from the North Island to Pelorus Sound for intertidal cultivation in the late 1800's.

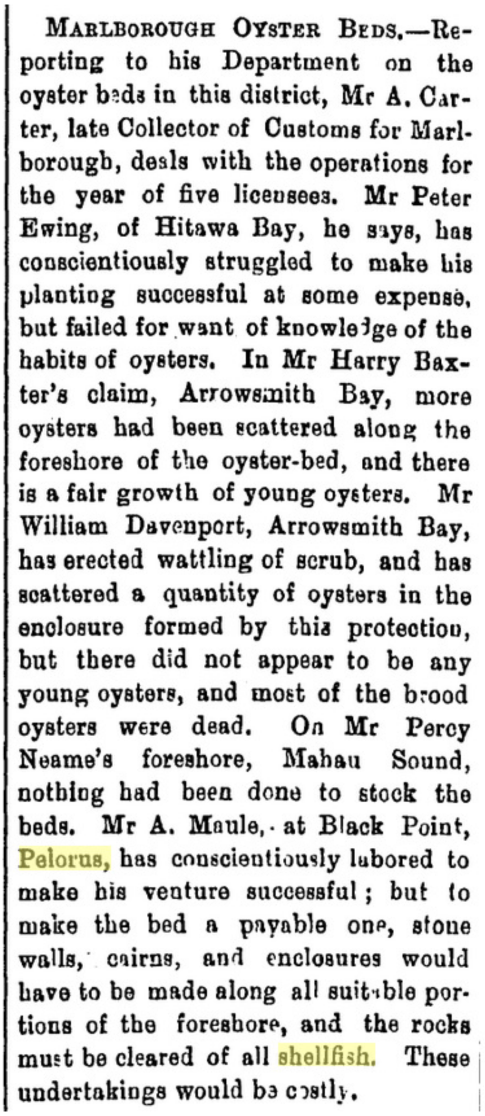


WELLINGTON, June 10.

Settlers in Pelorus Sound are taking steps to foster the oyster industry, and several asplications are to be sent in to the Commissioner of Customs for permissive licenses for artificial oyster beds. [9]



of illicit picking. An endeavour to establish the Northern rock oysters in Marlborough Sounds is to be made at an early date. On completion of her Northern lighthouse tour the Hinemoa is to call at Onehunga and take a shipment of rock direct to Pelorus Sound, where the first area is to be planted. Mr. L. F. Ayson, chief inspector of fisheries, is confident that the experiment will be successful. [10]



MARLBOROUGH OYSTER BEDS.—Reporting to his Department on the oyster beds in this district, Mr A. Carter, late Collector of Customs for Marlborough, deals with the operations for the year of five licensees. Mr Peter Ewing, of Hitawa Bay, he says, has conscientiously struggled to make his planting successful at some expense, but failed for want of knowledge of the habits of oysters. In Mr Harry Baxter's claim, Arrowsmith Bay, more oysters had been scattered along the foreshore of the oyster-bed, and there is a fair growth of young oysters. Mr William Davenport, Arrowsmith Bay, has erected wattling of scrub, and has scattered a quantity of oysters in the enclosure formed by this protection, but there did not appear to be any young oysters, and most of the brood oysters were dead. On Mr Percy Neame's foreshore, Mahau Sound, nothing had been done to stock the beds. Mr A. Maule, at Black Point, Pelorus, has conscientiously labored to make his venture successful; but to make the bed a payable one, stone walls, cairns, and enclosures would have to be made along all suitable portions of the foreshore, and the rocks must be cleared of all shellfish. These undertakings would be costly. [11]

Today, there are well over 500 marine farm sites in Marlborough, most of them within the Marlborough Sounds (MDC, 2014a). The early development of the mussel industry has been well reviewed by Dawber (2004) and will not be elaborated on herein. There is a perception by some farmers that have been involved in the industry from its outset that some of the changes relating to

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[9] Timaru Herald, Volume LVIII, Issue 1777, 11 June 1895, Page 3

[10] New Zealand Herald, Volume LIII, Issue 16398, 28 November 1916, Page 5

[11] Marlborough Express, Volume XXXIII, Issue 198, 24 August 1898, Page 2

marine farming have been positive. For example, in the later 1970's water clarity was only a few feet, and the seasonal krill blooms, and red and green algal blooms were common, whereas today 'the water is always clear' (Clarke, 2014). However, sea lettuce (*Enteromorpha* sp.) blooms were only recorded twice in a 33 year intertidal fish netting study (1971-2004) in Duncan Bay, Tennyson Inlet (10% cover) occurring for a sustained period in September 1980 and January 1981 (Bray and Struick, 2006). Clarke (2014) commented that farmed mussel stocking densities and growth rates have reduced over time, perhaps reflecting reduced productivity on the land and in the sea. Unfortunately, there are no published data on mussel growth rates prior to 1997 to verify long term changes. There has however been a steady increase in the area of mussel farm development in Pelorus over time (Figure 3-4). Analysis of mussel growth rates between 1997 and 2005 however show measured meat yield declined and then recovered, and that yield could be predicted based on modelled particulate nitrogen production data which indicated that the long term changes in mussel growth during that period appeared driven by climate variability rather than overstocking (Zeldis et al., 2013).

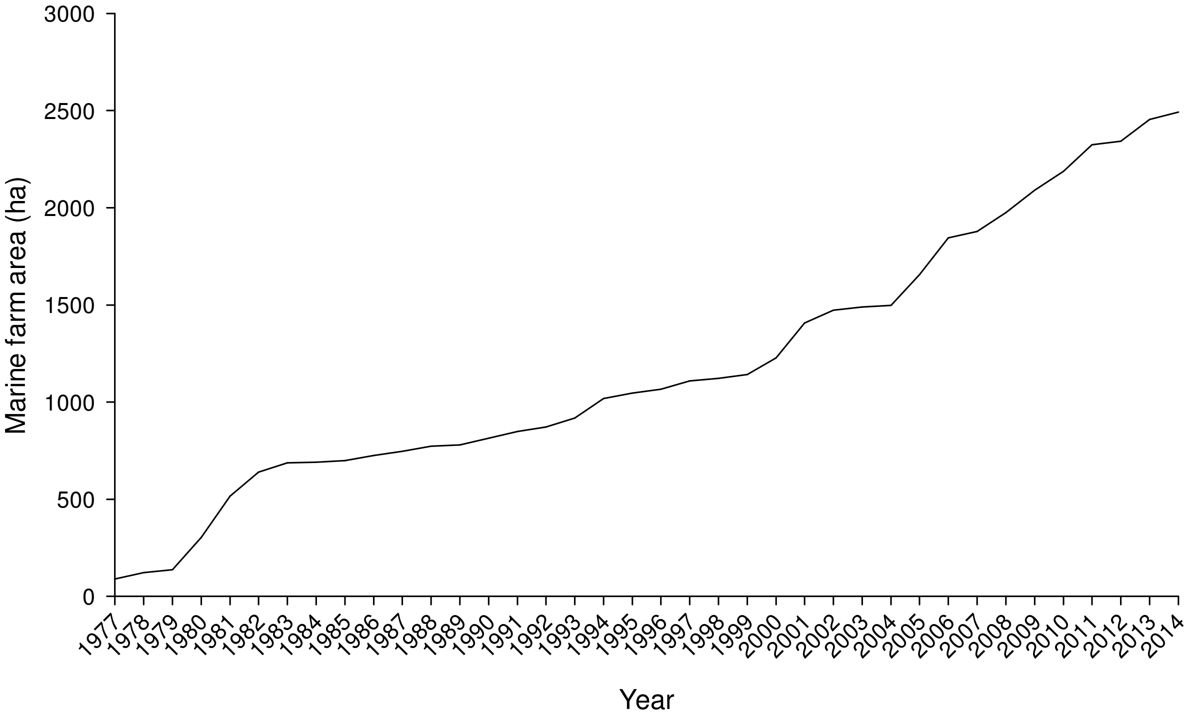

Figure 3-4: Cumulative area (ha) of Pelorus Sound marine farms with a status of "granted" by Marlborough District Council, 1977-2014.

Development of early aquaculture and forestry were shaped by various management and legislative processes that sometimes conflicted. For example, in the 1970's the Forest Service had a plan to turn the Sounds into a pine forest, whereas the Lands and Survey Department wanted it to be a National Park (Clarke, 2014). In relation to the development and management of marine farming and activities affecting it, there have been many changes to the governance role of various organisations including: the Marlborough County Council (jurisdiction stopped at mean high water mark); the Harbour Board (licensed boat sheds and jetties but did not get involved in regulatory issues involving marine farms); the Marlborough Harbour Board (appointed as the Maritime Planning Authority between the late ca. 1970's and early 1980's); the Marlborough Sounds Maritime Park board (established in late 1970's and took an interest in Marine farming but had no regulatory powers for Marine Farms); the Ministry of Agriculture and Fisheries (issued the first Marine Farm Licences); the Marlborough Regional Planning Authority (established in 1980's but they did nothing with marine farms); the Marlborough Harbour Board abolished in 1991 (their regulatory authority transferred to the Nelson Marlborough Regional Council); and then in 1991 the Nelson Marlborough Regional Council was abolished and all their powers in Marlborough were transferred to the Marlborough District Council and MDC was established as a unitary authority - the first time one Council had jurisdiction over both land and water (B. Pennington, pers. comm. to S. Urlich, MDC). Today, the Sounds landscape may reflect a random mix of decisions made by these various bodies resulting in "pockets of pastoral farms, pine forests, regenerating bush, a ribbon of buildings, with the degraded virgin bush on the tops, and mussel farms along the shore" (Clarke, 2014).

4 Benthic effects of suspended mussel farms

Marine farms in the Marlborough Sounds have tended to be placed over muddier habitats which represent the communities that are most widespread and abundant in the Sounds, and because muddier habitats and communities are considered more resilient to the effects of increased sedimentation resulting from marine farms (Baxter, 2012; DoC, 1995).

The effects of aquaculture on benthic communities have been comprehensively summarised previously (Keeley, 2013; Keeley et al., 2009; McKindsey et al., 2011) and will only be briefly reviewed herein. At the time of compilation of this report approximately 2500 ha of Pelorus Sound was occupied by marine farms, of which finfish farms represented a disproportionately small area of that space, operating in Crail Bay, Waihinau Bay and Forsyth Bay. The following brief summary therefore focusses predominantly on effects arising from suspended shellfish farms, which is the dominant consented activity in Pelorus Sound. While the effects are similar, finfish farms – or "fed aquaculture" – cause the deposition of faeces and uneaten feed, which leads to over-enrichment via organic particles reaching the seabed (Keeley, 2013; Wai et al., 2011). The principles governing the severity and spread of effects are similar, but finfish farms, because of the addition of feeds, and the nutrients they contain, add greatly to organic enrichment and smothering. Also, because of the requirement for net cleaning and net coatings, there is the potential for sediment contamination with trace metals (e.g., copper and zinc, Keeley, 2013).

Overall, the impacts from suspended shellfish farms have been described as typically limited in magnitude except under extreme conditions of poor tidal flushing or under very high stocking densities (McKindsey et al., 2011). Marine shellfish farms form a porous barrier to tidal, wind, and wave driven circulation (Plew et al., 2005; Stevens et al., 2008) and because of increased filtration capacity, they increase the deposition of faeces, pseudofaeces (un-digested material), and shell and associated fouling organisms – all additional sources of carbon and nitrogen (Christensen et al., 2003). The severity of effects on hydrodynamic circulation, sedimentation, and drop-off of fouling depends on the site, which brings other important mitigating factors into play. For example, farms exposed to large waves or currents typically produce lesser benthic effects than those sited in low flow sheltered locations, as deposited materials are dispersed more widely at exposed sites (Hartstein and Rowden, 2004; McKindsey et al., 2011). Sheltered, deep locations also typically have finer sediments at the seabed, meaning oxygenation and chemical flux in and out of the sediment is inhibited at such sites (McKindsey et al., 2011). The accumulation of shellfish and shell beneath farms may armour sediments from erosion and resuspension, further amplifying sedimentation and enrichment rates within the zone of impact (Kellogg et al., 2014; McKindsey et al., 2011; Ysebaert et al., 2009). The magnitude of benthic enrichment is a function of quantity and the digestibility of the food in the water column above the seabed, with greater deposition at sites with poor quality food and high sediment concentrations. The removal of biodeposits beneath a farm are affected by the rate of supply, initial dispersal, the rugosity (roughness) of the receiving seabed, the redistribution of biodeposits (via creep, siltation and/or resuspension) and the rate of decay of deposited material (Giles et al., 2009; Kellogg et al., 2014; McKindsey et al., 2011).

Increased quantities of biodeposits at the seabed pose both physical (smothering) and biogeochemical (microbial, geological, and chemical) effects which are interrelated (McKindsey et al., 2011). These biodeposits typically have high carbon and nitrogen content, are either eaten by deposit feeders or decomposed by microbes in the presence of oxygen (aerobic nitrification). If deposition rates are high and localised, the process of nitrification can strip the oxygen from the overlying water or surface sediments, rendering the sediments anaerobic (anoxic). Under anoxic conditions, sulphate reduction and methanogenisis of organic material can take place producing hydrogen sulphide and methane (Keeley, 2013). Hydrogen sulphide, the gas that smells of “rotten eggs”, can be toxic and enter living cells by passive diffusion (McKindsey et al., 2011). In extreme circumstances like under a poorly managed fish farm, the results of these anaerobic processes cause the sediments to be stained black and develop a whitish film or mat of filamentous *Beggiatoa* sp. bacteria at their surface. However, under a typical mussel farm in the Marlborough Sounds, organic enrichment is seldom assessed to be above low to moderate levels with ca. 7.5% enrichment of sediments (Keeley et al., 2009).

The anchoring and mooring systems of mussel farms have only a relatively small benthic footprint affecting the seabed at a small scale, but the longline and mooring structures can act as fish aggregation devices (Handley pers. observ.) and also provide habitat for fouling organisms which in-turn can also attract fishes (McKindsey et al., 2011; Morrisey et al., 2006).

An interesting outcome of mussel farms supplying accidentally deposited (drop-off) mussels to the seabed, is that live mussels seldom accumulate in large numbers under mussel farms like the former historic mussel reefs, whereas dead mussel shell readily accumulates (Davidson pers. comm., Handley, pers. observ.). The exception to this observation is live green-lipped mussels occurring at a few sites in Orchard and Forsyth Bays and Port Ligar beneath spat collection farms (Davidson, pers. comm.). It is likely that these mussels have fallen from the farm as spat and appear to have grown on the silty seabed to depths of 32 m (Figure 4-1).

A study of the recovery of the seabed previously occupied by a mussel farm retired 12 years previously in East Bay, Queen Charlotte Sound, demonstrated two types of recovery (1) species recovery (e.g., return of species displaced by mussel farms), and (2) physical recovery of the habitat/substratum (Davidson and Richards, 2014). The time frame for the recovery of species was less than the recovery of habitats. In turn the recovery of silt and clay (mud) substrata was more rapid than areas supporting coarse substratum (e.g. sorted shell and fine sand). Physical recovery of deep mud took between 5 and 11 years after the cessation of mussel farming whereas recovery of coarse soft substratum took up to 11 years after the cessation of mussel farming (Davidson and Richards, 2014).

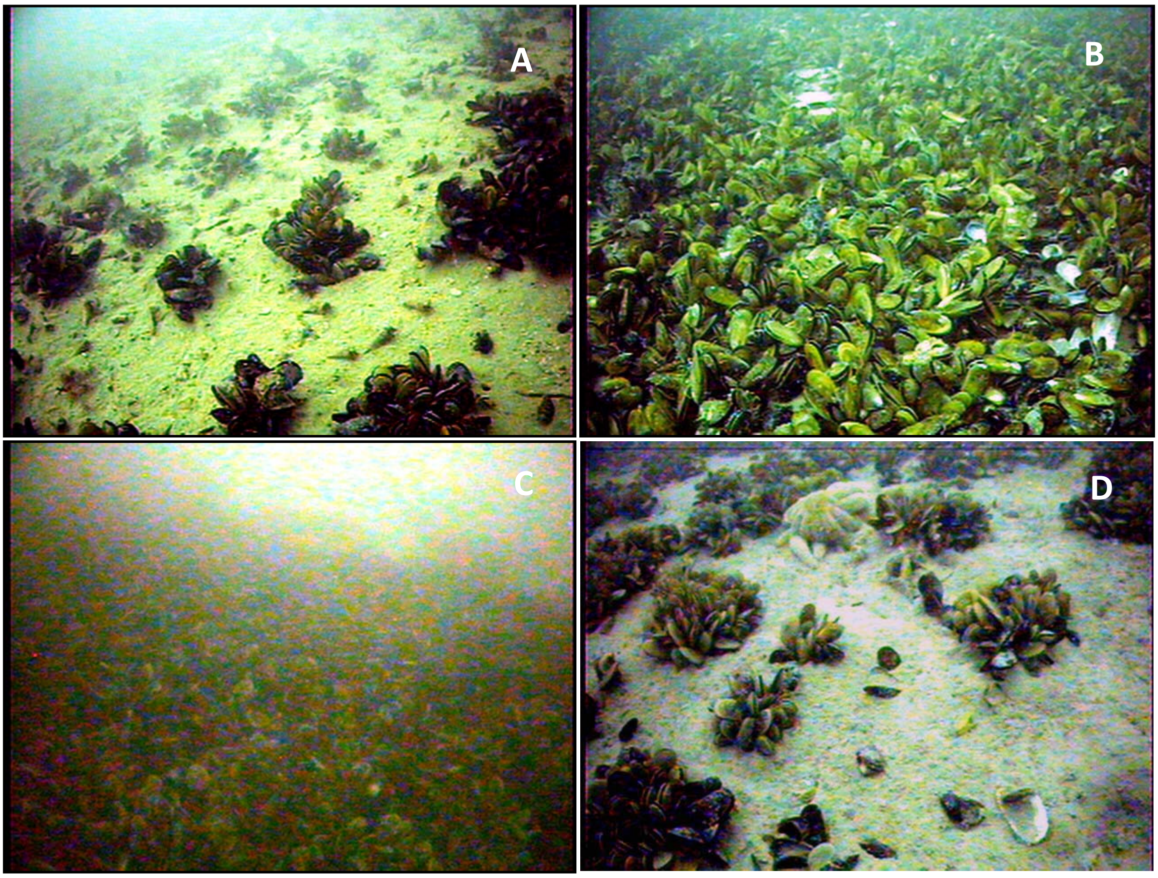

Figure 4-1: Live green-lipped mussels photographed in outer Pelorus Sound: beneath spat farms: Orchard Bay farm Pe 168 **A** 22 m; **B** 22 m; and **C** 32 m depth; and **D** Port Ligar, farm MF 197 at 27 m (Davidson and Richards 2004a & b, 2010).

4.1 Ecological role of historic mussel reefs

The loss of extensive mussel reefs has significantly altered the benthic ecosystem in many parts of New Zealand, removing hard surfaces upon which many invertebrate species settled, thus directly and indirectly impoverishing the communities preyed upon by several ecologically and economically important finfish species (Morrison et al., 2014; Paul, 2012).

All suspension-feeding bivalves filter particles, including phytoplankton, zooplankton, particulate organic matter, and inorganic particles from the water column (Peterson et al., 2010). These particles are bound up with mucus produced on the gills of the bivalves and any particles not ingested, are discharged as pseudofaecal deposits, a process that clarifies the water column, and transfers organically rich particulates to the seabed (Dame, 1996; Dumbauld et al., 2009; Newell and Koch, 2004; Peterson et al., 2010; Zeldis et al., 2004). The ability to reduce turbidity and deposit organic material depends on how densely concentrated the individuals are (Peterson et al., 2010). Mussels, although not typically forming reef structures that project up into the water column, provide complex interstitial and outward-projecting structural habitat for many marine invertebrates and modify the community composition, especially crustaceans and fish (Buschbaum et al., 2009; Paine and Suchanek, 1983; Reusch et al., 1994). Suspension-feeders help buffer shallow waters against developing and sustaining excessive phytoplankton blooms in response to anthropogenic loading of nitrogen (Officer et al., 1982) and by removing particulates from the water column they can mitigate soil erosion from catchments (Landry, 2002). Dense aggregations of shellfish can baffle water flow

(Lenihan, 1999) potentially reducing scour and resuspension of sediments. Overseas, intertidal mussel reefs have been trialled to provide coastal protection and stabilise intertidal flats in front of dikes, with variable success, but demonstrating their ability to attenuate wave energy and accumulate muddy sediment (Borsje et al., 2011; De Vries et al., 2007).

Suspension feeding bivalves benefit submerged plants like benthic diatoms and seagrass in two ways. First, they exert 'top-down' control by grazing on phytoplankton which allows greater water clarity and light penetration (Carroll et al., 2008; Everett et al., 1995; Wall et al., 2008), and secondly, they fertilize the bottom with their bio-deposits and excretion of soluble nutrients (Dame and Libes 1993, Reusch et al. 1994, Everett et al. 1995, Peterson & Heck 1999, 2001a, b, Carroll et al. 2008, Peterson et al. 2010). Soft sediment plants in-turn also provide important environmental services including providing food and nursery habitat for many commercially important fish, crustaceans, and molluscs (Heck et al. 2003, Francis et al. 2005, Peterson et al. 2010). Aquatic plants also help trap and stabilise sediments, and remove nutrients (Yallop et al. 1994, Underwood & Smith 1998, Disney et al. 2011), further maintaining water quality allowing more light to reach the seabed, again enhancing benthic photosynthesis. These interactions between filter-feeders and soft sediment plants are thought to reinforce the restoration process by enhancing water quality improvements once they have been initiated (Kemp et al. 2005).

McLeod (2009) made estimates of lost secondary small invertebrate productivity following mussel biogenic reef loss in the Firth of Thames, and found the associated small mobile invertebrate assemblages had four times the average density, seven times the biomass, six times the productivity, and greater species richness than bare sediment areas. Morrison et al. (2014) concluded that based on these estimates, a strong cascading effect to epibenthic carnivores such as fish (including fisheries species such as snapper) was highly likely. McLeod (2009) estimated that the pre-1958 mussel reefs in the Firth of Thames could have supported an additional fish biomass of between 200 to 16,000 T y^{-1} of small predatory fish above that supported by bare sediment. It was also estimated that the remnant mussel population would take more than two years to filter the entire volume of the Firth of Thames as compared with less than two days for historic populations (McLeod 2009), with historic reports of sailors being able to see the seabed sailing into Coromandel Harbour (Morrison et al. 2014).

As a potential tool for removal of nitrogen and carbon, *Mytilus edulis* mussel tissue (excluding gametes) is approximately 33% to 68% nitrogen and mussel tissue carbon can range between 32% to 70% dry weight (Rodhouse et al. 1984). The shells comprise approximately 12% to 15% nitrogen and 8% to 11% carbon by dry weight. An estimate from the Gulf of Mexico pertaining to the flow-on cost of a 20% loss of submerged aquatic vegetation attributed to eutrophication from land-based nitrogen estimated a $56USD/kg/$N_2$ loss to crab and shellfish production (Compton et al. 2011). As mussels can mitigate nitrogen inputs through sequestration (Rodhouse et al. 1984), and also provide important feedback mechanisms helping maintain benthic primary production by increasing nutrient utilisation and exchange at the seabed (Kemp et al. 2005), their economic value as ecosystem engineers is likely to be significant.

5 Discussion

It is evident that there has been significant sedimentation from erosion of the steep slopes within Pelorus Sound since European occupation of the catchments, driven by: deforestation, timber extraction, livestock farming, gold mining, with ongoing effects from land development and forestry. In addition, the seabed of Pelorus has been modified by the removal of large areas of filter-feeding green-lipped mussel and horse mussel reefs, especially in the inner Pelorus, and the seabed effects from bottom trawling and ongoing scallop dredging that likely homogenised the sediments and removed biogenic species (e.g. Handley et al., 2014c).

From the interviews conducted herein, long-term users of Pelorus Sound spoke of a trend of decreasing productivity over time. For example, a long-term user and Kaitiaki of the Sounds, could until recently not recall being unable to collect a meal of kai moana from the intertidal in Beatrix Bay (John Allen, pers. comm.). He spoke of a proverb, “when the tide goes out, the table is laid”. “But now there is nothing”. This year there are anecdotal reports from line fishers that snapper are very scarce in the Pelorus and instead, there is an overabundance of spiny-dog fish (*Squalus acanthias*) caught. The apparent decline in snapper catches over recent years has raised fears that a tipping point has occurred in the health of the Sounds (M. Connolly pers. comm.). Corroborating the observation about snapper, data from the Te Mako Bay study in Tennyson Inlet shows a steady decline in snapper abundance over 33 years (Bray and Struick, 2006). After 2006, carpet sharks (*Cephaloscyllium isabellum*) entered Te Mako Bay, and together with kahawai, contributed half to two thirds of netted fish in the last 2-3 years (G. Struik, pers. comm.). Spiny-dog fish also appeared in catches after 2006, albeit in low numbers. It appears that the composition of fish populations netted over more than 40 years has changed, with reductions in especially larger predatory sharks (rig), with a notable increase in smaller sharks. It is possible to speculate that the changes recorded by Struik are an example of a trophic cascade. For example, it has been reported that the loss of large apex predatory sharks can lead to increasing numbers of smaller sharks and rays that top predators feed on (Myers et al., 2007). A similar trophic cascade is also very likely to have occurred in the rocky reef communities of Pelorus as a result of the reductions in snapper abundance and of lobster as noted by Clarke (2014). It has been shown in marine reserve studies that at fished locations without predation of lobster and snapper, kina populations increased and created grazed barrens, with reductions in the extent of macroalgae and associated abundance of invertebrates and fish (Cole and Keuskamp, 1998, Shears and Babcock, 2002; Shears and Babcock, 2003; Eddy et al. 2014).

5.1 Factors preventing recovery of biogenic habitats including mussel reefs

The most likely factor preventing recovery of biogenic habitats including green-lipped mussel reefs is habitat change driven by seabed disturbance from trawling and dredging. Trawling and dredging cause physical disturbance to the seabed, homogenise habitats and their benthic assemblages, and reduce biodiversity (Handley et al., 2014a, c; Jennings and Kaiser, 1998; Kaiser et al., 2006; Rice, 2006; Thrush and Dayton, 2002; Tillin et al., 2006). Biogenic habitats (like soft sediment mussel reefs) are in many respects ‘self-structuring’ (Reise, 2002), as they are contingent on settlement, growth and death of large bivalves at the sediment water interface – a process akin to an evolving biogenic reef over a foundation of soft sediment (Handley et al., 2014c). Because biogenic species are fragile, they can only persist in the absence of high disturbance. As bottom fishing can homogenise soft sediments - removing, breaking up or burying shell and associated faunal assemblages - benchmarking pre-impact sediment composition is important for management (Handley et al., 2014c) and informing potential restoration efforts. Notably, maximum productivity of soft sediment habitats has been correlated with sediments containing a range of grain-sizes including shell or gravel (Bolam et al., 2013; Handley et al., 2014c). In early green-lipped mussel surveys in Pelorus, mussels were found occurring in clusters attached to empty shells or horse mussels in offshore areas (Stead, 1971b). Towards the entrance to Kenepuru at Skiddaw, mussels were also found attached to empty shells, broken coral (potentially rodoliths), and sunken branches.

Another important factor preventing innate recovery of biogenic habitats is likely to be land-derived sedimentation. A recent review of the effects of land-based effects on coastal fisheries argued that the most important land-based stressor is sedimentation, including both suspended sediment and deposition effects, and associated decreases in water clarity (Morrison et al., 2008). As little as 26 mg l^{-1} of sediment fed continuously to sponges, oysters, and mussels adversely affected their health after thirteen days (Schwarz et al., 2006). Suspended sediments were also conjectured to have serious consequences at the ecosystem level from indirect effects, through reduced epifaunal abundance, as epifauna are responsible for about 80% of the flow of energy and materials through rocky reef animal communities (Taylor and Cole, 1994). Schwarz et al. (2006) thought that it was likely that epifaunal density reductions will have knock-on effects throughout the rocky reef foodwebs, both downwards through reduced epifaunal grazing on seaweeds and algal epiphytes, and upwards through reduced availability of food for small fishes.

The relative importance of different factors hindering recovery probably vary spatially. For example Davidson (pers. comm.) proposes that physical disturbance from fishing is the most likely factor preventing biogenic habitat recovery in the outer Pelorus, whereas from Tawero Point inwards, ongoing pulses of sediment from the Pelorus River hinders recovery.

In comparison, factors that have prevented the intrinsic recovery of soft-sediment mussel beds in Tasman Bay and elsewhere are considered likely to be complex, potentially involving: over-exploitation of stocks, habitat change, reduced water quality/clarity, and food chain effects (Handley and Brown, 2012). Mussels can go through multiple settlement phases, with a “primary settlement” phase occurring as the larvae (<0.5 mm) attach to filamentous substrata like hydroids and tufting algae, and then metamorphose (Buchanan and Babcock, 1997). “Secondary settlement” occurs whereby post settlement larvae (<6 mm) drift by extruding mucus then reattaching to substrata including byssal threads in adult aggregations. The secondary settlement phenomenon is thought to be an adaptation to avoid predation of the early larval stage by adult mussels (Bayne 1964), which are capable of consuming zooplankton (Zeldis et al., 2004). In the U.S.A., mussels *Mytilus edulis* settle as larvae especially on taller reproductive shoots of eelgrass (*Zostera marina*) that provide a refuge from predators during metamorphosis (Newell et al. 2010, Disney et al. 2011). In fact, successful recruitment of *M. edulis* to seabed reefs is thought to depend on this availability of suitable primary settlement substrate provided by eelgrass. It may not be a coincidence that harbours that once contained green-lipped mussel reefs, that have failed to recover in New Zealand, also contain only remnant seagrass (*Zostera muelleri*) beds that are severely threatened – that is, the Firth of Thames (Graeme, 2006), Tasman Bay (Robertson and Stevens, 2009) and Pelorus (Stevens and Robertson, 2014). It is also intriguing that all <5 mm recruit spat collected and measured by Stead (1971b) were found amongst adults in the intertidal zone, rather than subtidally. Perhaps the wave action in the intertidal zone somehow provided necessary resources (e.g. oxygenation, food) or afforded green-shell mussel larvae protection from cannibalism. Or the spat accumulated while rafting on detached and drifting macroalgae as they do on Ninety-Mile Beach. Bull (1976) reported that scallops, which also attach themselves as larvae using byssal threads, were found in areas of the Pelorus Sound attached to brown alga *Cystophora retroflexa,* red algae attached to horse mussels *Atrina zelandica*, and drifting seagrass *Zostera* debris, however sand, mud and broken shell in the area was not colonised by scallop spat (Bull 1976). The loss of species that once provided settlement surfaces for mussels and scallops was likely driven by siltation, concomitant loss of water clarity for photosynthesis in deeper water, and bottom-contact fishing methods (Handley and Brown, 2012). For these reasons, (Handley and Brown, 2012) proposed that recruitment failure due to habitat change appears to be the most likely reason for lack of mussel bed recovery.

5.2 Mussel farm footprint vs benthic shellfish beds – a comparison

5.2.1 Benthic effects of mussel farms

As described above, mussel farms alter the composition of the seabed directly below the farms by the addition of biodeposits and also the drop-off of live mussels and associated fouling organisms. The functional changes these factors cause include a reduction in bioturbating species that have physical difficulty moving through the shell material that accumulates beneath mussel farms (NIWA unpub. data), and increases in suspension feeders, scavengers and predators (Christensen et al., 2003; Ysebaert et al., 2009; Handley, unpub. data). These effects may be driven by the increased physical complexity on the surface of the soft sediments provided by the accumulation of shell and fouling species, changes in grain size and biogeochemical differences from the accumulation of biodeposits. The effects of placing waste shell on soft sediments produces similar effects with ultimately an increase in diversity of species (Brown, 2011b).

5.2.2 Comparing farms and natural mussel beds

Suspended long-line mussel farms have known benthic effects as summarised above. The difference in the ecological effects of mussel farms compared with natural benthic mussel beds is currently unknown, and has not been previously researched in New Zealand. This may be because of a shifting baseline whereby over decades, shellfish beds have been removed from subtidal and intertidal habitats due to land-based effects and fishing, and because little attention has been raised regarding their lack of innate recovery (Handley and Brown, 2012; Handley et al., 2014b). The international literature has not attempted to tackle the question of equivalence between cultured shellfish versus natural shellfish beds, as shellfish beds are globally in decline (Beck et al., 2011; Kirby, 2004; Pauly, 1995). However, the question of equivalency has been partially addressed in the scientific literature by studies investigating the efficacy of using shellfish to remediate land-based nutrient inputs, and as part of international shellfish restoration and aquaculture literature. In the land-based nutrient remediation literature, the fate of nutrients like nitrogen (N) and phosphorus (P) have attracted greatest focus. In marine systems like Pelorus, nutrients including N and P are considered limiting nutrients, that is, during peak phytoplankton growth in warm spring and summer months, these nutrients can be stripped from the water column by phytoplankton (Elser et al., 2007; Gibbs et al., 2002). Availability of N in Pelorus is dominated by supply of particulate N from Cook Strait, with a lesser contribution from land, with the relative contribution of N sources each season influenced by climate variability (Zeldis et al., 2013).

The composition and density of fauna and flora present beneath a mussel farm and amongst an historic mussel reef would likely differ because the higher densities of mussels suspended in the water column on farms typically alter the bottom directly beneath the dropper lines. There would be a disproportionate accumulation of biodeposits and drop-off of mussels and associated fouling organisms. The accumulation of biodeposits and dead shells alters the physical composition of the affected seabed, which then affects infaunal and microphytobenthos composition and standing stock. A study of ecological benefits of remnant mussel reefs in New Zealand found that fauna were 3.5 times the density, 3.4 times the biomass and 3.5 times the productivity of bare mud, and the density of small fishes was 13.7 times higher than in surrounding areas (McLeod et al., 2014). These changes are contrasted by similar “benefits” associated with mid-water mussel culture including: 11 times the biomass of invertebrates (Brooks, 2000), positive fish associations with farm structures and fouling (Carbines, 1993; Morrisey et al., 2006), and addition of physical structure atop soft sediments that attracts hard-bottom communities increasing diversity (McKindsey et al., 2011).

5.2.3 Mechanisms affecting nutrient cycling by mussel farms

In the process of filtering suspended particles, and the production of biodeposits, suspended shellfish farms concentrate and redistribute nutrients that affect nutrient cycling in two ways: through "top-down" grazer control clearing the water column of phytoplankton and binding sediment in mucus thus allowing for increased light at the seabed; and also by "bottom-up" nutrient control on phytoplankton production (Christensen et al., 2003; Newell, 2004a; Ysebaert et al., 2009). In the former, the N and P are recycled by the regeneration of shellfish biodeposits at the seabed by aerobic bacteria (a process called "nitrification") and through direct excretion by the shellfish of soluble nutrients like ammonium (NH_4^+). These dissolved nutrients in turn can be re-utilised by benthic primary producers (macroalgae & microphytobenthos) and phytoplankton in the water column (Ogilvie et al., 2000). The standing stock of algae is directly controlled by ambient nutrient levels, unless, in the case of fin-fish aquaculture, where feed containing N and P is added (Newell et al., 2005). Although the microphytobenthos (microscopic seabed plants including diatoms) may compete with bacteria that utilise N, the microphytobenthos retain N and P within sediments, further reducing return of these nutrients the water column, thus they can play a role in inhibiting harmful algal blooms (MacIntyre et al., 2004). In the case of "bottom-up" control, shellfish change the nutrient regenerative processes within the sediment, by helping bury N and P in the sediment in the form of undigested mucous-bound biodeposits. At locations where surface sediments are aerated well, for example where there are abundant burrowing infauna that irrigate the sediment with oxygen (Christensen et al., 2003; Pelegri et al., 1994), anaerobic denitrifying bacteria (that don't require oxygen) that live deeper in the sediment can convert buried N to inert nitrogen gas (N_2). If this N_2 gas bubbles to the surface of the sediment, it can be permanently removed from the system – a process called "denitrification". This process of degassing of nitrogen to the atmosphere is important in acting as a sink for global marine nitrogen which can help regulate the amount of primary production in coastal waters (Seitzinger et al., 1980; Seitzinger, 1988). Ecosystem engineering by sediment-burrowing macrofauna stimulates benthic nitrification and denitrification, which together allows fixed nitrogen removal (Stief, 2013). If biodeposit concentrations at the sediment surface become too great, and oxygen at the sediment surface is removed by bacterial production, then hydrogen sulphide can be produced, which inhibits the activity of nitrifying bacteria which require oxygen (Kemp et al., 2005). When anoxic conditions occur, more efficient N and P recycling can occur via anaerobic pathways to be released to the water column, which further supports production of phytoplankton production including harmful algal blooms. The other problem with this process is that with the loss of oxygen, the microphytobenthos and infaunal organisms that enhance denitrification are also inhibited, and the positive-feedback nature of these interactions means that they will tend to reinforce and accelerate the eutrophication process (Kemp et al., 2005).

5.2.4 Small-scale processes causing nutrient enrichment by mussel farms

Ultimately mussel farms alter "bottom-up" N cycling in ways that cause more N to be conserved in the water column, for example in the form of ammonium, rather than being buried in the sediment or being degassed to the atmosphere as N_2 gas (Christensen et al., 2003). Ammonium is a form of N that is readily used by phytoplankton production. The increased organic content and fine particle nature of the mussel biodeposits decreases the oxygen penetration of the sediments and/or through microbial break-down, increased oxygen demand at the sediment surface. Concomitantly, the rain of faecal and pseudofaecal sediments buries the microphytobenthos reducing photosynthesis and the production of oxygen in and at the sediment surface. Combined with increased microbial demand, (McKindsey et al., 2011) this causes shallower redox levels, and the presence of sulphide-reduced sediments close to the sediment surface. With the increase in biodeposits and shell material from dead mussels, there are reductions in bioturbating species, potentially further reducing oxygen penetration depth (Christensen et al., 2003; Handley unpub. data). In addition, the presence of the farm structures shade the sediment, reducing light levels at the seabed, reducing photosynthesis and the standing stock of microphytobenthos. The outcomes of these processes include a five-fold lower oxygen penetration depth in the sediment and fourteen-fold increase in ammonium release from the sediments (Christensen et al., 2003). The questions then raised are, what are the significance of these changes to the broader Pelorus Sound, and how do these effects compare to historic benthic mussel beds?

5.2.5 Larger-scale factors increasing or decreasing nutrient cycling by mussel farms

Many factors can affect the ability of shellfish to mitigate nutrient inputs in coastal systems including: dissolved oxygen concentrations, redox depth of sediments, sediment geochemistry, nutrient concentrations of waters, seabed faunal and floral composition, farm age, shellfish stocking density, longline configuration and orientation, distance of dropper lines from the sediment, hydrodynamics and local environmental conditions, and light availability which is affected by water clarity (Giles et al., 2006; Kellogg et al., 2014; Newell, 2004b). Because of all these dependent factors, which can vary spatially and over time (diurnally-annually), it may not be surprising that the international literature concerning the benefits of shellfish being able to mitigate human induced nutrient inputs into coastal systems are not clear cut, with contrasting results reported. In the Firth of Thames NZ, measures of dissolved inorganic N levels released under a mussel farm equalled 94% of the primary production requirements, indicating how farms may affect the nutrient dynamics in at least the vicinity of farms (Giles et al., 2006). Previous comparisons of the impacts of mussel farms on denitrification rates have been inconsistent, showing both increased (Kaspar et al., 1985) and decreased (Christensen et al., 2003) denitrification in farm-affected sediments (Giles et al., 2006).

5.2.6 Implications for Pelorus Sound and farms vs reefs

In the context of Pelorus Sound, questions about equivalency of mussel farm effects versus extinct mussel reefs could be addressed at two levels: 1) in the water column whereby shellfish like mussels could be used to mitigate nutrient inputs from land-based human inputs (farming, humans, forestry) or for entrapment of nutrients delivered from outside Pelorus via oceanographic processes; and 2) regarding changes to the benthos in terms of flora and fauna, which in-turn has implications for the former - water column nutrient assimilation and cycling. Nitrogen contained in phytoplankton consumed by shellfish may be returned to the water column, assimilated into shellfish tissue and shell (to be harvested), buried in the sediments (drop-offs), or returned to the atmosphere as N_2 gas, primarily via denitrification (Carmichael et al., 2012; Kellogg et al., 2014). The difficulty is that measurements of bivalve induced N fluxes have occurred in cultured situations which can vary in orders of magnitude both within and among sites, so caution is needed when transferring results between regions (Kellogg et al., 2014). Although land-based N loads can be partially mitigated by restoring or culturing bivalves (Carmichael et al., 2012), there are knowledge gaps as to the spatial and temporal scale at which mitigation occurs (Kellogg et al., 2014). Although the microphytobenthos (microscopic seabed plants including diatoms) may compete with bacteria that utilise N, the microphytobenthos retain N and P within sediments, further reducing return of these nutrients to the water column, thus they can play a role in inhibiting harmful algal blooms (MacIntyre et al., 2004). However, it appears that the ability of shellfish to mitigate anthropogenic N loads in estuaries is best achieved where nutrient loads are relatively low and quality habitat is abundant (Carmichael et al., 2012; Kellogg et al., 2014). Denitrification may be best achieved when the benthos (macrofauna and flora) is functioning in an aerobic state with good water clarity allowing light to reach the benthos supporting benthic primary production. The converse is likely to occur under low flow situations and high biodeposition rates, where denitrification may be hindered by low oxygen levels, which will negatively affect infauna and flora. This will likely increase the release of N and P from the sediments further enhancing phytoplankton production – a positive feedback loop (Kemp et al., 2005).

5.2.7 The importance of benthic primary production and using this as a risk metric

It is not well understood what constitutes an acceptable balance between pelagic versus benthic primary production in coastal systems. Benthic microalgae, or the "secret garden" (MacIntyre et al., 1996) can be overlooked, despite them contributing very significantly to coastal food supply (Kennish et al., 2014; Valiela, 1984). For example, measures of benthic chlorophyll in the Nelson-Marlborough region were: 92, 89, and 84% of total production (benthic + planktonic) at depths of 8, 16, and 20 m, respectively in Tory Channel; and 32-51% in Tasman Bay; demonstrating benthic production can provide very significant contributions to food webs (Gillespie et al., 2000). Of concern, several studies have demonstrated that with increasing nutrient enrichment, the proportion of phytoplankton production increases and shades out the benthic production (Borum and Sand-Jensen, 1996; Staehr et al., 2012). In cases of high nutrient inputs, eutrophication can become established, driven by short-circuited nutrient cycling via anaerobic pathways, and tipping points or regime shifts can occur which tip the system into an alternate, self-reinforcing state (Kemp et al., 2005). Early warning signs of 'regime shifts' (alternate system states; Scheffer and Carpenter, 2003) include increased nutrient loadings, increases in chlorophyll concentrations and decreasing benthic primary production (e.g. Glibert et al., 2014; Kemp et al., 2005; Riche et al., 2014). To prevent excessive modifications to nutrient dynamics associated with mussel farms, Giles et al. (2006) suggested that site-specific hydrodynamic and biogeochemical conditions should be assessed along with monitoring of sediment–water nutrient fluxes. Perhaps the simplest early warning tool would be to measure oxygen and light levels at the benthos over time at high risk sites with low flows and high deposition rates, to gauge if nutrient pathways are being adversely affected. In terms of natural mussel reefs historically present in Pelorus, it is expected denitrification would have been more likely to have occurred in such reefs (c.f. nitrification or accumulation of nitrogen in the sediments). This is because mussel biodeposition rates in these reefs would be expected to be lower than under mussel farms, resulting in fewer changes to the aeration or redox depth of the sediments by infauna which may help support a healthy microphytobenthos (Lohrer et al., 2010) in the absence of shading by marine farm structures.

5.2.8 The importance of marine farm site suitability

Whilst the benthic effects of mussel farming are reported to be relatively benign, not all changes arising could be considered positive, as some studies have shown that sites with adversely elevated enrichment had reduced numbers of infaunal organisms directly beneath farms (Callier et al., 2008) and decreased species richness (Keeley et al., 2009). How these changes to the flora and fauna affect nutrient dynamics including denitrification remain to be tested. However, literature reviews concur that the impacts on infaunal communities beneath mussel farms are limited in magnitude except at sites suffering poor flushing and high stocking densities (Keeley et al., 2009; McKindsey et al., 2011), but such growing conditions would likely also negatively affect mussel farming productivity.

5.3 Summary

- Pelorus Sound was habited by various Māori tribes, whom likely benefited from abundant green-lipped, blue, fan, and horse mussels as an important component of their diets.

- Since European settlement of Havelock in 1860, resource-uses in the Pelorus Sound and river catchments have included: native forest harvesting and clearance for farmland, farming, pine forestry, gold-mining/dredging, fishing, dredging and the widespread hand-picking of shellfish.
- Oyster bars in Blenheim and Nelson were an important commerce in the early 1900s, when overharvesting of shellfish depleted the resource. Rock oyster (imported from the North Island) farming was attempted in the Pelorus in the late 1890s and early 1900s without success.
- The environmental effects of these activities on seabed habitats included: sedimentation, loss of biodiversity from overfishing and depletion of fishing stocks, and the destruction and modification of living reefs from bottom trawling, dredging and illegal fishing methods.
- Harvesting of naturally occurring green-lipped mussels occurred in earnest in the 1960s and 1970s. The collapse of the Hauraki Gulf mussel reefs from over-exploitation led to the attention of industry turning to the Marlborough Sounds and Tasman Bay. By the time a comprehensive survey of remaining mussel reefs was done in 1969, only approximately 350 hectares of mussel beds remained. These were mainly in Kenepuru Sound, Hikapu Reach and in side bays in the inner Pelorus.
- The collapse of the mussel beds in the Pelorus led to the development of the mussel farming industry in the 1970s to over 2000 ha of production today.
- The ecological consequences of the loss of the mussel beds have been profound. Extensive areas provided complex three-dimensional habitats for algae and invertebrates, which in turn provided food for fish species. A recent study in the North Island found 10-times the number of fish around green-lipped mussel beds than in bare sediments. Mussel beds provided ecosystem services by filtering, binding, and stabilising sediments. Other benefits likely included nitrogen and carbon sequestration and recycling. The loss of these areas meant that fine sediments from the Kaituna and Pelorus rivers, and from farming and forest harvesting around the Sound, likely smothered the seabed preventing re-establishment.
- Loss of fish diversity and abundance was noted by a number of people interviewed for the study. Long-term research in Duncan Bay from the 1973-2006 found that fish declined in diversity, abundance, length, and weight. This was caused by the unregulated fishing in the 1960s and 70s, and the degradation of seabed habitats by dredging.
- Because these changes have not been widely appreciated, it may have led to the concept of ‘shifting baselines’. This can lead to a belief that modified benthic habitats and communities are unchanged and closely resemble historic composition. Or that seemingly unmodified habitats require protection as they appear unchanged. Ecologically significant biogenic habitats are likely to have been removed or remnants’ ecologically simplified, less resilient and abundant, and therefore needing restoration and protection.
- There is currently a lack of information available to robustly examine the equivalence between the ecological role provided by extinct mussel reefs as compared to the effects or benefits of mussel farms. While benthic effects from mussel farms are reported to be relatively benign, site selection criteria should maximise water exchange, and seek to protect benthic primary production and functional diversity. Farm management should also seek to

optimise stocking densities at low flow sites likely to suffer from high deposition rates to reduce benthic nutrient loading. Such measures should enhance resilience of the benthos and also maximise mussel production potential.

5.4 Future research and recommendations

The lack of recovery of formerly substantial mussel reefs in Nelson Bays, Firth of Thames and Pelorus (ca. 350-2000 ha) after being removed by fishing and intertidal hand-picking indicates that some components of these systems are no longer in natural balance. The affected components are likely to be water quality and clarity (sedimentation, nutrients), seabed habitat change (loss of shell and biogenic structure), and loss of shellfish (fishing, sedimentation, habitat loss) as summarised above. There is also the potential for unmeasured effects from disease, pests or predators that may have contributed to the mussel reef decline (e.g., Diggles, 2013) and continue to suppress recovery. If habitat change is the driver of failed mussel larval recruitment to soft sediments in Pelorus, then recovery of mussel reefs may require broader restoration efforts including improvements to water quality and clarity to enhance recovery of filamentous seaweeds and seagrass. It is of significance to future management or restoration goals, that factors preventing recovery of biogenic habitats including mussel reefs are likely to be interrelated and the relationship between individual factors may not be linear (e.g., Kemp et al., 2005). It is encouraging however that overseas restoration efforts indicate that once restoration is initiated (e.g., shellfish restoration), benefits flow to other components (like seagrass and benthic microalgae), which in-turn reinforce and enhance broader restoration goals including stabilisation of soft sediments that help maintain water clarity (Greening et al., 2014; Kemp et al., 2005).

Regardless of the mechanisms preventing recovery of mussel beds, there appear to be ecological benefits in returning waste shell to the seabed (Brown et al., 2014; Handley and Brown, 2012), especially for providing settlement habitat for species that may facilitate shellfish larval settlement, or recruitment of other filter-feeders (e.g., sea-squirts) that help improve water quality and clarity and armour soft sediments from resuspension. To help restore mussel beds, intervention by placing live juveniles on the seabed or on shell piles has been suggested (Handley and Brown, 2012). To quantify the relative effects or ecological benefits between mussel farms and historic mussel reefs, direct comparisons at comparable locations should be made and measurements conducted so that results can be compared with international data - as wild shellfish population decline is a global issue (Beck et al., 2009; Kellogg et al., 2014). A further factor to consider is that if mussels are placed directly on soft sediments, studying nutrient exchanges may be confounded by shifting baselines because of the loss of shell component in soft sediments due to the effects of fishing (e.g. Handley et al., 2014c) and sedimentation. As bottom contact fishing gear homogenises the seabed, burying, removing or breaking down shell content in soft sediments the response to this repetitive disturbance is a reduction in the abundance of filter feeders and grazers, and selection for smaller bodied deposit feeders, scavengers and predators (Handley et al., 2014c). However, when shell is returned to soft sediments, these processes are reversed with increases in the numbers of mussels and oysters (filter feeders) and large macrofauna (Brown et al., 2014). As occurs beneath a mussel farm (Christensen et al., 2003), the shell that used to naturally occur in the sediment beneath mussel reefs could obstruct bioturbators, favouring filter feeders and deposit feeders (Handley unpub. data; Handley et al., 2014c). For these reasons, restoration of mussel reefs may be best achieved by first returning some shell to the seabed, before stocking with mussels. Appropriate experimental comparisons of the provision of ecosystem services and mitigation by soft sediment communities should then be: beneath mussel farms, in soft sediments after introduction of mussel shells, and after introduction of live adult mussel aggregations atop shell. Annual waste shell production from green-lipped mussel production was estimated in 2010 at 12,000 tonnes per annum (Patterson, 2013).

Given that restoration of biogenic habitats is likely to be hindered by ongoing sediment input from land and in-situ resuspension, it would be valuable to determine the land-use practises that contributed to historical sediment contamination, and areas of unstable soft sediment that require stabilisation. To address the former, NIWA recommends that a sediment coring study be undertaken to determine sources of sediment contamination back through time. This coring study can also be used to validate the importance of mussel reefs as biogenic habitat in Pelorus by investigating shell content composition in historical sediments and potentially isotopic signatures from seabed mussels recorded in the sediment profiles (e.g., Edgar and Samson, 2004). Gibbs (2008) from NIWA was first to develop a stable isotope method that can 'finger-print' and apportion, by land use on a catchment scale, the sources of soil contributing to the sediment at a location of an estuary. The results of these analyses give a "best estimate", within definable limits, of the proportional contribution of each potential source soil. Information obtained using this method allows for development of management strategies to alter land use practices to reduce the sediment load to rivers, and thus, the impact on the aquatic ecosystem downstream in estuaries. The method uses compound-specific isotopic analysis of naturally occurring biomarkers (fatty acids) derived from plants to link source soils to land use within a single catchment (Gibbs, 2008). A coring study would allow for contextualising why recovery of biogenic habitats has not occurred, especially if shell content in sediments has undergone a shifting baseline, and the lack of settlement substrata is a bottleneck in the recovery of biogenic species (Morrison et al., 2008). To evaluate the role of current sediment loads near or at the seabed, modifications could be made to current Pelorus site monitoring to better measure near-bed sediment conditions. Unfortunately, near-bed sediment loads are likely to fluctuate with storm events that are not easily sampled, so in-situ turbidity probe moorings may be required to investigate the periodicity and frequency of high turbidity events close to the seabed where biogenic species once occurred. If shellfish restoration efforts are implemented, monitoring 'Universal Metrics' (Baggett et al., 2013) at experimental restoration sites and near seabed turbidity levels "before" experiments are deployed is recommended to provide insight into feedback mechanisms and the value of ecological services provided for by restoration. Other useful indicators to measure are benthic light levels, dissolved oxygen, and pH.

In relation to anecdotal reports of declining mussel production and reductions in growth over time, it could be a valuable exercise to hind-cast mussel yield prior to 1997 based on the methods of Zeldis et al. (2013) if long term climate and rainfall data are available. These predictions could be used to test if historic climate variation and rainfall levels could have supported the higher mussel stocking rates and faster growth rates reported by Clarke (2014). To detect long term regime shifts or degradation of the system, perhaps changes to farmed mussel growth rates that deviate from model predictions of mussel growth based on seston availability as devised by Zeldis et al. (2013) should be calculated annually as an index of health of the Pelorus system.

In the absence of clear signs (or empirical evidence) of organic enrichment, eutrophication or declining quality of macrofaunal communities in areas adjacent to mussel farms (i.e., control sites) in Pelorus, the question could be asked, is the state of the environment monitoring undertaken by MDC adequate to detect long-term changes to soft-sediment habitats? Monitoring our coastal waters and their watersheds is of paramount importance because "history is long; human memory is short" (Swaney et al., 2012). Without appropriate monitoring, gradual degradation can escape our notice, as can the gradual, cumulative impacts which can lead to relatively swift transitions or ‘regime shifts’ in ecological communities (Scheffer and Carpenter, 2003). Associated with potential shifting baselines, how do we decide when sustainability or carrying capacity of, for example the benthos of Pelorus is being negatively affected, especially in the context of nutrient absorption and recycling? The public and the aquaculture industry need to be informed and educated of the history of benthic change, but also of the potential for detrimental changes (tipping points or regime shifts) in Pelorus. The lack of recovery of benthic and intertidal mussel reefs in Kenepuru Sound may indicate a regime shift has already occurred, with the species composition present today representing an aberrant state – resulting in a shifting baseline after decades. Similarly, changes to reef and fish communities resulting from reductions of apex predators like larger sharks, snapper and lobster have been reported elsewhere. Determining cause and effect in Pelorus, especially when monitoring data are limited, leaves analysis of long term changes to be based on anecdotes and open to speculation. For these reasons, stakeholders need to form part of the evaluation of shifting baselines in order to include societal valuation and perception of the detected changes (Swaney et al., 2012).

In the future, there are predictions that climate change will increase stress in marine systems with increasing intensity and periodicity of storms (Willis et al., 2007). Therefore, any measures that can be taken to protect and enhance the resilience of the Pelorus should be encouraged, otherwise the rate of degradation related to sedimentation especially, will likely increase.

The goal of detecting long term change, and the factors causing such change, raises issues of what to measure, when and how often, to guard against failure to anticipate regime shifts. These issues are not unique to Marlborough, and should perhaps be a topic for future research at a National level.

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