An analysis of historical impacts and composition of the benthic environment of Tasman and Golden Bays

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Authors
Sean Handley

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Tasman District Council

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National Institute of Water & Atmospheric Research Ltd
217 Akersten St, Port Nelson
P O Box 893, Nelson, New Zealand
Phone +64-3-548 1715, Fax +64-3-548 1716
www.niwa.co.nz

Contents

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Executive Summary

Over the last two centuries the benthic ecology of Tasman and Golden Bays has been impacted firstly bythe impacts of human colonisation with heavy inundations of sediment from the effects of fires, deforestation, agriculture, and more recently by urbanisation. Secondly, there is evidence that fishing methods have modified the environment. As early as the 1800's and up to the introduction of the QMS system in the 1980's, fisheries resources have been continually overexploited especially as new fishing gear and larger vessels became available. This has likely led to changes in the food webs as predator and prey populations have been modified and caused homogenisation of the sediment characteristics in the bays, which are now dominated by silt and mud.

Studies of organisms inhabiting the seafloor of Tasman and Golden Bays are rare, and due to the modified state of the environment and the reduction in fisheries resources, the composition depicted by early studies in the 1960's and 1970's was unlikely to reflect a fully functional, undisturbed ecosystem. During this time the seafloor was dominated by deposit feeding species and included; *Gari lineolata, Echinocardium cordatum, Pratulum pulchellum, Dosinia lambata, Nucula hartviginia,* and *Amphiura rosea.* Data available from fisheries trawl surveys today indicates that these organisms are still present and are obviously resilient to the impacts of continued dredging, trawling, sedimentation and resuspension of sediments. As there are still living communities of bryozoan colonies at Separation Point, relatively healthy coastal reef margins, and sustainable utilisation of fin and shellfisheries in Tasman and Golden Bays, these modifications have not been entirely detrimental. Their continued survival and function shows the ecosystem has adapted to and in the case of the bryozoan colonies fortuitously avoided human impacts.

As Tasman and Golden Bays were historically dominated by deposit feeders with most of the productivity of the bays taking place on the benthos, examples of habitat degradation and restoration efforts in the US are discussed to indicate the importance of maintaining water clarity and benthic primary production to help mitigate the impacts of terrestrial and fisheries impacts. A potential model for managing terrestrial impacts, fisheries, and aquaculture within the bays is discussed.

1. Introduction

This report has been compiled in an effort to piece together what the seafloor habitats might have been like prior to major human-induced impacts within Tasman and Golden Bays. In doing so, there was a realisation that the impacts present today should also be looked at in the context of human habitation of the district, as there were likely significant effects on the environment during colonisation of NZ. This expanded the original brief for this report, but may give some insight into the nature of the changes taken place with human colonisation, the introduction of fishing techniques, especially dredging for shellfish, and, later bottom trawling. The physical factors alone are probably only half the story, as there is likely indirect effects changing species composition through human-induced changes to food webs and community structures. That section is followed by an analysis of ecosystem collapse overseas and some warning signs and measures to prevent such drastic loss. To finish off, there is a discussion about difficult issues surrounding management of fisheries, aquaculture and conservation values within Tasman and Golden Bays.

Before we can look at the biology of Tasman and Golden Bays, the complex physical environment must first be described, as it has an important role in biological structure. For example, the nature of the seafloor in Tasman and Golden Bay is related to the sediments supplied to it via erosion, the hydrology of rivers feeding the bays, and the hydrographic conditions of currents driven by tides and wind within the bays, which distribute and disperse sediments.

Geography and geology of Tasman and Golden Bays

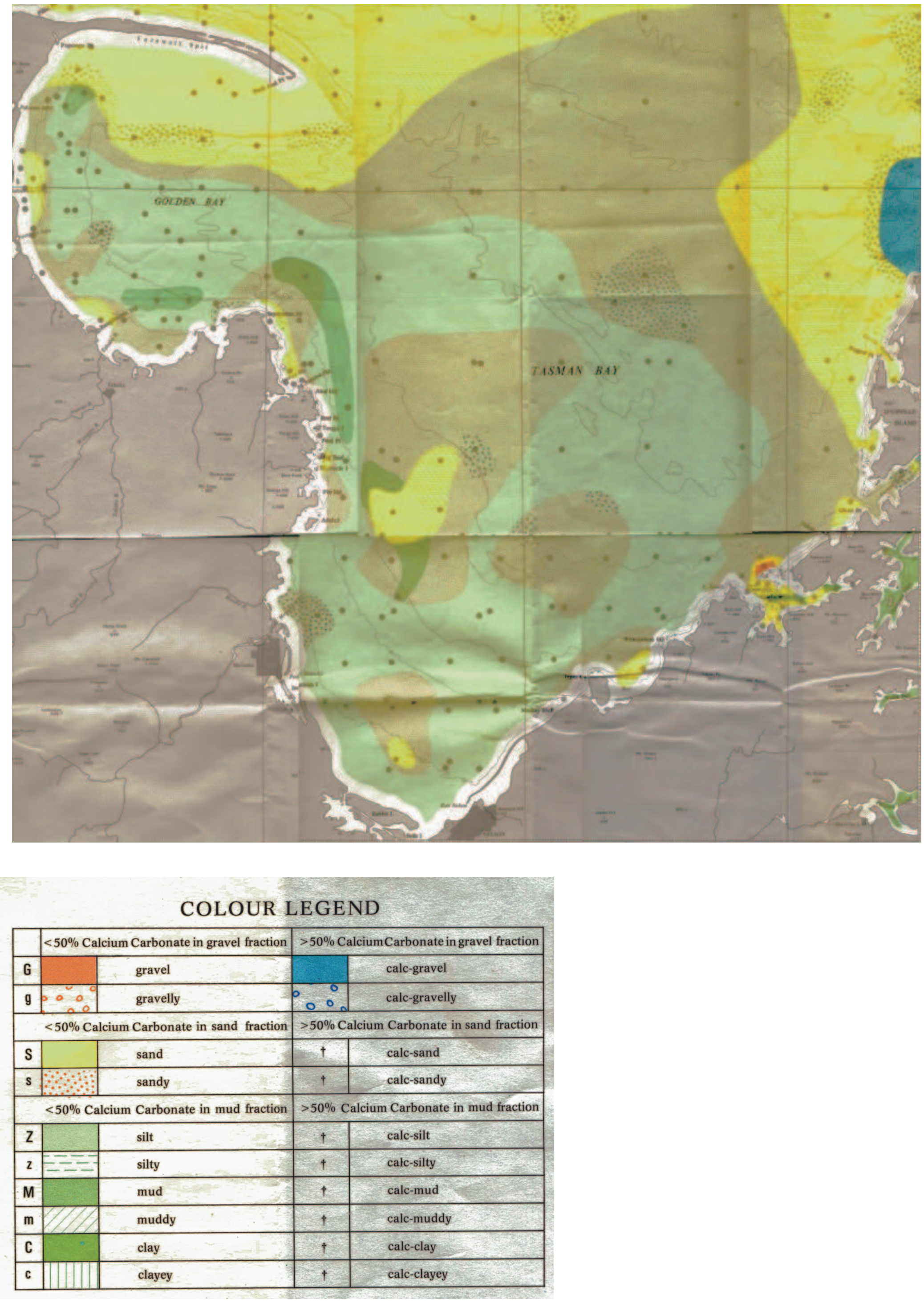
Tasman and Golden Bays are shallow embayments situated adjacent to each other on the northern cost of South Island opening onto the western Cook Strait (Fig 1). Tasman Bay is north-facing and triangular shaped located between Separation Point and the eastern tip of D'Urville Island, with an approximated surface area of 3,600 km^2. Golden Bay extends between Separation Point and Farewell Spit and is semi-circular in shape, faces north-east, and is approximately 1,000 km^2. The seafloor of Tasman and Golden Bays is characteristic of a gentle sloping gradient (1:1000, Mitchell 1986) shallower than 50 m depth. Areas of rocky reef habitat generally lie within 10 m depth and 1-4 km from shore.

Oceanographic charts of Tasman and Golden Bays show the dominant sediment type to be silt (Fig 1). Sandy silt is more common at the northern opening of the bays to the west of Cook Strait. Patches of sand are associated with most of the inlets, bays and harbours that line the margins of Tasman and Golden Bays, and near the mouths of the Aorere and Takaka Rivers. There are also patches of course-grained shelly deposits in parts of Tasman and Golden Bay, and a discontinuous clay belt 5-6 km offshore from Takaka and Able Tasman National Park.

Sedimentation and sediment transport in Tasman and Golden Bays

Sedimentation rates in Tasman and Golden Bays are comparatively high compared to other shelf areas of New Zealand (Van der Linden 1969). Sediments are introduced by two means; from the west coast and from riverine inputs from within the bays. There is a prevailing northward drift of currents and sediment along the west coast of the South Island with rapid deposition of sediments on Farewell Spit. Prevailing clockwise current rotation in Golden Bay transports courser sandy bed-load sediment introduced by the Aorere and Takaka Rivers. In Tasman Bay, the Motueka and Waimea Rivers characteristically discharge sandy silt and calcareous gravel material. The Aorere and Takaka Rivers however contribute four times the amount of sediment (0.7×10^6 tonnes/yr) than the Moteuka and Waimea Rivers (2.7×10^6 tonnes/yr; Griffiths and Glasby 1985). Sediment moving out past Farewell Spit will ultimately be swept into Tasman Bay and Cook Strait. Coastal erosion is a very minor source of sediment (Shell BP and Todd Oil Services (NZ) 1975). Golden Bay, which is less than a third of the size of Tasman Bay, receives four times the amount of sediment which is sandier in nature than the silts predominant in Tasman Bay.

The nature of the currents which have been modelled for the greater Cook Strait indicate that the bottom stresses in Tasman and Golden Bays are typically within the ranges where fine-grained deposition would dominate (Proctor & Carter 1989). The resuspension and transport of bottom sediments is expected periodically by favourable wind-wave conditions, particularly those generated from northerly storms (Muir 1979). This suspended sediment could then be transported around the bays by tidal and oceanic currents within the bays.



COLOUR LEGEND

		<50% Calcium Carbonate in gravel fraction		>50% Calcium Carbonate in gravel fraction
G	🟧	gravel	🟦	calc-gravel
g	○	gravelly	○	calc-gravelly
		<50% Calcium Carbonate in sand fraction		>50% Calcium Carbonate in sand fraction
S	🟨	sand	†	calc-sand
s	⁘	sandy	†	calc-sandy
		<50% Calcium Carbonate in mud fraction		>50% Calcium Carbonate in mud fraction
Z	🟩	silt	†	calc-silt
z	‐ ‐	silty	†	calc-silty
M	🟩	mud	†	calc-mud
m	▨	muddy	†	calc-muddy
C	🟩	clay	†	calc-clay
c	▥	clayey	†	calc-clayey

Figure 1. Map of Tasman and Golden Bays showing sediment characteristics (Mitchell 1987)

2. History of human settlement and land development potentially affecting Tasman and Golden Bays

Maori colonisation

Around 1350 AD there was a great migration of people from Tahiti. These Polynesians brought with them taro and kumara to cultivate the land of Aotearoa and were huntsmen and fishermen of the North Island (Allan 1965). Some time in the sixteenth century sections of the tribe of tangata whenua crossed Cook Strait and as Rapuwai and Waitaha remained in peaceful occupation of the South Island for about a century. Ngati Mamoe later moved to the South Island seizing land whilst absorbing and exterminating the Witaha and Rapuwai. About the same time Ngati Mamoe came to the South Island, a second tribe, Ngati Tumatakoriri, occupied most of the Nelson Province with settlements in Wakapuaka, Wakatu, Waimea, Motueka, Rotoiti, Rotoroa and Golden Bay. As population pressures increased in the North Island there were further waves of migrations and downfalls of existing tribes, with Ngai Tara acquiring some land at the mouth of the Waimea where they were joined by Ngati Whata and Ngati Rua. Some Ngati Apa and Ngati Kuri also settled in Nelson. However, in 1650 Ngai Tahu moved south, relinquishing ancestral lands at Poverty Bay to take up residence in the South Island, but largely ignored the Nelson district, concentrating on lands further south across to the greenstone bearing Arahura on the West Coast. Ngati Apa then invaded Nelson from Wanganui and between them and Ngai Tahu wiped out most of the residence. By the time Abel Tasman arrived in New Zealand, Ngai Tahu ruled most of the South Island, but Ngati Apa held most of the Nelson Province, and Rangitane and related tribes the Sounds districts.

Between 1824 and 1827 a section of Ngati Koata, related to Ngati Toa, settled at Rangitoto (D'Urville Island) and at Pelorus, and later tried to claim lands across to Separation Point. Between 1828 and 1830 there was much warfare from invading tribes from the North Island, now armed with muskets acquired from Pakeha sealers and whalers. Among the conquereres were Ngati Koata retaining land around Rangitoto, Croisilles, and Wakapuaka, wth some Ngati Tama joining them later. Te Atiawa and Ngati Rarua both claimed land near the Riwaka-Motueka area. Ngati Rarua were more effective and had settlements round the Bay from Moutere and Marahau. Te Atiawa and Ngati Tama both claimed the Waimea.

There is evidence that early Maori colonisation of New Zealand was fuelled by the easily available protein supplied by the moa. Archaeological research from moa butchering sites like those found near the Wairau Bar show that there was enormous wastage of meat where it was estimated that 9,000 moa were killed and almost 2,400 eggs destroyed (Flannery 1994). Extinction of moa was possibly achieved within 3-400 years of Maori arrival. Moa were certainly present in the Nelson district with many well preserved remains found in limestone caves around Mt Arthur (Beatson & Whelan 1993). With the extinction of the moa, the Maori were forced to rely upon other, more difficult-to-obtain resources. These were the smaller birds, fish, shellfish, and marine mammals. By 1600 AD all breeding colonies of fur seals on the North Island and the northern South Island were exterminated. There was also evidence that Maori over-exploited fish species like snapper which were fished early on at the top of the South Island, but then vanished from middens suggesting local extinction. Shellfish must also have been important sources of food during times of depleting food resources. By the 16th century the Maori population had been growing exponentially for at least 300 years, and Flannery's (1994) thesis is that they were forced to live in small communities for that were all the land and sea could support. Agriculture in the form of kumara growing supplied food in the North Island, and parts of the South Island where it was near the extreme of its climatic range. There is also evidence people were forced to survive on bracken roots which in the south were rarely of edible quality. In the South Island the sugary base of the cabbage tree was utilised.

> "*Everywhere the flesh of dogs and rats (kiore) was highly valued, while the declining fish and shellfish resources provided most of the protein*" (Flannery 1994).

Fire, and the resulting deforestation, also became an important tool used by Maori.

> "*The Maori practice of setting forest fires lead to catastrophic soil erosion and biological impoverishment. As disastrous as this was for native vegetation, animal and soil, it was probably beneficial to the Maori… Fern root of a quality that can be eaten by people, only grows on the better soils. Soil erosion encouraged by fire stripped the hills of their nutrients and transported them into the valleys. There, on the lowland flats, the precious root of the bracken fern could grow to edible size. Furthermore, fire encourages the growth of the cordyline (cabbage tree) and it had assumed a critical importance as food source in the south. Soil erosion would also have released nutrients into the estuaries, where they became available to larval fish and other marine organisms, which were the main source of protein for the Maori after extinctions on land.*" (Flannery 1994)

By the 17th century economic and cultural crisis was evident, and forced by hunger, the Maori had set to war and building fortifications around the coast. This may have been the cause of the hostility that Abel Tasman first met with at the aptly named "Massacre Bay" (now Golden Bay) in 1642. By the late 18th century there was also evidence that the bodies of those killed in war were a prized source of food through cannibalism. As Abel Tasman sailed north up the West Coast he found it very desolate and unpeopled, but north of Kahurangi Point everything transformed, and from the lowered coast:

> "*about a mile from shore, in various places we saw smoke arising from fires made by the natives"… at almost every rivermouth or gap in cliffs from Kahurangi, past an inlet's entrance to Onetaua, or Farewell Spit, are the traces of other Ngati Tumatakokiri kainga – Kaukauawai, Ruakawa, Te Wahi Ngaki, Patu Rau, Te Hapu, Rakopi, Kaihoka.*" (Park 1995).

European settlement

When Colonel William Wakefield arrived in 1839 to buy land for the New Zealand Company he found Nelson occupied by a comparatively small Maori population having had possession of their lands for only about ten years. Before that sealing, then whaling were the major draw cards for European settlement. The European settlement of Nelson thus began in 1842 with the arrival of settlers under the direction of the New Zealand Company.

The purchase of lands was not without conflicts between Maori and Pakeha, with ramifications for the bays downstream:

> "*Once the New Zealand Co. took hold of a piece of level ground, their surveyors and axes didn't wait for land commissioners. No more than their squatters – Frederick Moor and Charles Heaphy among them – waited for proper title. Revered forests like Te Matu, The Great Wood of Motueka, the The Wood of Nelson appeared briefly in the earliest paintings and plans and then were gone. With them went the centre of the Maori landscape that Dumont D'Urville so admired: the food-rich country edges – kahikatea woods, flax swamps, coastal lagoons and rivermouths. Aggrieved Maori argued with Spain that they had stipulated the Company retain Te Matu as well as 'the pas and cultivations'. Spain was unmoved, saying that quite sufficient of the forest had been allotted to Native Reserves… To settlers who saw native reserves as good ground left empty and uncultivated, and the provincial administrators who had*

> *to deal with them, this was tantamount to self-dispossession…. For a century, a succession of land speculators, mining and timber companies stripped and logged most of what had been Maori reserves, and subdivided its coast into farms. By the 1970's it was rare to see a valley still forested right down to the sea anywhere in New Zealand.*" (Park 1995)

Despite the conflicts, Maori profited from the European settlement with the provision of metal tools, weapons, livestock and crops:

> "*Here, with fish and birds, were most of the plants that had found their way into the Maori diet; once, that is, the failed tropical root crops were distant memories. Yet the ardour with which Maori welcomed European potatoes suggests it was hardly a Garden of Eden. Extracting food from forests and swamps, like felling trees and building canoes before metal axes, was hard work, demanding energy and time and suffused with ritual and limitations. It succumbed to the new order as fast as Maori adopted cows, cabbages and fruit trees.*" (Park 1995)

The Nelson Provincial Government was established in 1853. Between the 1850's and 1860's there in the upland river valleys, there were great totara, kahikatea, rimu and beech trees along the river banks covering the land (Beatson & Whelan 1993). The Maori of the time easily lived off eels and birds. Early land clearances fed the hunger for farm land and by the 1930's areas like Ngatimoti up the Moteuka River only had small tracts of bush remaining below the hills of the Mt Aurthur Range. By 1846 Motueka had a population of 193 Maori and 850 Europeans, and by 1856 the population of Motueka Europeans was nearly 1,000 with hotels, stores, a church, a pa and canoes to be seen.

In the 1870's two severe floods affected the Motueka River and upstream settlements like Ngatimoti, and these serve to illustrate the potential impacts of deforestation, the altered forest ecology, storms, and the downstream impacts on Tasman Bay. The floods of 1872 and 1877 caused drowning, destruction of houses, and loss of livestock swept away.

> "*The best part of the land is rendered useless, the creeks running from Green Hill are vomiting forth their contents to the solid rock, trees barked, stones, boulders, etc., mixed in endless confusion… Next morning I got up and looked at the place. I saw it less than a week before, and I could hardly believe my own eyes. There in front of the whole stockyard was, and is, but lies buried, with ten feet of sand on the*

> *top of it; you could hardly tell it was there… I had now learned that not only had the river been terribly high, but that the creeks must have been damned up by slips from the hills, thus forming reservoirs, which suddenly busting, had thrown out on the flats such boulders and trees as would hardly thought credible…. Motueka was inundated throughout; boats and Maori canoes were rowed and paddled up and down High Street.*" (Beatson & Whelan 1993)

3. Biology of Tasman and Golden Bays

Ecological surveys

There have only been a few publicly available comprehensive ecological surveys carried out to characterise the species living within and upon the benthic sediments of Golden and Tasman Bays. These were principally from studies commissioned in the 1960's by the NZ Oceanographic Institute (now NIWA), and by a University of Auckland study for Shell BP and Todd Oil Services Ltd. Other biological information can also be gained from fisheries by-catch data collected as part of fisheries stock assessments which continue up to present.

The animals living within the sediments of Tasman and Golden Bays are primarily "soft bottom fauna" which are dominated by bivalves and echinoderms. In the sandy mud and mud substrates common in western parts of Tasman and Golden Bays, McKnight (1969) named the major assemblage of animals the "*Amphiura rosea – Dosinia lambata* community" between 1-50 m depth. The bivalves were more abundant than the brittlestars (*Amphiura*), and other characteristic species included: *Nucula nitidula* or *N. hartviginia*, *Neilo australis*, *Maoricolpus roseus*, and *Echinocardium cordatum.* Apart from another bivalve *Dosinia*, and *Maoricolpus* which are suspension feeders, the majority of this group are deposit feeders taking food from the sediment surface. In Golden Bay where the sediments are more sandy silt, *Maoricolpus* dominates.

In areas of the bay where the sediment is sand to sandy mud in central, eastern, and northern parts of Tasman Bay and Delaware Bay the community is dominated by the bivalve *Gari lineolata,* and McKnight (1969) called this group the "*Amphiura rosea – Gari lineolata* community" occurring in 15-50 m depth. Characteristic species of this group include: *Gari lineolata, Echinocardium cordatum,, Pratulum pulchellum, Dosinia lambata, Nucula hartviginia,* and *Amphiura rosea.* Again this group was dominated by deposit feeders apart from *Dosinia* and *Scalpomactra scalpellum* which are suspension feeders.

A third community was recognised in Tasman Bay as the "*Scalpomactra scalpellum-Mactra* [*Maorimactra*] *ordinaria* community" found in open shelf areas west of D'Urville Island between 20-60 m depth. Coarser substrates typical of byrozoan and molluscan gravel (broken shell) are dominated by largely the suspension-feeding "*Tucetona* [Glycymeris] *laticostata-Venericardia purpurata* community". This community was also found mainly on muddy sand and mud (University of Auckland 1975).

McKnight (1969) acknowledged that his characterisation of the seafloor assemblages was based on non-quantitative samples and a limited number of faunal groups. Polychaetes and small crustaceans might therefore turn out to be important components of these communities that are visually dominated by bivalves, ophiuroids, and echinoderms. Probert and Anderson (1986) quantitatively sampled assemblages at two stations in Tasman Bay and found the biomass to be 49.8-84.8 g wet weight m^{-2} with the most important taxa being polychaetes, bivalves, amphipods, ophiuroids and echinoids. These samples were taken within McKnight's "*Amphiura rosea-Dosinia lambata* community". Studies of a tube building polychaete worm *Pectinaria australis* over two years between 1971 and 1973 in the lower half of Tasman Bay showed them to be a conspicuous element of the community with rapid population growth and heavy mortality and an apparent annual life-cycle (Estcourt 1974). This species was later compared with a longer-lived carnivorous polychaete worm *Agloaphamus verrilli* which may live for as long as 5 years, which showed irregular recruitment and population densities between 15-7 and 18.5 m^2 (Estcourt 1975).

Mussels, oysters and scallops

Both bays in the past have supported commercial populations of mussels (*Perna canaliculus*), scallops (*Pecten novaezelandiae*), and flat oysters (*Tiostrea chilensis*), and these were found widespread in four of McKnight's (1969) communities. Tunbridge's (1962) survey in 1961 estimated oyster populations to be ca. 27.5 million of which 8-10 million were at harvestable densities mostly from central Tasman Bay and off Whangamoa Head. Tunbridge found only 1 mussel bed in 1961 at the north end of the Boulder Bank, but scallops were widespread with oysters and in greatest commercial concentration in the centre of Tasman Bay. Many juvenile scallops were collected off Pepins Island and Whangamoa Head.

Bryozoan colonies

Bryozoan corals form significant populations and coralline growths in parts of Tasman Bay, especially off Abel Tasman National Park (Separation Point), off D'Urville Island and parts of the outer Marlborough Sounds. These areas were identified as important juvenile fish habitats especially for snapper, tarakihi and john dory (Vooren 1975). The physical structure of the colonies also increases the microhabitat diversity and localised biodiversity in general (Gordon & Stuart 1993). These areas were traditionally known to fisherman prior to 1956 and avoided as their natural fibre nets were easily damaged by the coral. After the design of special nets that floated just above the bottom, an area off Torrent Bay was targeted where rather brittle bryozoan *Hippomenella vellicata* dominated. The harder corals such as *Celleporaria agglutinans* at Separation Point afforded greater protection until the 1960's when synthetic net making fibres became common. This gear caused significant damage to the hard corals which can reach up to 50% cover and colonies up to 0.5 m high. With a reduction in the number of juvenile snapper and tarakihi reported after fishing at Separation Point (Saxton 1980), 156 km^2 area off Separation Point was closed to all power-fishing methods in 1980 to protect the bryozoan habitat (Mace 1981).

A follow-up survey of the effectiveness of the Separation Point reserve was carried out in 2003 (Grange et al 2003). This study found that the exclusion of the area to power-fishing had protected the colonies from dredging as there was no evidence of trawl or dredge marks on the side-scan sonar images recorded. Thus the frame-building mounds present had not been destroyed by earlier fishing, allowing these colonies to persist for the last 23 years. Many of the colonies however only appeared to be growing from the distal tips and were covered by a film of silt, suggesting the community may be stressed by sedimentation. Juvenile fish, the main driver for the reserve, were also observed where visibility allowed their observation above 30 m depth; indicating the reserve status still justifies protection of the colonies and the associated microhabitats. Whether the bryozoan colonies are healthy and growing remains to be studied, although Gordon and Stuart (1993) imply that the bryozoan corals exist in such fine sediment areas due to the high currents (>30 $m.s^{-1}$) present around headlands like Separation Point. Thirty seven species of bryozoans were identified from a single dredge sample collected by Grange et al (2003) and another 49 invertebrate species associated with the habitat, mostly dominated by bivalves and gastropods. The fate and significance of the other bryozoan colonies formerly present off Torrent Bay and D'Urville Island are yet to be established.

During a West Coast South Island trawl survey (KAH0304) in southern Golden Bay 2003 specimens of an introduced "corn-flake coral" bryozoan *Biflustra grandicella* were identified (Grange & Gordon 2005). It was then shown that since establishment, this species had spread very rapidly to occupy an area of approximately 255 km^2 although the main distribution covered an area 44 km^2 in depths of 15-25 m on muddy sediment. Subsequently, the distribution appears to have retreated slightly to occupy only an area 44 km^2 north of Port Tarakohe. Epifauna associated with *B. grandicella* are lower in abundance than found attached to native mound-forming Bryozoa such as *Hippomenella* and *Celleporaria.* Given its rapid spread and lack of epifauna there may be biodiversity implications for its spread, but at present there is no evidence to suggest it has spread to Separation Point.

By-catch data from biomass surveys

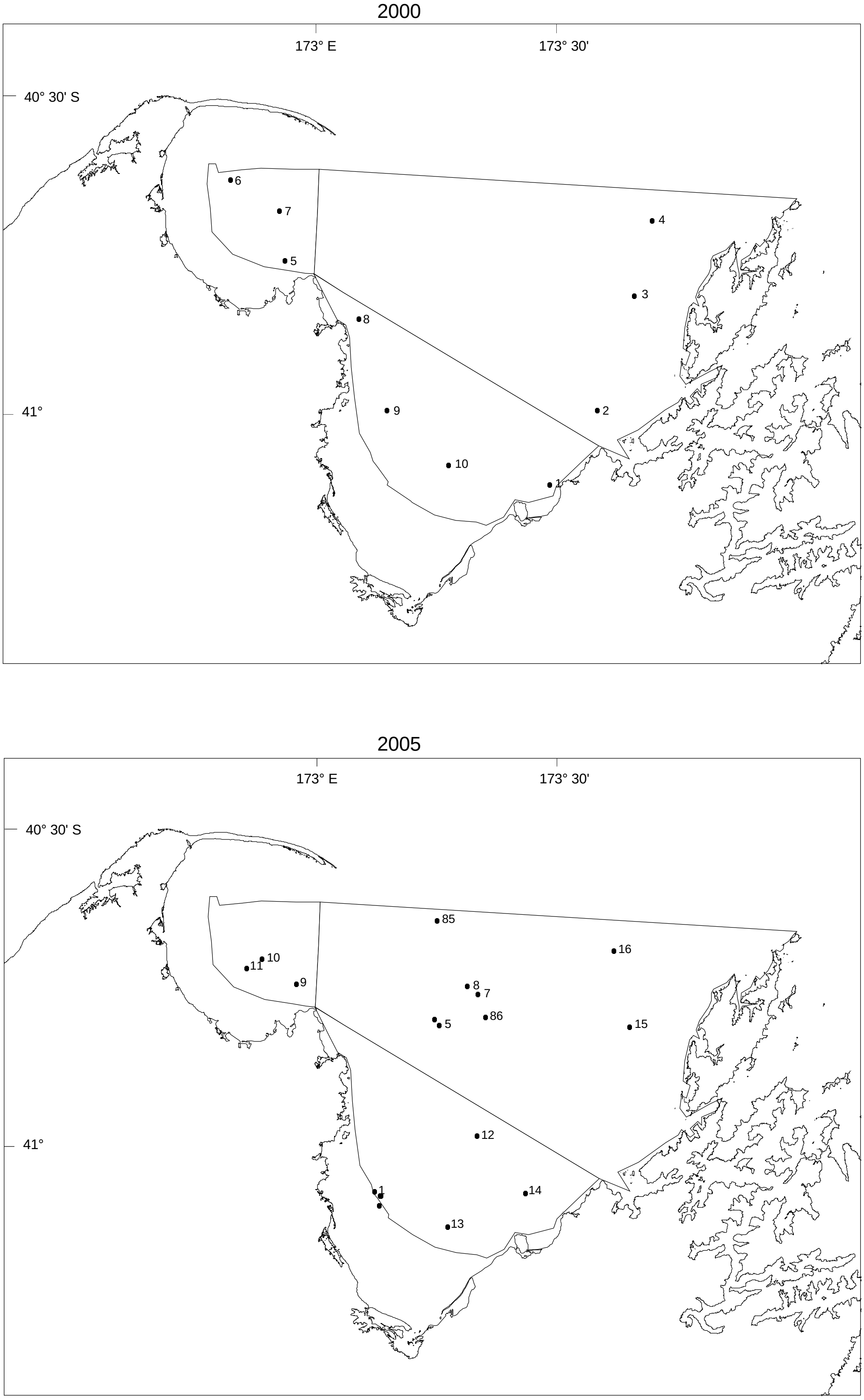
A brief analysis of invertebrate NIWA trawl survey by-catch data for areas in Golden and Tasman Bays for 2000 and 2005 is shown in Table 1. This is a rather qualitative look at what comes up in the trawl net with fish, and shows that in 2000, gastropods and bivalve molluscs were very common, but in 2005 they were notable by their absence, with more echinoderms, polychaete worms and bryozoans present in the later survey.

Table 1. Percentage occurrence of invertebrate by-catch in NIWA trawl surveys for 2000 and 2005 aboard Kaharoa. There were 10 stations sampled in 2000, and 19 stations sampled in 2005 (Figure 2).

Taxon	2000	2005
Echinodermata: Asteroidea		
Coscinasterias muricata	20%	16%
Psilaster acuminatus	10%	5%
Echinodermata: Echinoidea		
Pseudechinus albocinctus	-	5%
Echinodermata: Holothuroidea		
Stichopus mollis	20%	5%
Echinodermata: Ophiuroidea		
Astrothorax waitei	-	11%
Amphiura correcta	-	11%
Ophiocentrus novaezelandiae	-	5%
Mollusca: Gastropoda		
Alcithoe arabica	20%	-
Austrofusus glans	10%	-
Monoplex parthenopeus	10%	-
Penion cuvieranus	10%	-
Sigapatella novaezelandiae	10%	-
Zegalerus tenuis	20%	-
Mollusca: Cephalopoda	50%	42%
Mollusca: Bivalvia		

Aulacomya ater maoriana	10%	-
Barbatia novaezelandiae	10%	-
Cardita aoteana	10%	-
Chlamys gemmulata	20%	-
Chlamys zelandiae	20%	-
Chlamys dieffenbachi	10%	5%
Hiatella arctica	20%	-
Limaria orientalis	10%	-
Modiolarca impacta	30%	5%
Monia zelandica	10%	-
Ostrea lutaria	20%	-
Pecten novaezelandiae	70%	-
Crustacea: Anomura		
Diacanthurus rubricatus	20%	-
Pagurus novaezelandiae	10%	-
Paguristes pilosus	10%	-
Crustacea: Cirripedia		
Balanus decorus	10%	-
Cnidaria: Hydrozoa		
indet	30%	32%
Nemertesia elongata	10%	-
Brachiopoda		
Gyrothyris mawsoni	20%	-
Urochordata		
Ascidian (mixed taxa)	30%	-
Didemnum sp.	20%	-
Annelida: Echiuroida		
Echiurid sp.		5%
Annelida: Supunculoida		-
Spunculoid sp.		5%
Annelida: Polychaeta		
?*Chaetopterus* sp.	10%	-
Sabellidae	30%	-
Eunice sp.	-	5%
Terebellidae	-	5%
Glycera sp.		11%
Serpula sp.		5%
Maldane theodori		5%
Bryozoa		
Galeopsis porcellanicus	-	5%
Smittoidea maunganuiensis	-	5%
Cellaria immersa	-	5%
Cellaria tenuirostris	-	5%
Biflustra grandicella	-	5%
Bitectipora rostrata	-	5%
Porifera	20%	21%

Figure 2. Map of Tasman and Golden Bays showing the trawl survey stations used in 2000 and 2005, see Table 1.



4. History of fisheries and dumping impacts on the seafloor of Tasman and Golden Bays

Mussel fishery

Mussel fisheries were important sources of protein during early colonisation of settlements in New Zealand harbours like the Waitemata (Firth of Thames), Wellington, Kaipara, and Nelson. Mussels were taken with oysters in the first commercial dredge fishery in Tasman and Golden Bays during the late 1800's. There is however little published information on these early fisheries. Choat (1960) identified green lipped mussels to be in great abundance in some areas of Tasman Bay in 1959. During a 1962 survey of oyster beds by Tunbridge (1962), crew members of the "Ikatere" said that the mussels caught in Tasman Bay compared favourably with Auckland mussels, but local fishermen said they were in poor condition for much of the year. Mussels continue to be fished today as by-catch from the oyster and scallop fisheries and are now part of the Quota Management System.

Oyster fishery

The dredge oyster (=Bluff oyster, =mud oyster, =flat oyster) *Ostrea chilensis* is widespread throughout New Zealand and is currently the target of commercial fisheries in Foveaux Strait, Challenger (Tasman Bay, Golden Bay, and Marlborough Sounds) fisheries area, and the Chatham Islands. The Challenger oyster fishery is the second largest in New Zealand (Tunbridge 1962b), but has a history of marginal economics. There are reports of small-scale commercial activities for oysters dating back to 1845 with oysters sold through "oyster saloons" throughout the Nelson area during the mid-late 1800's (Drummond 1994). Signs of over-fishing were apparent even in the 1800's when local supplies ran short and there was evidence of imports from Wellington Harbour, Foveaux Strait and even from Australia. During the same period, a similar fate befell the Australian beds especially in South Australia, where about 30 sailing vessels and some 80 fisherman harvested the oysters with dredges at 5-20 m depth (Olsen 1994). The harvesting depleted the beds, and only a few vessels remained after 1885 (Nell 2001).

> "*Irrespective of cause or effect, regardless of legislative enactment, the toilers of the sea dredged and dredged until the demand overcame the supply. They paid little regard to the fishery in which they were engaged; in no case was a selection made, but the whole of the fish, great or small, were drafted off to*

> *supply the city. The end came and finally not a mollusc was available - not a solitary native oyster remained and the dredgers were constrained to seek fresh fields and pastures new. Coffin Bay, Port Lincoln and other desirable spots then furnished the gourmand with this luxury*." (http://www.slsa.sa.gov.au/manning/sa/industry/fishing.htm).

During a long break in commercial activities until the mid 1900s Nelson oyster supplies were met by regular supplies from Foveaux Strait ("Bluff oysters").

Between 1963 and 1981 oysters were taken as by-catch, firstly by the revived mussel fishery and subsequently by the scallop fishery, suggesting that targeting oysters was not economic during that time. From 1981 onwards, commercial operators, mainly in Challenger, targeted oysters (Annala and Sullivan 1997). Historical evidence suggests that early fishing in the 1800's was based on inshore beds accessible at low tide, with exploitation of at least one deepwater bed in Tasman Bay (Drummond 1994). These shallow water beds no longer exist, and the fishery has progressively worked grounds moving out into deeper water with an expansion of the dredge oyster beds over time. Tunbridge (1962) noted that as much of the substrate in Tasman and Golden Bay is mud, settlement was limiting for both oysters and mussels, and that to work these areas commercially "thought could be given to the deposition of a suitable substance on the grounds prior to settlement" (Tunbridge 1962) to enhance these fisheries.

Today, the Challenger dredge oyster fishery from Tasman and Golden Bay is comparatively small (505 tonne TACC) and is marginal in terms of economic returns. The biomass of the stock has been estimated to be around 2,000 tonnes, but the CPUE in the fishery has been steadily decreasing in recent years. The oyster beds in Challenger differ from those in Foveaux Strait in that the oysters largely occupy mud bottom rather than sand and shell (Tunbridge 1962b). This means the dredges used are lighter in construction than those used to work the shell and gravel beds in Foveaux Strait. The two basic types of dredges used were box and ringbag dredges, which have different efficiencies over different bottom substrate types (Doonan et al. 1985). The box dredge with teeth was less efficient on very soft bottoms than on hard bottoms, whereas the ringbag dredge was less efficient on hard bottoms. As Tasman and Golden Bays are dominated by mud, the ringbag dredges were found to be more efficient here, whereas the heavier box dredges are used in Foveaux. The habitat and biology of these two South Island fisheries differ to the extent that biological parameters from Foveaux Strait oysters cannot be used to model the Challenger populations (Drummond 1993). The same could also be said for comparisons between the impacts of the respective dredging activities between the two fisheries which have been described by Cranfield et al. (2003) for the Bluff fishery, but not for Challenger.

Scallop fishery

Tasman and Golden Bay, contributes to New Zealand’s major scallop fisheries, the Challenger Scallop Fishery, which also incorporates the Marlborough Sounds. Commercial dredging of wild scallops began in Tasman Bay in 1959, and expanded out to incorporate Golden Bay and the Marlborough Sounds by 1967. Maximum wild fisheries production was recorded in the 1970’s of 1,000 tonnes meat weight. This production crashed leading to the close of the fishery between 1981 and 1982. In 1983 enhancement trials proved very successful leading to large scale seeding of juvenile scallops allowing the enhanced fishery to recover to near peak levels managed by the Challenger Scallop Enhancement Co.

In 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, with an individual transferable quota (ITQ) of 640 tonnes collectively allocated to quota holders. Reseeding of spat collected in both Tasman and Golden Bays is followed by a two year growing period, and harvesting of scallops in a cycle of rotationally fishing nine areas (Arbuckle and Metzger 2000).

Trawl fisheries

Commercial trawling for snapper in Tasman and Golden Bays has occurred since at least 1945, with annual landings recorded in the early 1960’s to be between 500-600 tonnes. Peaks of landings have increased with strong year classes of snapper to 1,500 tonnes in the mid 1960’s. Landings of 600 tonnes in 1970 were typical until catch rates increased to 1,000 tonnes with the introduction of bottom trawling in 1972, which led to the decline of the fishery to 500 tonnes by 1975/76 (Mace & Drummond 1982). By 1977 purse seining of snapper utilising spotter planes targeted schooling snapper with a 2,700 tonne catch recorded for the 1978 calendar year. After this memorable year, steady decline of the fishery led to the purse seiners leaving the fishery, but bottom fishing continued with pair trawlers. With the advent of the QMS system in 1986, the total allowable catch (TACC) was set to 330 tonnes, but as this was not caught in the following two years, the TACC was reduced further to 160 tonnes in 1989. Up until 1992 this TACC had not been exceeded (Annala 1993), and the majority of snapper are now caught as by-catch by the inshore bottom trawling fleet. The average annual catch rate for the last five years has been 175 tonnes with the TAC set currently at 200 tonnes (R. Blackwell pers. comm., NIWA). There are currently voluntary summer closures to trawling in important inshore areas to protect juvenile snapper (Todd 1993).

Dredge spoil disposal

Maintenance dredging at the Port of Nelson over the last 30 years has seen ca. 50,000 m^3 of sediment dumped annually at the Tasman Bay spoil dumping area since 1974 (Roberts and Forrest 1999). Varying degrees of trace metals, organochlorine pesticides, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons contaminated the port sediments. Mildly elevated toxicity was shown in laboratory bioassays, with the macrofauna dominated by small-bodied polychaetes. There was very little indication of impact in the spoil disposal area despite this. Indications from the similarity of the sediment contaminants, sediment toxicity, neogastropod imposex, and macrofauna between the disposal area, spoil spreading zone and control sites, show that the spoil dumpings are dispersed rapidly by the dynamic sedimentary environment in Tasman Bay.

Aquaculture

Mussel farms have been in place around the coast of Golden Bay since 1980, and marine farms have been issued in Tasman Bay in 2004 for spat catching for scallops and mussel spat (K. Bonnington, MFish). There have been more applications granted RMA approval and awaiting MFish fisheries resource impact assessment (FRIA) approval in Tasman Bay. Mussel farms produce debris that falls to the seabed, namely faeces, pseudofaeces and shell of mussels, as well as intact mussels and fouling algae and marine invertebrates (Cole & Grange 1996). The amount that reaches the seabed and the extent of the “footprint” is dependent on water column depth, current speed and direction, the weight of the debris, and farming practices. This debris (biodeposits) has the potential to affect the stability of epifauna and infauna communities, and such disturbance may have ramifications further up the food web.

Comparison of the benthic faunas of muddy sediments beneath existing marine farms in the Marlborough Sounds with those of similar, adjacent areas suggests that there are differences attributable to the presence of the farms (NIWA Unpublished FRIA data). The magnitude of mussel farms effects is very small and consists of slight shifts in the relative abundances of the taxa present. Comparisons of the faunas of areas inside and outside farms do not identify any major differences in assemblage structure, and also identified high levels of variability in abundances among samples from both types of area. Total abundances of individuals and taxa were similar inside and outside farms, but the abundances of a few taxa (the brittle star *Amphiura rosea* and the bivalves *Nemocardium pulchellum* and *Ennucula strangei*) were higher outside farms. In contrast, the gastropod *Maoricolpus roseus* and, not surprisingly, green-lipped mussels (*Perna canaliculus*) tended to be more abundant inside farms.

5. Fisheries and species interactions

There is evidence of both species and fishing interactions impacting on other fisheries. For example, during the scallop growing period, the scallop grounds are closed to commercial scallop dredging, but not to other commercial fishing methods like trawling which can resuspend sediment (Durrieu De Madron et al. 2005). During the establishment of the scallop fishery enhancement program, areas closed to commercial fishing showed a trend of better survival compared with fished plots (Bull & Drummond 1994). It has been shown that scallops, especially the larvae and juveniles are susceptible to suspended silt (Stevens 1987).

Tunbridge (1962) noted that the presence of a large mussel bed to the north of the main oyster bed in Tasman Bay may constitute a barrier to the spread of oysters “a heavy set of mussels on any oyster bed often smothers the oysters especially the juveniles. Mussels also accumulate a large amount of silt around themselves”. He also thought that the act of fishing was potentially detrimental to oysters causing silt to lie in suspension. This may affect the oysters by clogging up the gills and palps or cause oysters to become buried in the mud (Tunbridge 1962).

6. Discussion

The structure of the seafloor communities of Tasman and Golden Bays prior to human colonisation and its associated impacts are difficult to reconstruct. Human colonisation of Tasman and Golden Bays brought with it a succession of unsustainable resource use starting with the moa, fur seals, then moving to other smaller vertebrates and likely also fisheries resources like snapper and inshore shellfish beds. Flannery (1994) hypothesised that it was the Maori’s diminishing food resources, especially in the North Island, that fuelled the waves of Maori wars and conquests, which continued with re-colonisation of the South Island up until the Europeans arrived. His assertion that fire was also used as a tool and this provided some respite to the lowlands and estuaries by supplying nutrients, indicates that Maori were in part responsible for the start of deforestation of much of New Zealand's lowland forests lamented by Park (1995). Deforestation was already well underway in parts of New Zealand when the Europeans sailed ashore, with a significant portion of human induced erosion occurring in the first 500 years of Polynesian occupation (McSaveney & Whitehouse 1989). With the European settlement in the mid 1800's and procurement of land by whatever means, rates of deforestation and erosion sped-up with the aid of steel axes and livestock to remove timber for house and ship-building activities in coastal settlements.

The effects on the ecology of Tasman and Golden Bays of the deforestation and erosion at the turn of the century are difficult to imagine. The floods described up the Motueka valley in the 1870's would have deposited millions of tonnes of sediment into Tasman Bay, and were probably a fairly regular occurrence. This sediment would have had a significant smothering effect as well as cutting down light levels in the water column. The communities described by Tunbridge (1962), McKnight (1969a) and the University of Auckland (1975) would have likely been heavily modified from those predating pre-Polynesian and pre-European times. Heavy inundations of sediment can completely bury infaunal and epifaunal bivalves (McKnight 1969b) unless waves and currents can disperse the sediment plumes. As little as 3 mm of terrestrial mud can have significant effects on seafloor communities (Lohrer et al. 2004). Scallops and oysters can become stressed with high sedimentation rates, and siltation by fine-grained particles can prevent settlement and recruitment of these shellfish (MacKenzie and Adamson 2004). The decline of the Nelson oyster fishery in the late 1800's could have equally been caused by smothering or choking by sediment during floods as much as over-fishing as was recorded in Australia during the same period (Nell 2001).

It has also been shown that diatom mats on the seafloor are important potential food sources for scallops and oysters especially during winter months of low pelagic productivity (Gillespies et al. 2000). These diatoms are likely to be even more susceptible to sedimentation following flooding, which is most likely to occur in winter months on wet catchments. Regardless of the physical effects of sedimentation, the nutrient loads associated with deforestation, agriculture, and later urbanisation would also increase the eutrophication of waters in Tasman and Golden Bays. Nutrients would feed phytoplankton production in the water column, further reducing light levels and with thermal stratification of the water column in summer, potentially lead to hypoxic (lacking oxygen) conditions in deeper water of the bays, as has been described in the US (Kemp et al. 2005).

Fishing can have two types of effects which have relevance to the seafloor communities. These are the abiotic effects resulting from the physical process of fishing, such as dredging impacts, and the biotic effects associated with altered food chains from removal of biomass of fish, shellfish, and associated by-catch. The physical effects of dredging and trawling have been shown to reduce the density of common macrofaunal populations for up to three months (Thrush et al 1995) and reduce populations of important bioturbators – the marine equivalent of terrestrial worms that increase oxygen penetration into the sediment, leading to an enhancement in the ability of the seafloor to absorb and release nutrients (Widdicombe et al. 2004). The loss of bioturbating species also has important implications for the maintenance of diversity which further reduces the coastal community's ability to cope with organic enrichment. The more subtle effect of fishing, especially over soft sediment communities is the resuspension of sediments (Durrieu De Madron et al 2005). Resuspended sediments can affect bivalves' ability to process food (Barillé et al 1997) as well as the smothering effects of sedimentation mentioned above. Resuspension of sediments can also be driven by wind and waves in shallow environments (Booth et al. 2000, Gibbs 2001), and sediment can also be supplied by other sources like dredge spoil disposal operations (Roberts & Forest 1999, Schoellhamer 2002).

The biotic effects of fishing are the subtle food chain effects and feedback mechanisms that help structure communities. Large predators like snapper and lobsters are very important in structuring reef communities by removing grazers, which allow algal beds to proliferate, providing habitat complexity for juvenile reef fish and invertebrates (Babcock et al 1999). The removal of significant predator populations of snapper during the 1970's by, for example, a single catch of 2,700 tonnes in one year (1978), must have had significant food chain and community structure effects on the Tasman and Golden Bays. One could wonder whether the success of Challenger's scallop enhancement venture during the 1980's was in part related to this reduction of predators. Other biotic effects of fishing are the removal of habitat structuring species like bryozoan corals and horse-mussel beds. Horse-mussels and bryozoan colonies have been shown to be important modifiers of habitat of soft sediment communities increasing biodiversity and recycling nutrients (Cummings et al. 1998, Norkko et al 2001, Grange et al. 2003).

Without proper fisheries management systems, which are now in place in New Zealand, the destruction of fisheries can have profound affects, as observed overseas. Twenty eight oyster fisheries supported by biogenic oyster reefs were exploited to collapse across three coastal margins in North America, western North America and eastern Australia (Kirby 2004). Their account sounds very familiar to that reported for the early exploitation of the Nelson oyster beds in the late 1800's:

> "*Fishery collapse began in the estuaries that were nearest to a developing urban centre before exploitation began to spread down the coast. As each successive fishery collapsed, oyster from more distant estuaries were fished and transported to restock exploited estuaries near the original urban centre. This moving wave of exploitation travelled along each coastline until the most distant estuary had been reached and overfished.*" (Kirby 2004).

These reefs were more analogous to the biogenic reefs typical in Foveaux Strait (Cranfield et al. 2003) rather than the population present over mud bottom in Tasman and Golden Bays. However, Kirby (2004) makes an important point, that the habitat degradation of oysters along these continental margins remains under-appreciated in estuarine ecology today, and this is likely because of the "shifting-baseline syndrome" (Pauly 1995), i.e. where no scientist today has ever seen an undisturbed, fully functioning reef. This raises an important issue for the seafloor ecology of Tasman and Golden Bays. What we see today and what was recorded in samples collected even half a century ago is unlikely to reflect an undisturbed, fully functioning, ecosystem. Even the bryozoan colonies at Separation Point today appeared impacted by silt and are remnants of habitats which persist only because of strong tidal currents preventing their smothering by sediment and the protection granted with foresight to the impacts of fishing activities. In the US, efforts at restoration of oyster reefs have been driven by there being viewed as a tool to mitigate eutrophication of areas like Chesapeake Bay where a combination of fishing pressures, habitat loss and degradation, and nutrient inputs into the bay have led to areas of hypoxia and dead water for 4-5 decades (Kemp et al. 2005). Attempts at restoring seagrass and oyster beds initially failed, as they failed to address nutrient inputs into the parts of the bay. Analysis of this degradation has revealed:

> "*enhanced particle trapping and sediment binding by benthic plants (seagrass, microalgae* [diatoms]*) help to maintain relatively clear water columns, allowing more light to support more benthic photosynthesis. As the Bay 'degrades' and becomes more turbid with enrichment, however, these benthic autotrophic communities decline, allowing more resuspension, decreased light and so on. Similarly, nutrient-enhancement phytoplankton growth and sinking support increased benthic respiration and severe anoxia, which causes more efficient benthic recycling of N* [nitrogen]*… and P* [phosphorous]*… so support further production of phytoplankton in overlying water*." (Kemp et al. 2005).

Kemp et al. argue that the positive-feedback nature of these mechanisms means that they tend to reinforce and accelerate either eutrophication via water column productivity or restoration processes via benthic primary (plant) production. Restoration of oyster reefs that increase filtration reduces phytoplankton biomass which increases water clarity, aids benthic primary production by plants which slows down the release of nutrients, and reverses the move towards water column primary production which increases the likelihood of anoxic conditions.

Tasman and Golden Bays during the 1960's were dominated by deposit feeders feeding on plants and detritus on the sediment surface (McKnight 1969), and these organisms are still present in the benthos today (Table 1). Pollution levels and habitat modification in Tasman and Golden Bays are far from the levels seen in Chesapeake Bay (Kemp et al. 2005), but if there is a degradation of water clarity driven by nutrient and sediment inputs from terrestrial sources, and fishing and wave action continue to resuspend sediments, it is perceivable that hypoxic conditions could follow especially during times of the year when the water column is stratified. Hypoxic conditions have been recorded at least three times in Tasman and Golden Bays associated with the collapse of a slime producing alga species in the 1860's (Hurley 1982), 1960-61, and 1981-82 (Bradstock & MacKenzie 1981, Hurley 1982, Chang 1983) which resulted in reduced fish catches, but undescribed benthic impacts. Offshore from the Motueka River during spring and autumn the upper water column is typically low in phytoplankton, but the bottom waters are turbid containing resupended sediments (MacKenzie and Adamson 1994), with up to 90% of the suspended solids caught in sediment traps estimated to be derived from resuspension (Gibbs 2001). A common feature of Tasman Bay is phytoplankton productivity peaking in the mid water column (10-15 m) throughout the rest of the year (MacKenzie and Adamson 1994), which going by the finding of Kemp et al. (2005) suggests Tasman Bay may already be suffering from eutrophication. Determining the relative efficiencies of nutrient conversion via phytoplankton in the water column versus that of seafloor productivity would be an important issue especially for fisheries production (Kemp et al 2005). Presumably as Tasman Bay and Golden Bays were historically dominated by deposit feeders, and also highly productive in terms of fisheries production, any options for management of terrestrial impacts, fisheries methods, and ecosystem restoration should be driven towards maximising benthic primary production (i.e. plants- e.g. diatoms & seagrass). These measures would help increase water clarity to prevent the short-cutting of the nitrogen and phosphorous cycles from the seafloor and help trap and bind sediments as suggested by Kemp et al. (2005).

It is clear from this historical analysis of colonisation and early and recent fishing activities that the ecology of the seafloor Tasman and Golden Bays is likely to be substantially modified from their pre-human state. The still-functioning communities of Separation Point, the coastal reef margins, and the sustainable utilisation of fin and shellfisheries show that these modifications are not entirely detrimental. Their survival and function shows the ecosystem has adapted to and in the case of the bryozoan colonies fortuitously avoided those impacts. The QMS system is designed to manage the fisheries so that they are not fished below sustainable levels. Activities like the scallop enhancement company and the potential for enhancement of the oyster fishery are remedial steps towards restoration of these important filter feeding populations.

An idealist model for discussion would be for all fisheries; finfish, scallops and oysters to be fished rotationally within the bays, with areas left fallow for 2-3 years after seeding with scallops and or oysters (or shell material for them to settle on). The use of set-lines or at least reductions in bottom trawling could be used to maximise water clarity and enhance primary production on the seafloor. Concomitant with this should be increased measures to reduce nutrient and sediment discharge to waterways from agriculture and sewage, restoration of riparian zones from farmland and urban areas, and tighter controls on discharge from land developments. Aquaculture could also play a mitigating role, by positioning marine farms adjacent to river inflows to best utilise water column productivity driven by terrestrial nutrient discharges (Valiela et al 2004), and therefore helping to increase water clarity to increase benthic primary production elsewhere in the bays. In doing so, water quality must be maintained to allow harvesting of shellfish like mussels, necessitating clean river discharges as well. The rest of the bays could then be “farmed” on a rotational basis for fisheries resources. An important research question posed by Kemp et al. (2005) could then be investigated, determining the relative efficiencies and sustainability of primary production via the water column which can be utilised by aquaculture, versus benthic primary production to be utilised by shellfisheries and fin fisheries. Valuable control sites to be used in these studies could be the deepwater communities of Separation Point, and the recovering offshore soft-sediment communities of the Hohoirongi and Tonga Island Marine Reserves.

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