Potential ecological effects of a proposed dredge fishing exclusion zone in Tasman Bay

NIWA Client Report: NEL2008-28
September 2008

NIWA Project: ELF08204

Potential ecological effects of a proposed dredge fishing exclusion zone in Tasman Bay

Stephen Brown

Prepared for

Nelson City Council

NIWA Client Report: NEL2008-28
September 2008

NIWA Project: ELF08204

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

Reviewed by:

Approved for release by:

Formatting checked

……………………….

1. Introduction

The commercial harvest of mussels, oysters and scallops from the seabed in Tasman Bay dates back to the late 1800s (Wright 1990) but extensive dredging and trawling using powered vessels began in earnest in the mid 1900s (Drummond 1994, Bradford-Grieve et al. 1994, Handley 2006). Based on our knowledge of the benthos in Tasman Bay and studies of the effects of dredging in other areas, these activities have undoubtedly modified the benthic environment in Tasman Bay (Cranfield et al. 2001, Cranfield et al. 2003, Handley 2006, Kaiser et al. 2006). The Challenger Scallop Enhancement Company Ltd and the Challenger Oyster Management Company Ltd are currently considering the establishment of a voluntary dredge exclusion zone in Tasman Bay as a measure to mitigate the effects of towed dredges on the benthic environment. The zone under consideration encompasses an area of 2700 Ha around the fringe of inner Tasman Bay (Figure 1). The purpose of this study is to characterise the potential effects from the introduction of the exclusion zone and to assess the value of the exclusion zone to the local community. To that end, existing literature is first reviewed in order to summarize information describing:

- The benthic biota and habitats occurring within the proposed dredge exclusion zone,
- The ecological values associated with those biota and habitats
- The effects of dredging in soft sediment habitats.

Based on the information summarised, an assessment of the likely outcomes from the introduction of the exclusion zone is provided. Hard substrate habitats such as boulder and bedrock reef were not considered in this study, because such habitats are not subject to the direct effects of dredging or trawling activities in Tasman Bay.

2. Seabed ecological features within the proposed exclusion zone

2.1 Soft sediment macrofaunal communities

Soft sediment communities existing within the depth range of 0 to 30 m encompassed by the proposed dredge exclusion zone inhabit substrata ranging from gravel dominated sediments, to firm sand and soft mud. The predominant soft sediment within the zone comprises varying components of sand (grain size between 2 mm and 63 μm) and mud (grain size <63 μm) with a small component of calcareous gravel

(>2mm grain size) ((Mitchell 1987), Barter and Forrest 1998, Forrest 1999, Cole et al. 2003, Keeley et al. 2006).

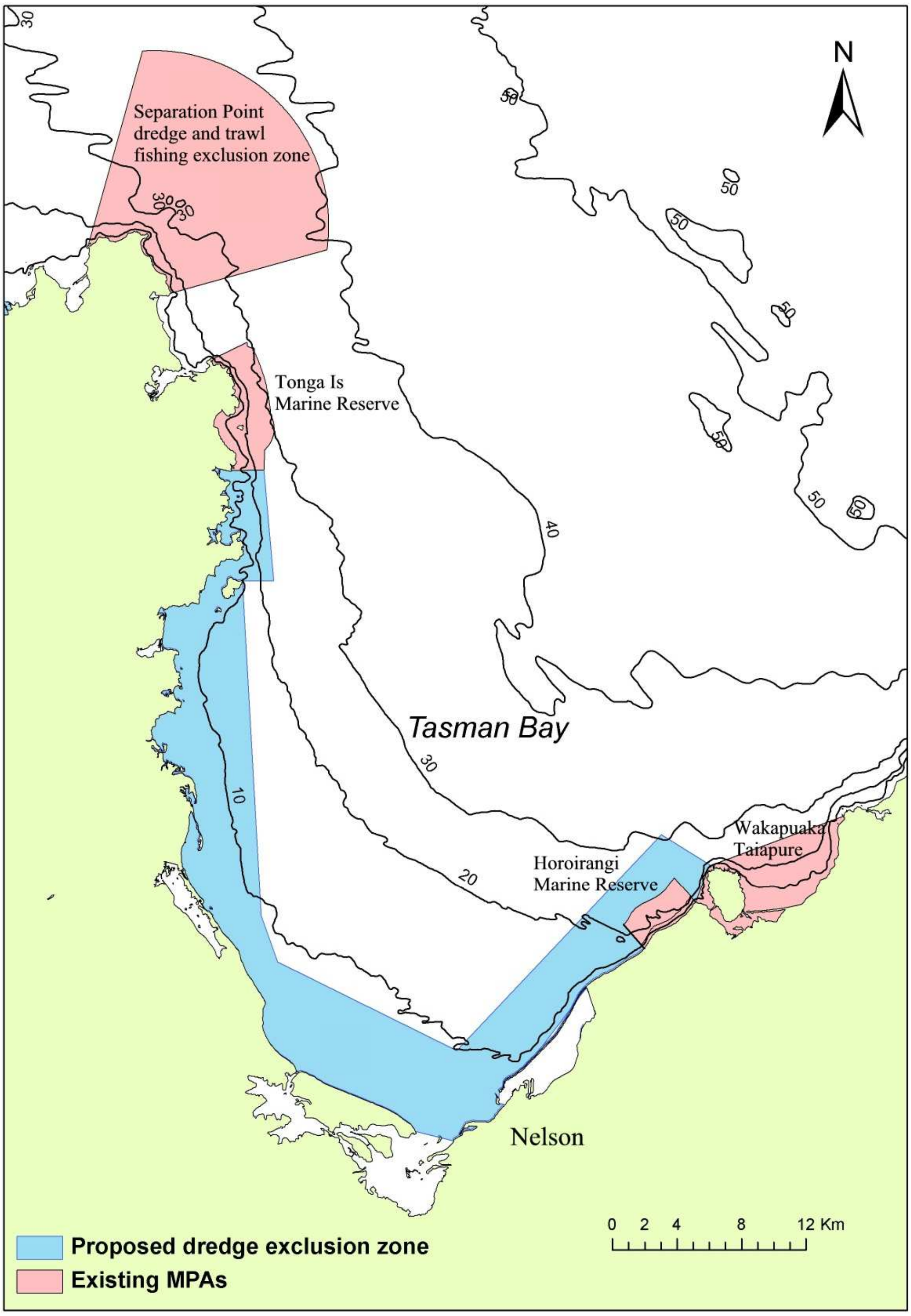

Figure 1. Location map showing proposed dredge exclusion zone and existing marine protected areas in Tasman Bay

The faunal communities associated with these sediments in Tasman Bay have been described in various benthic surveys and impact assessments (McKnight 1969, Barter and Forrest 1998, Forrest 1999, Brown 2001, Cole et al. 2003, Keeley et al. 2006). McKnight (1969) named the dominant soft sediment infaunal assemblage occurring in depths of 1-50 m in Tasman Bay an "*Amphiura rosea-Dosinia lambata* community". This assemblage was characterised by the species *Dosinia lambata* (bivalve mollusc), *Tellina charlottae* (bivalve mollusc), *Neilo australis* (bivalve mollusc), *Echinocardium cordatum* (heart urchin), *Nucula hartvigiana* (bivalve mollusc), *Maoricolpus roseus* (turret shell) and *Nemocardium pulchellum* (strawberry cockle). In terms of abundance, these communities tend to be dominated by several families of polychaete worm including lumbrinerids, cirratulids, sabellids and syllids in sandy areas (Barter and Forrest 1998) while nephtyids, onuphids spionids, flabelligerids, ampheretes, sigalionids and capitellids are more common in muddy substrates. Most of these echinoderms, molluscs and polychaete worms are deposit feeding species except for a few suspension feeders including the bivalve *Dosinia lambata* and the gastropod *Maoricolpus roseus*. Scallops (*Pecten novae zelandiae*), mussels (*Perna canaliculus*) horse mussels (*Atrina zelandica*) and flat oysters (*Ostrea chilensis*) are all large bodied suspension feeding bivalves also occurring in the proposed exclusion zone. Small bodied crustaceans including amphipods, isopods, cumaceans and ostracods are widespread and patchy in abundance, as are decapod species such as the ghost shrimp (*Callianassa filholi*), the mud crab (*Macrophthalmus hirtipes)* and the hermit crab (*Pagurus* sp.). The hermit crab and the sand-dwelling paddle crab (*Ovalipes catharus*) are carnivorous scavengers as are the carnivorous whelks *Amalda mucronata*, *Amalda australis*, *Austrofusus glans*, *Cominella adspersa* and *Poirieria zelandica*. Another commonly occurring gastropod species is the deposit feeding ostrich foot shell (*Struthiolaria papulosa*). Notable epifaunal species over Tasman Bay soft sediments include the carnivorous echinoderms the eleven armed starfish (*Coscinasterias calamaria*) and the cushion star (*Patiriella regularis*), the deposit feeding sea cucumber (*Stichopus mollis*) and the heart urchin (*Echinocardium cordatum*).

A notable species occurring at high densities in coarse sand habitat adjacent to the boulder bank on the southeastern side of the bay is the lancelet (*Epigonichthys hectori*). Lancelets are of scientific interest because they have features evolutionarily intermediate between invertebrates and vertebrates, and are considered uncommon at diveable depths (Barter and Forrest 1998). Dominant species in the shallow subtidal sandy habitat along the southwestern side of the bay include the sand dollar (*Fellaster zelandiae*) and the surf clam (*Paphies subtriangulata*) (Morrisey 2003).

2.2 Benthic microbiotic community

Photosynthetic microalgal species referred to as the microphytobenthos (MPB) grow in a thin layer or mat on the seabed in Tasman Bay, and contribute substantially to the photosynthetic biomass of Tasman Bay (Gillespie et al. 2000). Dominant taxa in Tasman Bay microphytobenthic assemblages include *Pleuriosigma amara* and *Paralia marina*. Other components of the soft sediment benthos are the meiofauna which includes the abundant nematode group (Barter and Forrest 1998) microfauna and various bacteria. These components of the benthic community in Tasman Bay are not well described.

3. Ecological significance of habitats and communities within the exclusion zone

3.1 Importance of the macrofaunal community

The macrofaunal community inhabiting the seabed fulfils a number of roles important for the functioning of the ecosystem in the bay. The burrowing, tube construction, locomotory, ventilation, feeding and excreting activities (bioturbation) of the macrofauna facilitate biogeochemical processes at the sediment water interface necessary for nutrient cycling through the ecosystem (eg Caradec et al. 2004, Valiela 1984). Seabed-dwelling invertebrate species occupy both predator and prey niches fundamental to the transport of energy through the marine food web (eg Schwartz 1982, Valiela 1984) and are the main food source for a variety of finfish species in Tasman Bay such as tarakihi (*Nemadactylus macropterus*), snapper (*Chrysophrys auratus*) and flounder (*Rhombosolea plebeia*)(Paul 1986).

3.2 Ecological buffer zone

The shallow margin of Tasman Bay where the proposed dredge exclusion zone is located may be considered a particularly important area in terms of the bay-wide ecosystem. A natural community with heterogeneous benthic structure and diverse faunal assemblages around the fringes of the bay has the capacity to entrap and stabilise sediment inputs, assimilate nutrients, and process other contaminants introduced to the bay via rivers and estuaries (Dame 1995, Caradec 2004). This area effectively provides an ecological buffer zone between nearshore estuarine, riverine and point source inputs, and deeper subtidal areas of the bay.

3.3 Benthic primary production

Microscopic algae living on the seabed (microphytobenthos or MPB) photosynthesize energy rich organic compounds from water and carbon dioxide. These types of organic compounds are the basis of the marine food web (Schwartz 1982, Valiela 1984). Within the shallower regions of the bay sufficient light energy reaches the seabed that the biomass of the microphytobenthos is likely to be substantial (Gillespie 2000). MPBs within Tasman Bay were estimated to contribute between 32 and 51 % of the total measured chlorophyll *a* during summer months. These microalgal species dwelling on the seabed are a significant component in the diet of many deposit and suspension feeding benthic macrofauna including molluscs such as scallops and oysters (Shumway et al. 1987, Pelizzari et al. 2005), and Gillespie et al. (2000) emphasizes that these benthic diatoms represent a potentially important contribution to the benthic food web in Tasman Bay.

4. Effects of dredging in shallow soft-sediment communities

There is a substantial body of scientific literature describing studies of the impacts of dredging and trawling to marine benthic habitats and also to the wider marine ecosystem. This review is limited to summarising the impacts identified by some of the most relevant studies in the context of shellfish dredging within shallow soft-sediment communities.

The primary negative impact resulting from dredge fishing is a reduction in abundance and diversity of seabed flora and fauna (Currie and Parry 1994, Kaiser 2006). This impact arises through direct physical damage to biota, and from the resuspension of sediments on the seabed. The severity of impact varies depending on the type of dredge, the nature of the habitat, and the frequency of disturbance. Dredging causes significant negative short term impacts in sand and muddy sand habitats, where intense scallop dredging has been found to reduce biota by up to 20 to 30% (Currie and Parry 1999, Thrush et al. 1995) for several months post-disturbance, but the effects of dredging are most severe in biogenic habitats composed of shell hash, bryozoan coral and other biologically derived substrata, where studies have demonstrated measurable impacts up to 4 years following the dredging event (Cranfield 2003, Kaiser 2006).

Secondary effects of dredging arising from the alteration of the physical structure of the seabed, a reduction in abundance of particular faunal taxa, and the resuspension of sediments, can impair ecosystem function. The physical effects of repeated dredging activities cause a decrease in the 3 dimensional structural complexity of the seabed which results in lowered biodiversity and affects the provision of ecosystem services by various components of the benthic community (Thrush and Dayton 2002, Cranfield et al. 2003, 2004, Kaiser 2006). Talman et al. (2004) found evidence that predation of scallops was greater in areas of low habitat complexity in Tasman Bay and suggested this may be due to the refuge from predators afforded by 3-dimensional features on less disturbed seabed areas. Widdicombe et al. (1999) used a mesocosm experiment to demonstrate that a decrease in large bodied bioturbating species can lead to reduced macrofaunal diversity. They asserted that dredging causes a decrease in abundance of large bodied bioturbators leading to a reduction in oxygen penetration into the sediment. This reduces the ability of the benthic community to process organic material, and in areas subject to eutrophication from other anthropogenic activities, may exacerbate effects of excessive nutrient enrichment leading to a reduction in ecosystem resilience and further reduction in faunal diversity. Several other studies have highlighted the effects of dredging in reducing the diversity and abundance of large bodied bioturbating species in light of their importance to ecosystem functioning in terms of exchange processes of organic matter and nutrients (Thrush and Dayton 2002).

Watling et al. (2001) found a significant reduction in microbial biomass in surface sediments following dredging, and a shift in composition of the microbial assemblage from microeukaryotes and phototrophic microeukaryotes to anaerobic prokaryotes. This change effectively reduced the quality and availability of feed in the surficial sediments that could be utilised by scallops and other suspension feeders.

By generating turbid plumes of resuspended sediment, dredging may cause a range of detrimental effects to the seabed biota including burial, clogging of respiratory and feeding mechanisms, and reduced light availability (Black and Parry 1999, Beninger 2008). By breaking up the biological bonds which bind loose sediment, dredging also facilitates further resuspension of sediments during naturally occurring turbulent events such as storms or during periods of particularly high current flow (Black and Parry 1999). Scallops, especially young spat are considered to be particularly vulnerable to the inhibitory effects to feeding and respiratory function caused by excessive inorganic sediment concentrations in the water column (Stevens 1987, Silina and Zhukova 2007).

Photosynthetic microalgal species forming MPB communities require light to photosynthesize and in Tasman Bay their biomass decreases with light levels as depth increases from inner Tasman Bay to Cook Strait. The direct and indirect effects of dredging which increase sediment resuspension and water turbidity levels could potentially have a significant detrimental effect on the growth and persistence of microphytobenthic communities due to a reduction in light reaching the seabed

(Cahoon and Cooke 1992, Black and Parry 1999). This could result in reduced benthic primary productivity and decreased food availability for deposit and suspension feeding components of the macrofaunal community including scallops and oysters.

With increased deforestation and excavation of catchment hillsides due to human activities, the quantity of terrigenous sediment entering coastal bays via river catchments is increasing (Lohrer et al. 2004). Deposition of these sediments can have negative impacts on coastal marine benthic communities (Lohrer et al. 2004, Forrest et al. 2007), and these effects are likely to be exacerbated by the effects of dredging disturbance.

In summary, regular dredging in soft sediment habitat subjects the affected communities and ecosystems to chronic physical disturbance. This changes the physical habitat and biological structure of ecosystems resulting in loss of structural complexity of the seabed, reduced biodiversity, and increased resuspension of sediments. These changes can ultimately reduce benthic productivity, and impair ecosystem function, to the detriment of a range of organisms including commercially and ecologically important species.

5. Effects of the exclusion zone

Commercial dredging occurred to only a limited degree within the proposed zone on the western side of the bay in the past and the current level of commercial dredging within the area is negligible (Mitch Campbell, Challenger Scallop Enhancement Co. pers. comm.). Furthermore, the frequency and extent of disturbance due to trawling and amateur dredging is unknown. Under the proposed initiative establishment of the dredge exclusion zone would only prohibit commercial dredging. Therefore this assessment considers the outcomes of protection of benthic habitat and communities within the dredge exclusion zone from the effects of potential commercial dredging activities in the future.

The exclusion of commercial shellfish dredging activities within the proposed zone would prevent direct impacts associated with commercial dredging disturbance to the soft sediment communities, and enable the maintenance of the existing natural benthic community diversity and ecosystem services. The continued absence of a significant anthropogenic ecosystem stressor in the form of dredging would help to preserve resilience of the benthic community in the face of natural disturbances such as storms and floods, or anthropogenic impacts such as industrial and stormwater point source discharges (Bevilacqua et al. 2006).

The dredge exclusion zone would confer a limited level of protection to a continuous corridor of benthic habitat from the Tonga Island reserve in the northwest of Tasman Bay around the perimeter of the bay to the Horoirangi Marine Reserve on the eastern side of the bay (Figure 1). This would aid existing shallow subtidal benthic species vulnerable to the effects of dredging to persist in a more continuous distribution, rather than a fragmented distribution imposed by dredging activities. This corridor may facilitate connectivity between marine protected areas (MPAs), in terms of the exchange of marine benthic species. One benefit of MPAs is increased larval export, potentially increasing recruitment in unprotected areas (Hare and Walsh 2007), thus the exclusion zone has the potential, along with the established MPAs, to act as a refuge and source of recruitment for benthic biota to deeper regions of the bay (Bevilacqua 2006).

Previous studies have demonstrated significant benefits to populations of commercially targeted bivalve molluscs such as scallops, oysters and mussels resulting from the restoration of various ecosystem services following the introduction of dredge fishing exclusion areas (Kaiser et al. 2007, Cranfield et al. 2001). Benefits of an exclusion zone in terms of buffering from anthropogenic disturbance, and as a refuge and source of broodstock, could extend beyond the boundaries of the exclusion zone to bay-wide populations of commercially targeted species in Tasman Bay (Bevilacqua 2006).

6. Summary and conclusion

The soft sediment habitat within the proposed dredge exclusion zone supports a diverse community of fauna and flora from a range of functional groups that contribute to the functioning of the marine ecosystem within the bay. The macrofaunal component of the community is well described from previous studies carried out at various sites within the exclusion zone.

The shallow region of the bay encompassed by the proposed exclusion zone is of special ecological significance as a buffer zone between the nearshore, and deeper subtidal areas of the bay. The maintenance of a resilient benthic community is important in preserving the capacity of this area to absorb anthropogenic impacts including industrial and stormwater point source discharge, and recover from disturbances such as storms and floods. Microscopic algae living on the seabed which contribute to primary productivity of the bay and are likely to be an important component of the food web occur abundantly in the shallow regions of the bay including areas within the proposed exclusion zone.

Regular dredging in soft sediment habitat subjects the affected communities and ecosystems to chronic physical disturbance causing a loss of structural complexity of the seabed, reduced biodiversity, and increased resuspension of sediments. These changes can ultimately lead to reduced ecosystem function and compromise provision of key ecological and commercial ecosystem services.

Establishment of the dredge exclusion zone would prevent future direct impacts of commercial dredging disturbance to the soft sediment communities, and promote the maintenance of natural benthic community diversity and ecosystem function. Special ecological values including the ecological buffering capability of the nearshore area, and the microphytobenthic community within the zone would be afforded protection from future commercial dredging activity. In addition, the increased protection would enhance the potential of the area within the exclusion zone to provide:

- A refuge for benthic biota and a source of recruitment to unprotected deeper regions of the bay, and

- A potential linkage corridor between marine protected areas already established in the bay.

Establishment of the dredge exclusion zone is not likely to result in significant measurable improvements to the ecological function of the bay in the short term. The area within the proposed exclusion zone is not commonly utilised by dredge fishers although historical and anecdotal evidence indicates dredging has taken place there in the past (Wright 1990, Mitch Campbell CSEC pers. comm.). This exclusion applies to commercial scallop and oyster dredging activities only, and while the boundaries coincide broadly with a voluntary finfish trawl exclusion zone, portions of the dredge exclusion zone are opened to inshore trawling on a seasonal basis. In addition, scallop and oyster dredging by recreational fishers is not restricted within the zone. The continuance of those activities dilutes the efficacy of the dredge exclusion, and in order to maximise the ecological benefits, all forms of towed gear fishing would have to be excluded within the zone. Nevertheless, formal establishment by the fishing industry of an area off-limits to commercial dredging would constitute a tangible mechanism for protection of valuable habitat from potential future impacts from that activity, and therefore confer some benefit to the ecosystem of the Bay.

Anecdotal evidence suggests that there are further areas of benthic habitat within Tasman Bay which have high ecological value, may be vulnerable to damage from dredging and trawling, and are of little commercial value to towed gear fishers. It would be beneficial for the ecosystem of the bay if such areas were identified, delineated and protected in consultation with dredge and trawl fishery managers and other interested parties.

7. References

Barter, P; Forrest, B. (1998). Effluent mixing and environmental impacts at the Wakapuaka Sewage Outfall. *Cawthron Report No. 420.* Cawthron Institute Nelson. 48 pp plus appendices.

Beninger, P.G.; Valdizan, A.; Decottignies, P.; Cognie, B. (2008). Impact of seston characteristics on qualitative particle selection sites and efficiencies in the pseudolamellibranch bivalve Crassostrea gigas. *Journal of Experimental Marine Biology and Ecology 360(1)*: 9-14.

Black, K.P.; Parry, G.D. (1999). Entrainment, dispersal, and settlement of scallop dredge sediment plumes: Field measurements and numerical modelling. *Canadian Journal of Fisheries and Aquatic Sciences 56(12)*: 2271-2281.

Bradford-Grieve, J.; Bull, M.; Drummond, K.; Gordon, D.; Laing, A.; Mackenzie, L.; Moore, M.; Murdoch, R.; Nodder, S. (1994). Summary of knowledge of the Tasman and Golden Bay marine environment relevant to fisheries enhancement. Report prepared for the Southern Scallops Fishery Advisory Committee, MAF Fisheries(Central) and Tasman District Council

Brown, S. (2001). Fisheries Outfall: Seabed effects survey and summary of water quality monitoring. *Cawthron Report No. 619.* Cawthron Institute Nelson. 13 pp plus appendices.

Bevilacqua, S.; Terlizzi, A.; Fraschetti, S.; Russo, G.F.; Boero, F. (2006). Mitigating human disturbance: Can protection influence trajectories of recovery in benthic assemblages? *Journal of Animal Ecology 75(4)*: 908-920.

Cahoon, L.B.; Cooke, J.E. (1992). Benthic microalgal production in Onslow Bay, North Carolina, USA. *Marine Ecology Progress Series 84(2)*: 185-196.

Caradec, S.; Grossi, V.; Hulth, S.; Stora, G.; Gilbert, F. (2004). Macrofaunal reworking activities and hydrocarbon redistribution in an experimental sediment system. *Journal of Sea Research 52(3)*: 199-210.

Cole, R.; Grange, K.; Morrisey, D. (2003). Marine habitats, fish and benthic species within a proposed marine reserve, Glenduan to Ataata Point, Nelson. *Niwa Client report: NEL2003-005.*Report prepared for the Ministry of Fisheries and the Department of Conservation. 37 pp plus appendices

Cranfield, H.J.C., G.; Michael, K.P.; Dunn, A.; Stotter, D. R.; Smith D. J. (2001). Promising signs of blue cod and oyster habitat changed by dredging in Foveaux Strait, southern New Zealand. *New Zealand Journal of Marine and Freshwater Research 35*: 897-908.

Cranfield, H.J.M., B.; Michael, K. P.; Hill, A. (2003). Effects of oyster dredging on the distribution of bryozoan biogenic reefs and associated sediments in Foveaux Strait, southern New Zealand. *Continental Shelf Research 23*: 1337-1357.

Cranfield, H.J.R., A.A.; Smith, D.J.; Gordon, D.P.; Michael, K. P. (2004). Macrofaunal assemblages of benthic habitat of different complexity and the proposition of a model of biogenic reef habitat regeneration in Foveaux Strait, New Zealand. *Journal of Sea Research 52(2)*: 109-125.

Currie, D.R.; Parry, G.D. (1999). Impacts and efficiency of scallop dredging on different soft substrates. *Canadian Journal of Fisheries and Aquatic Sciences 56(4)*: 539-550.

Currie, D.R.; Parry, G.D. (1994). The impact of scallop dredging on a soft sediment community using multivariate techniques. *Memoirs of the Queensland Museum 36 (2)*: 315-326.

Dame, R.F. (1995). Oyster reefs as components in estuarine nutrient cycling: Incidental or controlling? In Oyster Reef Habitat Restoration: A synopsis and synthesis of approaches. Proceedings From the Symposium. Williamsburg, Virginia. Edited by Luckenbach, M.; Mann, R.; Wesson, J. A. pp 267-280.

Drummond, K. (1994). The Challenger dredge oyster Tiostrea chilensis fishery. Draft New Zealand Fisheries Assessment Document 94/xx. New Zealand Ministry of Agriculture and Fisheries. 21 pp.

Forrest, B. (1999). Tasman Bay dredge spoil disposal: 1998 environmental monitoring. *Cawthron Report No. 475.* Cawthron Institute Nelson. 13 pp plus appendices.

Forrest, B.M.; Gillespie, P.; Cornelisen, C.D.; Rogers, K.M. (2007). Multiple indicators reveal river plume influence on sediments and benthos in a New Zealand coastal embayment. *New Zealand Journal of Marine and Freshwater Research 41(1)*: 13-24.

Gillespie, P.A.; Maxwell, P.D.; Rhodes, L.L. (2000). Microphytobenthic communities of subtidal locations in New Zealand: Taxonomy, biomass, production, and food-web implications. *New Zealand Journal of Marine and Freshwater Research 34(1)*: 41-53.

Handley, S. (2006). An analysis of historical impacts and composition of the benthic environment of Tasman and Golden Bays. Report prepared for Tasman District Council.NIWA Client Report: NEL2006-002. 28 pp.

Hare, J.A.; Walsh, H.J. (2007). Planktonic linkages among marine protected areas on the south Florida and southeast United States continental shelves. *Canadian Journal of Fisheries and Aquatic Sciences 64(9)*: 1234-1247.

Kaiser, M.J.; Clarke, K.R.; Hinz, H.; Austen, M.C.V.; Somerfield, P.J.; Karakassis, I. (2006). Global analysis of response and recovery of benthic biota to fishing. *Marine Ecology Progress Series 311*: 1-14.

Kaiser, M.J.; Blyth-Skyrme, R.E.; Hart, P.J.B.; Edwards-Jones, G.; Palmer, D. (2007). Evidence for greater reproductive output per unit area in areas protected from fishing. *Canadian Journal of Fisheries and Aquatic Sciences 64(9)*: 1284-1289.

Keeley, N.; Gillespie, P.; Bennett,C. (2006). Horoirangi Marine Reserve soft sediment baseline ecological survey, 2006. *Cawthron Report No. 1186.* Cawthron Institute Nelson. 18 pp plus appendices.

Lohrer, A.M.; Thrush, S.F.; Hewitt, J.E.; Berkenbusch, K.; Ahrens, M.; Cummings, V.J. (2004). Terrestrially derived sediment: Response of marine macrobenthic communities to thin terrigenous deposits. *Marine Ecology Progress Series 273*: 121-138.

McKnight, D.G. (1969). Infaunal benthic communities of the New Zealand continental shelf. *New Zealand Journal of Marine and Freshwater Research 3*: 409-444.

Mitchell, J.S. (1987). Tasman Sediments. New Zealand Oceanographic Institute Chart. Coastal Series.1:200 000

Morrisey, D. (2003). Assessment of ecological effects of beach renourishment at Tahunanui Beach, Nelson. *NIWA Client report: NEL2004-001*. Report prepared for Staig and Smith Ltd Nelson. 18pp.

Paul, L. J. (1986). New Zealand fishes. An identification guide.Published by Reed Methven Limited. 184 pp.

Pellizzari, F.; Borzone, C.A.; Pezzuto, P.R.; Zehnder-Alves, L. (2005). The contribution of microphytobenthos for scallop Euvola ziczac (Bivalvia: Pectinidae) feeding in a shallow area of the south-eastern Brazilian continental shelf. *Journal of the Marine Biological Association of the United Kingdom 85(4)*: 961-967.

Shumway, S.E.; Selvin, R.; Schick, D.F. (1987). Food resources related to habitat in the scallop *Placopecten magellanicus (*Gmelin 1791): A qualitative study. *Journal of Shellfish Research 6(2)*: 89-95.

Schwartz, M. L. (1982)The Encyclopedia of beaches and coastal environments. Encyclopedia of Earth Sciences Series,. Volume 25. Published by Hutchinson Ross. Stroudsburg, Pennsylvania.940 pp.

Silina, A.V.; Zhukova, N.V. (2007). Growth variability and feeding of scallop *Patinopecten yessoensis* on different bottom sediments: Evidence from fatty acid analysis. *Journal of Experimental Marine Biology and Ecology 348(1-2)*: 46-59.

Stevens, P.M. (1987). Response of excised gill tissue from the New Zealand scallop *Pecten novaezelandiae* to suspended silt. *New Zealand Journal of Marine and Freshwater Research 21*: 605-614.

Talman, S.G.; Norkko, A.; Thrush, S.F.; Hewitt, J.E. (2004). Habitat structure and the survival of juvenile scallops Pecten novaezelandiae: Comparing predation in habitats with varying complexity. *Marine Ecology Progress Series 269*: 197-207.

Thrush, S.F.; Hewitt, J.E.; Cummings, V.J.; Dayton, P.K. (1995). The impact of habitat disturbance by scallop dredging on marine benthic communities: what can be predicted from the results of experiments? *Marine Ecology Progress Series 129(1-3)*: 141-150.

Thrush, S.F.; Dayton, P.K. (2002). Disturbance to marine benthic habitats by trawling and dredging: Implications for marine biodiversity. *Annual Review of Ecology and Systematics 33*: 449-473.

Valiela, I.(1984). Marine Ecological Processes. Published by Springer-Verlag New York. 546 pp.

Watling, L.; Findlay, R.H.; Mayer, L.M.; Schick, D.F. (2001). Impact of a scallop drag on the sediment chemistry, microbiota, and faunal assemblages of a shallow subtidal marine benthic community. *Journal of Sea Research 46(3-4)*: 309-324.

Widdicombe, S.; Austen, M.C. (2004). Mesocosm investigation into the effects of bioturbation on the diversity and structure of a subtidal macrobenthic community. *Marine Ecology Progress Series 189*: 181-193.

Wright, K. (1990): Nelson and Marlborough oyster history. The Journal of the Nelson and Marlborough historical societies. Volume 2, No. pp. 3-8.