6 Potential drivers of shellfish production

6.1 Primary production – food for shellfish

There are two sources of primary production for filter feeders: phytoplankton in the water column and benthic microalgae on the seabed. Both sources of food are likely to be important to shellfish, especially scallops at different periods during the year. Both require nutrients, adequate light levels and duration, and vertical mixing of waters for photosynthesis and production. Plant growth is greatest in clear water, close to the surface where there is maximum light, especially in summer when days are long and the sun is brightest.

Nutrients are mainly transported in to the bays by wind driven circulations from oceanic sources (~80–90%, spring summer). Nelson Bays are typically nutrient limited (nitrogen and phosphorus). Primary production is dependent on nutrients transported on-shore from upwelling off the West Coast and around Farewell Spit by wind and tidal currents. There are few data on the persistence, seasonality, and the effects of ENSO (El-Nino/La Nina) on upwelling and the delivery of nutrients in to GBTB. Nutrients from land sources are dependent on freshwater inflow making up estimated 10–20% of total nutrients. El Nino years are characterised by strong south-westerly winds, which are likely to aid the transport of oceanic water in to Cook Strait. La Nina years are likely to result in reduced nitrogen levels in the bays, and could reduce primary production, and its flow on effects. No data are available on the relative importance of terrestrial and offshore sources of nutrients, and how they respectively fuel primary production consumed by benthic shellfish.

Factors that can limit primary production include: stratification of the water column (lack of mixing; e.g. layering of warmer on colder, or fresh on salty), lowered light by season (short days and low sun angle), and suspended sediments. "Seasons" may vary in timing and intensity, but generally:

- Winter: nutrients high, low plankton, water column stratified by salinity;
- Late winter spring: high plankton abundance; mixed water column, and increasing light to produce bloom conditions, wind may increase turbidity.
- Summer: thermally stratified, nutrient depleted, deep boundary layers, near bottom, increased turbidity near the seabed may reduce ability to feed, benthic algae become more important.

Consistent year round availability of food is more likely at depths shallower than 20 m. Benthic production is generally greater in the shallows, but can vary depending on location in the bays. Comparisons of the benthic and planktonic cycles indicate that benthic microalgae can play a major role in shellfish nutrition by ensuring continuity of the particulate food supply during periods of particularly low phytoplankton abundance.

Trends in availability of food for benthic bivalves from phytoplankton in late winter early summer to benthic algae in late-summer and early-winter. Shellfish food production is mainly driven by water column stratification, nutrients and light. Stratified conditions were most prominent following moderate to high rainfall events. Such conditions can persist for a period of weeks after a significant flood event. Freshwater affects primary production in a number of ways: enhancement or inhibition of primary production, contamination of seawater and/or sediment environments.

Water clarity can, in turn, affect the amount of light available for photosynthesis, both within the water column and at the seabed. Sufficient light penetrates to the seabed throughout a majority of Tasman Bay to support some degree of photosynthetic activity. However, light levels at the seabed can be highly variable, depending on the clarity of the water, and often low enough to limit microalgal growth, particularly at depths greater than 15 m. Phytoplankton and benthic microalgal production can therefore be inhibited by sediment inflows.

What we know

Two sources of primary production: phytoplankton (water column), and seabed plants like benthic microalgae, seaweed, and seagrass.

Plant growth is optimum in clear, well mixed water with high nutrient levels, and long light exposure.

Waters of GBTB are limited in nitrogen and potentially phosphorus. These nutrients are supplied mostly from Cook Strait, but originate from upwelling of nutrient rich deep water off Cape Farewell and the West Coast (~80%). Less than 20% of nutrients come from rivers.

ENSO affects upwelling and nutrient supply; likely to be more primary production with El-Nino than La-Nina.

Primary production is generally greater in shallows (less than 15m), but variable in the bays. It is strongly seasonal.

What we don't know

Has benthic and pelagic primary production changed significantly preceding declines of shellfish populations?

How variable is the delivery of nutrients in to the bays and what drives that variability?

Is phytoplankton biomass mainly derived from within the bays or dependent on coastal and oceanic sources and delivery mechanisms?

How are nutrient levels and primary production driven by long-term ENSO patterns?

What are the critical food limiting periods for shellfish condition/health and how does this vary spatially across habitats and across seasons?

What we know continued

Benthic microalgae can be an important food source for shellfish, especially during low phytoplankton abundance (late summer and early winter).

The availability of food is mostly limited by stratification of the water column by floods/freshwater inflow in the winter and temperature stratification in the summer.

Light levels at the seabed are highly variable depending on suspended sediment loads and depth, the lack of light can limit plant growth especially in depths greater than 15m.

What we don't know continued

How productive are benthic algal communities in GBTB and how do environmental and man-made effects affect their abundance?

What role do benthic filter feeders play in water clarity and benthic primary production?

6.2 Suspended Sediments

6.2.1 Terrestrial sediments

Sediments are introduced from rivers within the bays and the west coast. There is a prevailing northward drift of currents and sediment along the west coast of the South Island, with rapid deposition of sandy sediments on Farewell Spit. The relative significance of the indirect marine sediment contribution compared to the direct terrestrial input in to Golden and Tasman bays is unknown.

The average annual sediment load delivered to the bays was calculated using NIWA's Suspended Sediment Yield Estimator, and temporal variation (annual and storm) and land use effects on sediment load are inferred from results from the Motueka River. The biggest contributor to the average annual suspended sediment load to Tasman and Golden bays is the Motueka River (41% of the total load delivered to the bays), with significant contributions from the Waimea (13%), Aorere (12%), the Wainui catchments (9%), and the Takaka (8%).

The variation of sediment generation from the land reflects the influence of rainfall and geology. The highest specific suspended sediment yields are from the granite catchments of the Wainui and Marahau (>300 t km–2 y–1), with moderate loads from the Motueka, Whangamoa, Aorere, and Waimea rivers (100–170 t km–2 y–1). The highest yields come from high rainfall areas under native vegetation (DOC estate), or areas underlain by highly erodible Separation Point Granite (native vegetation or plantation forest).

Annual sediment loads are highly variable. In the Motueka they ranged from 49 000 t to 1.7 Mt (1969–2008) and have been relatively low for the last two decades. The years with highest sediment delivery to Tasman Bay had big floods and/or high numbers of floods. It is likely that similar patterns of variation of sediment delivery to the bays apply to the other major rivers.

Most sediment transported to Tasman and Golden bays is carried in flood flows, with small numbers of events carrying a high proportion of the sediment. Large storm events can elevate sediment loads for a period of several years following the event. The December 2011 floods are unlikely to have made an especially large contribution to total sediment load delivered to the bays because they were localised to the coastal areas around Takaka–Pohara and Nelson City–Cable Bay.

Most flood events have a relatively short duration (hours to days), so most sediment is delivered to the bays over short periods. Transit times for floodwaters, and associated sediment, from the headwaters to the coast tend to be short (a maximum of 8–12 hours).

There is little information on the composition of sediment delivered from the rivers into the bays. In two tributaries of the Motueka the suspended load was dominated by coarse sand. At the coast it is likely to be considerably finer. It is likely that the grain size of sediment delivered from the rivers is similar in Golden Bay and Tasman Bay.

Land use is likely to have a minor influence on sediment yield. Most of the catchments draining to Tasman and Golden bays are covered by indigeneous (56% of the contributing area) and plantation forests (18%), with smaller areas of pastoral grassland (13%) and cropland (12%). On average pastoral grassland is likely to generate more sediment than plantation forestry, although the latter can cause elevated sediment yields when forests are harvested. Forest harvesting is not likely to have a major influence on temporal variation in sediment load to the bays since there is a relatively small proportion of plantation forest and only a small proportion is harvested each year. There are no data on changes in the size of areas of plantation forest harvest over time. Estimated harvest of plantation forests from the Nelson region doubled from 1994 to about 1.60 ±0.1 Mm^3 from 1999 to 2005.

Little is known of the longer-term history of catchment erosion and sedimentation in Tasman and Golden bays, but it is likely that there was an increase in sedimentation following European-era deforestation, with anecdotal records of large floods and severe erosion. Currently coasts are eroding and riverbeds are degrading suggesting sediment supply is limited compared to previous times. Gravel extraction also contributes to this trend.

If sediment has been an influence on the state of the benthic environment and the shellfish fisheries, it is more likely to be a legacy effect or a cumulative effect, since the fishery has declined at a time when sediment yields, at least in Tasman Bay, have been relatively low.

6.2.2 Dredge spoils

Maintenance dredging at the Port of Nelson over the last 30 years has seen about 50,000 m^3 of sediment dumped annually at the Tasman Bay spoil dumping area since 1974. Varying degrees of trace metals, pesticides, and other chemicals contaminated the port sediments, and laboratory test show mildly elevated toxicity. Animals on the seabed were dominated by small worms. There was very little indication of any other impacts in the spoil disposal area. The spoil dumpings are dispersed rapidly by currents and wave action in Tasman Bay.

Some coarse gravel and mudstone was present about 10 years ago that became colonised by green-lipped mussels and juvenile crayfish, but this habitat is now largely gone. No undue changes have been noted in subsequent surveys. A five-yearly report is to be released soon.

6.2.3 The transport, deposition, suspension and final deposition of sediments

Suspended sediments enter the bays in low density freshwater that is buoyant and sits over the denser oceanic water. Coarse, heavy sediments settle out of the water column quickly. Fine sediments are carried in the more buoyant water until it is mixed with oceanic water, allowing fine sediments to reach the seabed in the mixed water and to settle. The influence of river plumes on the seabed sediments of the bays have been modelled using salinity field simulations. These described different river flow and wind direction/velocity scenarios that suggest that the Motueka River plume can cover considerable proportions of western side Tasman Bay, extending into Golden Bay during flood conditions. A sediment transport model was also used to investigate the fate of fine sediments entering the bays. Simulated distribution patterns of fine sediments entering the bays from the four major tributaries were found to be consistent with existing bathymetric and seabed substrate characteristics (Figures 16 & 17).

The seabed characteristics within the coastal river plume extending from the Motueka River were described along a series of transects. A mineral-rich geological formation in the headwaters of the river was identified as a storm-generated source of highly elevated concentrations of nickel and chromium in river margin sediments, and coastal sediments extending more than 5 km offshore. A major storm in 2005, focused in the upper catchment, resulted in an estimated suspended sediment discharge of 161 000 tonnes into the Bay. Spatial gradients of a suite of sediment trace metal signatures, organic content, and the community structure of animals living in the seabed were used to define a river plume depositional footprint of about 180 km^2 (Figure 18).

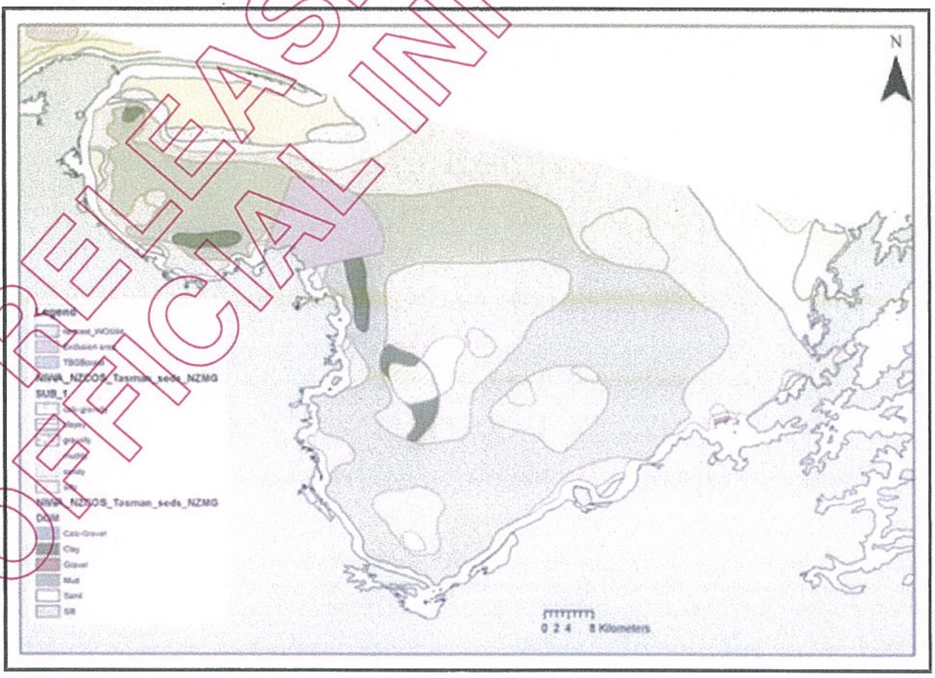

Figure 16: The distribution of sediments in Golden and Tasman Bays.

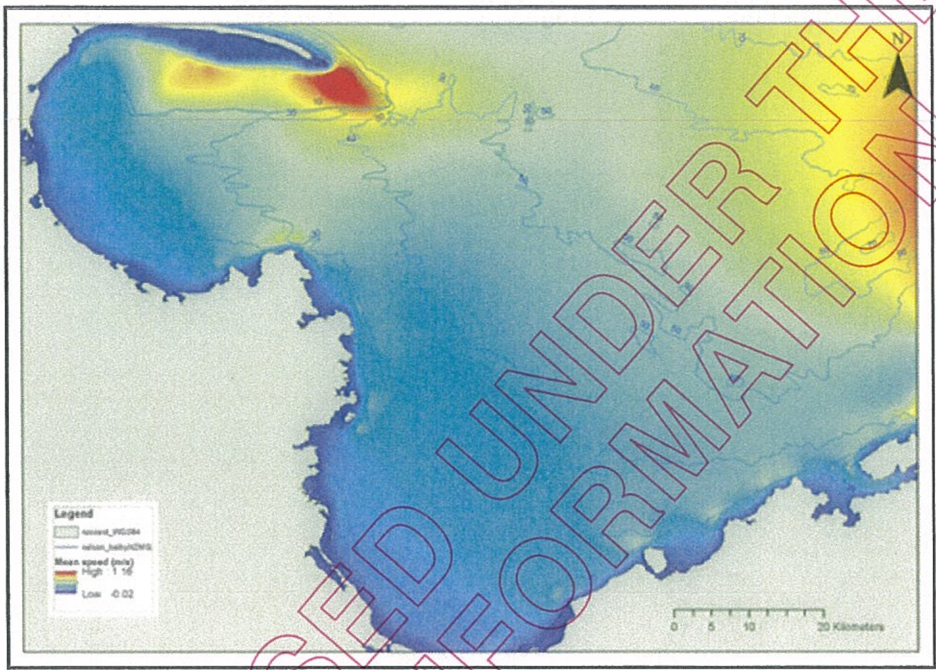

Figure 17: Mean current speeds in Golden and Tasman Bays.

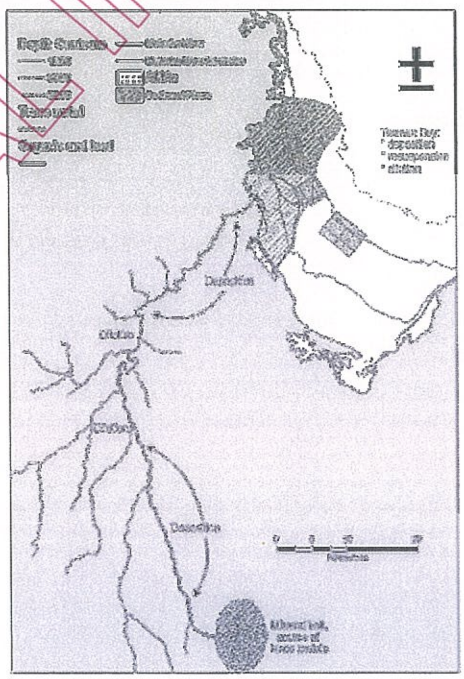

Figure 18: Depositional area and mechanism of delivery nickel and chromium enriched sediments from the upper Motueka River catchment into Tasman Bay. The mineral belt region is not drawn to scale.

6.3 Turbidity

6.3.1 TASCAM time-series data

TASCAM timeseries data includes turbidity data from a site 6 km from the Motueka river mouth. High turbidity 'events' near the seabed appear to be a function of the resuspension of sediments by the effects increasing wave action on the water mass (increases in significant wave height) (Figure 19). At a depth of 20m, turbidity levels are generally two to three times higher about 0.1 m above the seabed, than at 0.5 m above it. High turbidity events typically coincide with storms, and although elevated discharge by the Motueka River also occurs during these times, the increase in turbidity begins prior to the river plume reaching the monitoring site. Hence although river plumes result in the input of fine sediments into the Bay (Figure 20), the elevated near-bottom turbidity during storm events is associated with resuspension of sediments already present on the bottom. Based on the data in Figure 19, it would appear significant wave height must exceed about 1 m to result in resuspension.

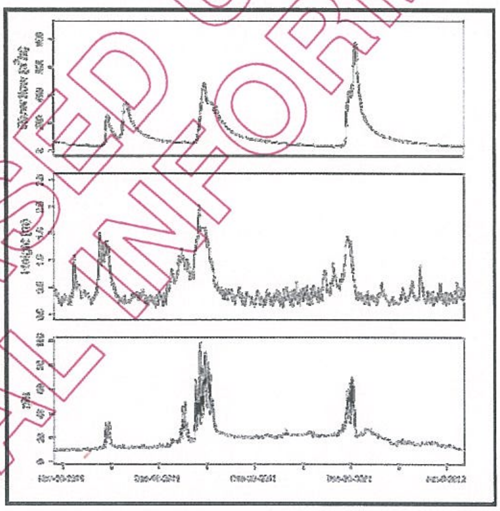

Figure 19: Time series of Motueka River flow from Woodmans Bend (top), significant wave height at the Nelson Port Beacon (middle), and turbidity (bottom) measured ~ 0.1 m above the seabed.

Figure 20: High river discharge results in a buoyant low salinity plume that transports land-derived sediments out into the Bay.

Elevated turbidity during storm events occurs throughout the entire water column and decreases with distance from the river mouth. For instance, during a moderate flood (~400 m^3/s), turbidity 3 m below the water's surface ranged between 3 and 25 NTU at a distance of 3 km from the river mouth, which was approximately twice as high as the turbidity measured at a distance of 6 km (Figure 21). This is likely due to increased resuspension associated with waves in shallower water. As was the case described above, increased turbidity at these locations coincided with the high wind period prior to the arrival of the outwelling river plume.

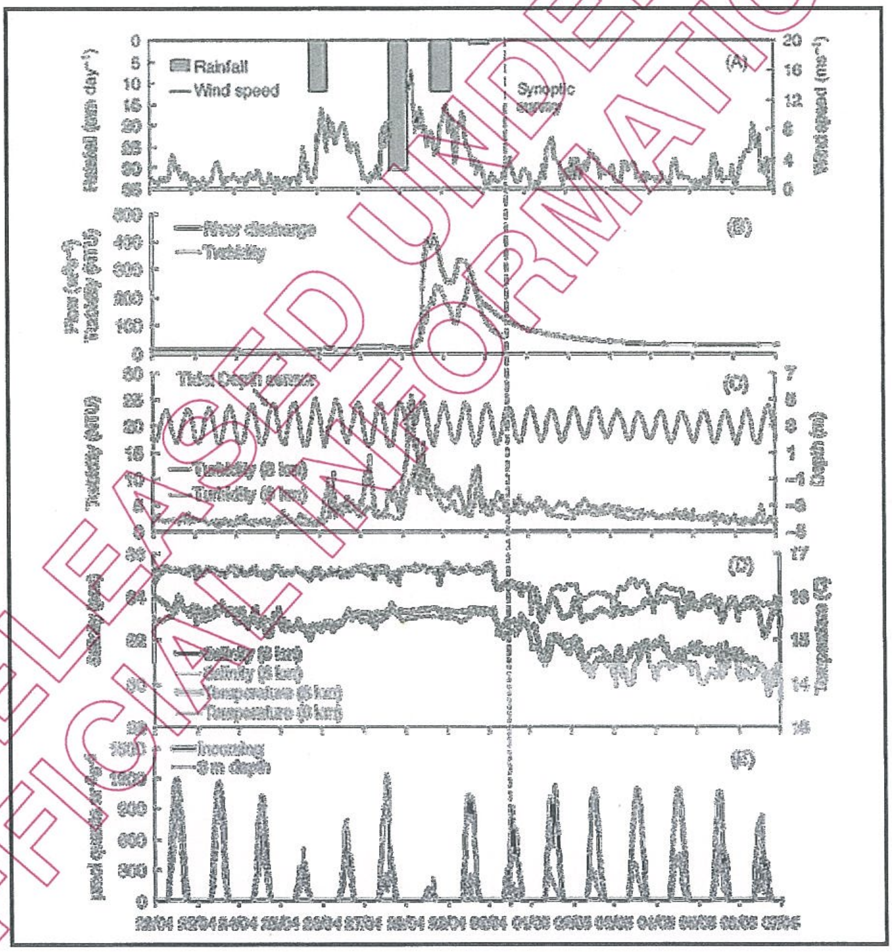

Figure 21: Weather conditions, river flows and water quality conditions in Tasman Bay between 22 April and 7 May 2009. A. Rainfall measured at Tapawera and wind speed measured at the Nelson Airport. B. River flow and turbidity measured at Woodmans Bend. C. Turbidity (NTU) measured at c. 3 m depth at the two moorings located at 3 and 6 km distance from the river mouth and the tide signal as measured by a pressure-depth sensor mounted on the buoy at 3 km. D. Salinity and water temperature measured at the two buoys. E. Incoming and sub-surface (3 m) irradiance measured at the buoy located 6 km from the river mouth.

6.3.2 Near seabed turbidity

In shallow coastal areas such as GBTB, suspended particulate matter including sediments and plankton may be re-suspended several times before being permanently bound on the seabed. During periods of high wave action and swells such as storms, turbulence created by wave action reaches the seabed and suspends particles on, and at times from within the seabed sediments. The amount of suspension depends on the amount of wave energy and the size (density) of lose material. In light wind conditions, when wave energy isn't great enough to penetrate to the seabed, and there is density stratification (temperature or salinity), the greatest turbidity occurs nearest to the seabed.

The sediment is suspended by shear forces caused by turbulence of the water moving across the seabed water interface. This turbulence is the result of complex flows between tidal currents, separate cross currents for example caused by onshore movement of oceanic water, and vertical oscillation and "pulsing" of the water below the boundary layer (thermocline) known as seiching. Seiching forces the cross shelf current flow against the seabed producing highly variable turbulence that picks up and suspends sediments and plankton.

The presence of a near-bottom turbidity layer is now a characteristic feature in Tasman Bay (and to an unknown extent in Golden Bay). These highly turbid bottom waters have a high concentration of plankton and also carry a substantial suspended sediment load. In Tasman Bay, the turbulence is the result of complex flows between tidal currents moving across the bay, cool deeper water entering the bay across shelf from Cook Strait, and seiching of the boundary layer (thermocline). The greatest turbidity occurs across a depth zone of about 12 m to 18 m, where the shear stress of the boundary layer moves in and out with the tide across the seabed.

Limited summer sampling in Tasman Bay has shown areas of the bay less than 20m depth had higher turbidity, with highest values near the bottom and in the surface waters, the latter presumably associated with the Motueka River plume. Outside the plume, inshore waters had substantially higher plankton densities throughout the water column than deeper waters, consistent with good mixing and light penetration. In deeper parts of Tasman Bay (~22 m), the thermocline occurred at 18 m and light penetrated to the sediments. These areas of the bay were nitrogen limited throughout the water column. Plankton concentrations and turbidity both increased rapidly in the 2-4-m-thick layer between the boundary layer and the sediments, in depths of 14–22 m.

6.3.3 Spatial extent of near-bottom turbidity

The presence of a thick, high turbidtity layer has been observed to extend more than 40 km out into Tasman Bay, particularly during the spring and early summer months. CTD surveys (conducted between 2009 and 2012) have also demonstrated the presence of a high, near-bottom turbidity layer extending out to at least 15 to 20 km from the river mouth during summer months. These surveys have primarily focused on the area influenced by the Motueka River plume; hence the full spatial extent of the near-bottom turbidity layer has not yet been determined and it could at times cover even larger areas of the Bay. An Autonomous Underwater Vehicle collected data within the turbidity layer along transects;

results demonstrated that tides have a strong influence on the layer and its relative extent at a given location (Figure 22).

During floods flows the Motueka River plume can extend several tens of km offshore and in a northerly direction, with an associated depositional footprint of fine river-derived sediments. Overseas studies have revealed a coupling between river plume distribution and seabed effects, suggesting that the Motueka River out-welling plume has the potential to affect benthic habitats across many kilometres. The plume represented by the salinity field can extend considerable distances into western Tasman Bay and under large flood conditions, extend into Golden Bay. Although the flow rate into Golden Bay by the Aorere River was much higher than the Motueka River, the plume from this river was inconsequential when compared to the plume of the Motueka River. It is thought that the circulation pattern of Golden Bay makes scallops much less prone to these plumes.

Bottom contact fishing gears generate localised sediment plumes during fishing. The relatively low settlement rates of these suspended sediments are likely to result in small plumes extending from fishery areas. The significance will be related to the numbers of vessels and intensity of fishing activity, but is likely to be relatively small when compared to bays wide suspension of sediments by boundary currents and storm conditions.

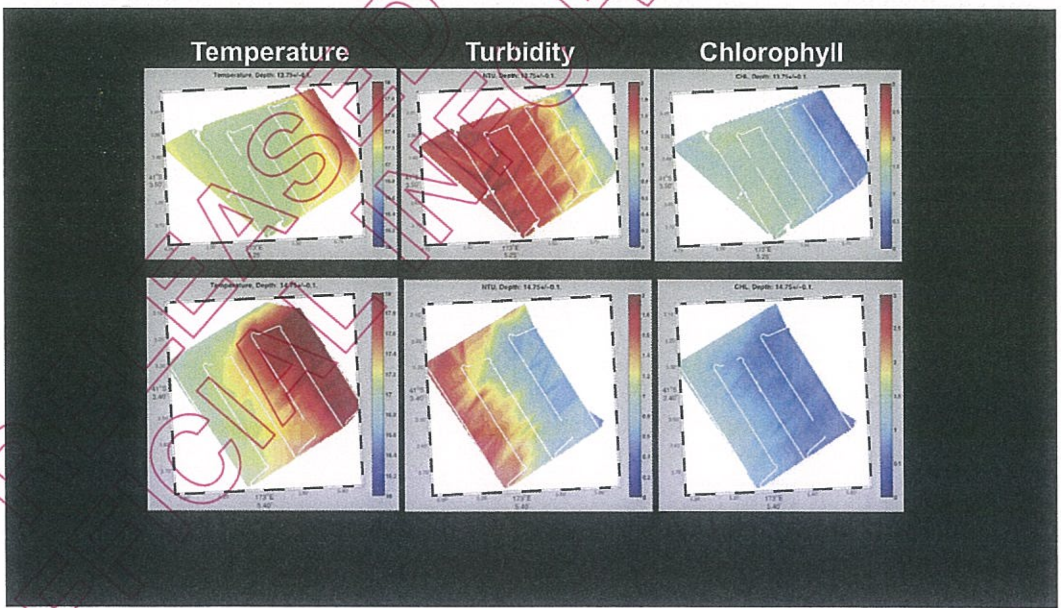

Figure 22: Interpolated horizontal AUV surveys of near bottom temperature, turbidity and chlorophyll a in the vicinity of the TASCAM buoy during various stages of an incoming tide.

6.4 The effects of suspended sediment

6.4.1 Smothering by sediment

Sediment covered 30% of the surface area of piles of scallop shell placed on the seabed for oyster enhancement in Tasman Bay, and increased to around 55% cover after 12 months. Poor survival of oyster spat due to smothering by sediments is one of the main reasons enhancement has not been successful in Australia. There are numerous examples of shifting sediments burying scallop bed and leading to mass mortality of scallops, but usually in higher energy environments. The generally low swell and wind driven wave size in the bays suggests the burial of shellfish by sediments is unlikely to be a significant problem.

6.4.2 The effects of suspended sediment on primary production

Benthic microalgae (e.g. diatoms) are likely an important food source for scallops, particularly when phytoplankton concentrations in the water column are low. It is likely that frequent resuspension of bottom sediments disturbs microalgae communities inhabiting surface sediments. Following sediment resuspension, the persistence of a layer of high turbidiy near the bottom would in turn inhibit light and reproduction in benthic microalgal communities.

Benthic microalgal communities, such as diatom mats, are known to enhance cohesion of sediments; hence the inability of microalgae to sufficiently re-establish would further contribute to the persistent nature of the high near-bottom turbidity layer and the susceptibility of bottom sediments to resuspension.

6.4.3 Scallop physiology

The resuspension of sediments can inhibit shellfish growth and reduce survival rate by having a detrimental effect on the respiration and ciliary activity. A detrimental effect on these activities leads to a reduction in the pumping and feeding in scallops. Increases suspended sediment loadings can reduce growth and reproductive capability.

Scallop feeding physiology also varies with degree of aggregation of individual sediment particles. Fine suspended silt (<5 µ) was found to be more deleterious than those between 5–25 µ because there was an inability of cilia to clear the finer particles (<10 microns) that accumulate in gills.

The tolerance of scallops to suspended silt also varies with size. Juveniles may be less tolerant to suspended silt than adults. The intolerance of smaller scallops to silt and depleted dissolved oxygen levels, relative to bigger scallops, may explain why juveniles have poor survival rates in muddy habitats. Aside from having a detrimental effect on the respiration of bivalves, high levels of sedimentation can also inhibit the metamorphosis of larvae and the settlement larva. These stresses can also pre-dispose shellfish to disease.

6.5 Water circulation

Water circulation patterns in Golden and Tasman Bays are driven by tidal flows, flows of freshwater in to the bays, wind forcing, and the general eastward flow in Cook Strait. The mean circulation involves a clockwise flow, in Golden Bay, and an anticlockwise gyre in Tasman Bay. In southern Tasman Bay, a counter (clockwise) flow exists. The variability in circulation within Tasman Bay and Golden Bay was associated with tidal flows, but simulation models show high variability in circulation patterns from local wind-driven flows.

Wind conditions are predominantly from the west across Golden Bay and northern Tasman Bay with a higher incidence of northerly and southwesterly winds in southern Tasman Bay. Strong winds are infrequent, especially in the southern part of Tasman.

Wind-driven currents have speeds of a similar or larger magnitude than the mean flow and are quite significant for the dispersion of suspended material and of the surface waters. They may be quite significant in moderating the exchange of water between Tasman and Golden Bays.

The wind-driven flows are likely to show seasonality, based on the seasonality in the wind field, and wind fields are likely to be location dependent. There is little information available on wind fields to model current flows more precisely. We also have inadequate information on where return flows occur to balance the wind-driven flows. That is, do surface flows out of the bays create narrow inward flows on the surface or do they produce upwelling of bottom waters? Upwelling may be possible under low stratification conditions, and could be quite significant for nutrient recycling and retention of shellfish larvae.

Mean residence time of the water mass in Golden Bay was estimated to be 11 days, and 29 days for Tasman Bay. The shorter residence time in Golden Bay is due to its lower volume (13 km^3 compared to 31 km^3), and Golden Bay has a higher residual net freshwater flows, and more intense tidal mixing than Tasman Bay. Residence times below 21 days have implications for larval retention and the recruitment of shellfish to the bays.

What we know

The large rivers, particularly the Motueka, dominate sediment load to Tasman and Golden Bays.

Annual sediment loads are highly variable and at least in the Motueka have been relatively low for the last two decades.

The variation of sediment from the land largely reflects the influence of rainfall and geology, with a minor influence of land use.

Orbital velocities associated with wave heights exceeding 1 m are sufficient to suspend fine sediments at a depth of 20 m.

Wind driven current will determine flows within the bays.

Dredge spoil dumpings contain contaminants that have the potential for mildly elevated toxicity; and these effects are localised around the dump site.

What we don't know

Have the timing, magnitude, and duration of flood events changed?

Are there differences in sediment composition and grain size between rivers?

How do rates of sedimentation vary through time in Tasman and Golden bays?

What is the extent of the near bottom turbidity layer on the scale of bays, and how does it vary over space and time within the bays?

What are critical levels of sediment composition, concentration and duration of exposure that cause mortality in different commercial species of shellfish, and how do these effects vary with shellfish size?

Are some shellfish species (or ascidians) more tolerant of suspended sediments; and can they be used to mitigate near-bottom turbidity layer?

What we know continued

Sediment plumes can disperse sediment over a considerable distance, and the core distribution of scallops, oysters, and mussels is most likely within these plumes.

Surface turbidity is caused by plumes of outwelling from rivers, whole of water column turbidity from mixing and the suspension of bottom sediment by strong winds and waves greater than 1 m, and near bottom turbidity in calm weather especially during the summer when the water column is strongly stratified by temperature (or by salinity).

Suspended sediments can reduce primary production, both in the water column and on the benthos, affect the physiology of shellfish including reduced reproductive success, reduced growth and increased mortality especially in early life stages, and can predispose shellfish to disease.

Water mass residence times are likely to affect recruitment and spat catch, especially in Golden Bay that has a shorter mean residence time than in Tasman Bay.

6.6 Historical and modern changes to benthic communities, sediments

There are no biological data available for GBTB before the 1960's, when shellfish fisheries were first developed. The first reports were from disturbed habitats. Historical effects have however been measured using sediment cores showing signatures from tsunamis, Maori colonisation, European settlement, and modern times. Deforestation, flooding and agriculture likely had significant historical effects on the seabed of the bays. The animals living within the sediments of Tasman and Golden Bays are primarily "soft bottom fauna" which are dominated by deposit feeding sea urchins and brittlestars, and historically filter feeding bivalves. Historical newspaper accounts (Figure 23) indicate sponges and mussel beds were extensive at the end of the 1800's. There is some evidence that shellfish beds only occur in deeper water now.

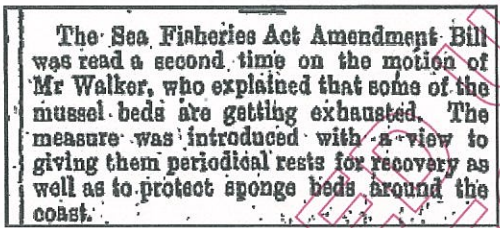
The Sea Fisheries Act Amendment Bill was read a second time on the motion of Mr Walker, who explained that some of the mussel beds are getting exhausted. The measure was introduced with a view to giving them periodical rests for recovery as well as to protect sponge beds around the coast.

Figure 23: Article from the Nelson Evening Mail (1896).

Since the 1960's, the largest known change in the seabed communities in the Nelson bays is the removal of significant quantities of shellfish by dredging including: green-lipped mussels (total landings 1962-1982, 20,534 t), horse mussels (unknown), flat oysters (1963–2009, 10,797.8 t) and scallops (1959–2009: 10,746 t). The lack of re-colonisation of green lipped mussels and scallops is most likely caused by lack of settlement substrata and poor spat survival caused by suspended sediments. Both mussel and scallop larvae will not settle on bare mud, and prefer to settle on filamentous or fibrous material, a role historically provided by red algae, seagrass detritus, and sea fans (hydroids). This was evidenced by the need for scallop enhancement in the 1980's in especially Tasman Bay after suitable settlement surfaces were most likely reduced. Flat oysters also require hard surfaces like shells to settle on. Comparisons of sediment characteristics inside and outside Separation Point exclusion zone show that fished sediments appear to have been homogenised removing, eroding or burying shell content. Habitats in Tasman Bay with less complexity provided by shells, horse mussels (Figure 24), and sponges had higher rates of predation of juvenile scallops. Habitats within the Separation Pt. exclusion zone have greater diversity, higher biomass and productivity of organisms including large surface living shellfish. Changes in last 5 years appear to have occurred at the SOE monitoring TASCAM site with reductions in heart urchin numbers and potentially diatom densities.

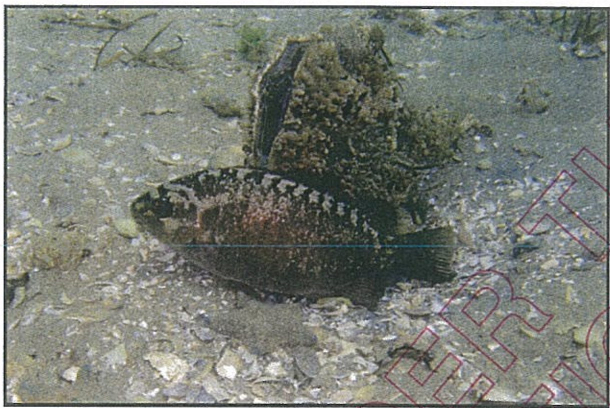

Figure 24: Horse mussel colonised by red algae.

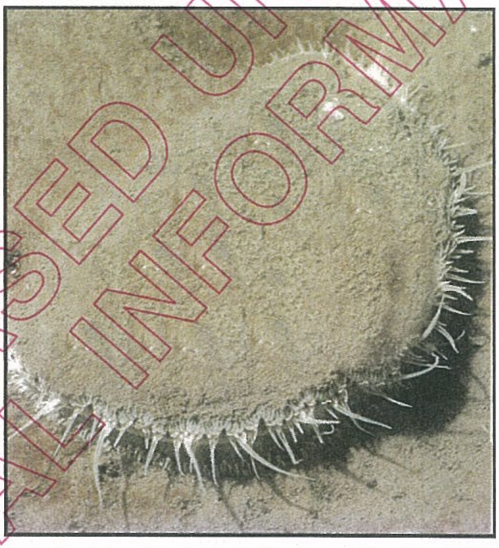

Figure 25: Scallop with diatoms (brown film) on sediment.

Large shellfish have been called "ecosystem engineers" as they provide important ecosystem services including; filtering and clearing the water column of algae and sediment to allow light to reach the seabed, and transferring nutrients to the seafloor where they are utilised along with enhanced light levels by plants (e.g. microalgal diatoms, red algal, and seagrass). These plants in-turn provide important feedback services to the shellfish; seafloor diatoms (Figure 25) are a significant food source for shellfish and help bind sediments that choke shellfish feeding; and red algae and seagrass provide settlement surfaces for scallop and mussel larvae. Other benefits shellfish beds provide include enhanced habitat for other invertebrates which become food for fish.

Mussel beds in the Okiwi Estuary, Bay of Plenty, were measured to support 10-fold more predatory fish than bare mud, and overseas oyster reef restoration has shown similar benefits to fish populations. Complex habitats like those of shelly habitats and shellfish beds are thought to be more stable and resilient to disturbance because they are more diverse and contain species with more functions. A recent study in Tasman Bay showed that habitat enhancement by returning scallop shell to the seabed increased species diversity and functional diversity of the seabed community.

What we know

GBTB are typical of soft sediment communities adapted to low levels of natural disturbance; dominated by deposit feeding animals (sea urchins and brittlestars), worms, and historically filter feeding bivalves.

Natural disturbance is limited to wind, waves, small swells, and flooding.

Historically, sponges and shellfish beds (mussel, oysters, and scallops) were extensive even after Maori and European colonisation.

There is some evidence that shellfish beds only occur in deeper water now.

Largest ecological change since 1960's has been the removal of filter feeding animals such as green-lipped mussels, oysters and scallops and that their removal has greatly reduced filtration capacity, the ability to remove sediment and phytoplankton from the water of the bays.

Mussel, oyster and scallop larvae will not settle on bare mud, and prefer to settle on filamentous or fibrous material, a role historically provided by; red algae, seagrass detritus, hydroids, and shells. The lack of shellfish recovery is most likely caused by lack of settlement substrata and suspended sediment affecting spat survival.

What we don't know

How much have seabed communities and shellfish beds changed prior to the start of records in 1960's, and how have they changed since?

Have there been any changes in frequency/timing of natural disturbance?

Was the contraction in the distribution of shellfish beds to deeper water related to the cumulative effects of fishing and or other factors?

What functional roles do shellfish and other animals play in stabilising sediments and minimising land-based sediment and nutrient loads?

What are the most preferred settlement surfaces and conditions for shellfish settlement and survival?

What effects are increases in the near bottom turbidity and low light levels likely to have on historically important species to shellfish settlement?

Can we rebuild shellfish fisheries through habitat and stock enhancement?

Can we still detect benefits of the fisheries scale oyster enhancement trial, and if not, why not?

What we know continued

Small scale oyster enhancement experiments using waste scallop shell increased settlement and survival of oysters. Shell mounds had higher species diversity and functional diversity.

Large shellfish clear the water column of algae and sediment to allow light to reach the seabed, and they transfer nutrients to the seafloor where they enhance plant growth (e.g. microalgal diatoms, red algal, and seagrass).

Seafloor plants provide important feedback services to shellfish; diatom mats are a significant food source for shellfish and help bind sediments that choke shellfish feeding.

Studies here and overseas show shellfish beds provide habitat for other invertebrates which become food for fish greatly enhancing associated fish biomass.

What we don't know continued

Is seabed (benthic) primary production important to shellfish, in which parts of the year, and does this vary in different parts of the bays?

Which habitat components, or combinations of components, help maintain shellfish production by minimising the effects of natural disturbance and fishing?

If you restore habitat complexity, will shellfish predation levels drop?

6.7 Effects of fishing

The sheltered embayments of GBTB are low energy systems characterised by soft sediments, and relatively low natural disturbance of the seafloor. The seafloor communities comprising species poorly adapted to high levels of natural disturbance from oceanic swells, large waves, and strong currents rendering them less resilient to effects of bottom fishing gears.

The international literature reports that bottom contact fishing gear homogenises soft sediment habitats, alters benthic assemblages, and reduces biodiversity. Filter feeders and grazers are most affected by fishing disturbance compared with predators and scavengers (including fish), and deposit feeders. A study at Separation Point comparing macrofauna (everything >0.5mm) inside and outside the exclusion zone found: disturbed sites were dominated by fine mud with little or no shell content, reduced diversity, and smaller average size of animals, with reductions in biomass and productivity (Figure 26). A larger scale MFish (MPI) study was carried out comparing gradients of habitats and fishing intensity across the whole of GBTB to investigate the importance of the different factors affecting the benthic communities. Analyses were conducted separately for communities living on top of the sediments and for those living within sediments. Depth, salinity, sediment, and wave exposure were the most important factors, depending on species group, but fishing was consistently identified as an important factor in explaining variation in the communities, with recent trawl and scallop effort (averaged over previous three years) being more important than other fishing terms. The Nelson bays are relatively sheltered from wave disturbance, and the seabed communities are likely to be more sensitive of fishing disturbance than those in more exposed areas.

Figure 26: Separation Point sediment grab sample from inside (left) and outside (right) the exclusion zone.

What we know

Bottom contact fishing gear changes the composition of seabed fauna, and sediment structure.

Soft sediment habitats are more likely to be vulnerable to the effects of fishing because they have evolved with little direct physical disturbance.

The greatest change occurs after only a few fishing events.

Differences in sediments inside and outside the Separation Point exclusion zone show that fished sediments appear to have been homogenised removing, eroding or burying shell content. Habitats within the exclusion zone have greater diversity and higher biomass, of organisms including large surface living shellfish.

Less complex fished habitats in Tasman Bay had higher rates of predation of scallops. Complex habitats like those of shelly habitats and shellfish beds are thought to be more stable and resilient to disturbance because they are more diverse and contain species with more functions.

What we don't know

Precisely where have dredge tows or trawls shots occurred, and how intensely have different parts of the bays been fished

What are the localised and immediate effects of bottom contacts gears on benthic communities and seabed sediment structure?

If and how do the effects of different bottom contact gears differ?

How persistent are the localised effects are and do they accumulate over time?

What are the effects of these changes on the functioning of seabed communities in the bays and the services they deliver?

Which animals are important to maintaining sediment structure, and does this structure minimise sediment suspension?

Was the exposed shell component of surface sediments higher before fishing began?

Which fishing gears, fishing methods, and patterns of fishing optimise production for shellfish fisheries?

6.8 Diseases of shellfish, algal blooms, toxins, and pollutants

6.8.1 Shellfish diseases

A number of diseases capable of causing significant mortality in shellfish have been identified in Golden and Tasman Bays. Some diseases such as the Ostreid herpes virus (OsHV-1) can cause mortality in larvae and spat, which can be difficult to detect, while others can cause mortalities in adult shellfish of commercial, customary, and recreational importance. Some of these diseases have been wide spread and at levels of infection high enough to have caused mortality (high prevalence and intensity). Further, environmental and mechanical stress and the presence of concurrent infections can predispose shellfish to disease mortality. The stresses facilitate immunosuppression of the shellfish hosts, increasing the risk of disease outbreaks. Shellfish diseases are a likely threat to shellfish populations in the bays, but this threat has not been adequately assessed at fishery scales.

Shellfish mortality from disease can be difficult to detect. The tissue of dead shellfish is quickly eaten by scavenger and predator species leaving little trace of the cause of death. During severe disease outbreaks, the heightened mortality is sometimes detected by chance, through the presence of large numbers empty shells of recently dead shellfish, also known as clocks. When these events occur, it can be difficult to establish whether the mortality is caused by disease or other causes; and whether the cause was a newly introduced pathogen, or a pathogen that has been present in the population for some time, and the spread and levels of infection have increased to cause heightened mortality.

The surveillance of shellfish diseases in GBTB is currently based on staged-monitoring, mainly in and around aquaculture sites. Overseas experience in disease monitoring has found "the more you look the more you find". There are many advantages of baseline screening of likely pathogens and disease profiles in important shellfish stocks: the ability to determine the introduction of new pathogens from endemic species, and to investigate the effects of concurrent infections and environmental stressors on diseases mortality.

There have been several reviews of pathogens and potential pathogens of molluscs in New Zealand, and the risk they pose to aquaculture and wild stocks. Many pathogens have the potential to cause significant mortality, either as sole infections or together with other diseases. Some of the key diseases known to cause mortality are listed below by the potential host species:

<u>Scallops</u>

Rickettsial diseases have been associated with scallop mass mortalities. Ricettsiosis in scallops is wide-spread in GBTB and occurs at high prevalence and high intensity of infection, and could be a major driver of population scale mortality.

Other affects include predation by polyclad flatworms and infestations of spionid polychaetes. The role of these and digestive epithelial virosis, Picorna-like viruses (P-LVs), Mycoplasmosis is unknown.

Oysters (flat or dredge oysters)

Most of the documented collapses of commercial oyster fisheries worldwide including in the US, UK, France, other European countries, and catastrophic mortality in New Zealand have been caused by oyster diseases. New Zealand flat oysters harbour many infections and diseases. Bonamia (*Bonamia exitiosa*) is thought to be an endemic disease, and is the most devastating disease of oysters. Bonamia is an OIE notifiable disease. Bonamia occurs in oysters in Golden and Tasman Bays.

Other oyster diseases include Apicomplexan infections (APX) that can occur with bonamia increasing the risk of disease mortality. The Ostreid herpes virus infections (OsHV-1), another OIE notifiable disease, was been found in water samples taken off the Glen in Nelson. Bucephalus longicornutus can cause mortality in oysters; oysters are infected in summer and an increasing infestation, particularly in the gonad causes parasitic castration and death; and may reduce recruitment.

Green-lipped and blue mussels

None of the three OIE notifiable diseases have been reported in mussels in New Zealand. The biggest disease risk to mussels is likely to be through the introduction of pathogens by invading ship-borne mussels and other marine fouling.

Polyclad flatworms detected in the Nelson Marlborough region can be significant predators of mussels. Mussels are known to host a number of non-fatal pathoghens.

Pacific oysters

A virulent OsHV-1 µVar in larvae and adult of pacific oysters was detected in samples achieved in 2005 from the Glen, Nelson. OsHV-1 found in hatchery produced oyster larvae in Mahurangi, Northland, in 1991 caused 100% mortality at 11 days, post-spawning. OsHV-1 is known to infect a number of bivalve species.

6.8.2 Algal blooms (toxic and non-toxic)

Toxic algal blooms

Harmful algal blooms that occur in inshore areas of New Zealand and may cause increased disease susceptibility and mortality in the Nelson bays. Forty two species of toxic or potentially harmful plankton species have been recorded from New Zealand. These include bloom producing species responsible for neurotoxic shellfish poisoning, paralytic shellfish poisoning, diarrhetic shellfish poisoning, and species responsible for ciguatera seafood poisoning, although a ciguatera outbreak has never been reported in New Zealand. Fish killing species in this group include *Karenia brevisulcata* that exhibit high cytotoxicity in a wide range of marine organisms; a bloom in Wellington Harbour in 1998 caused massive kills of fish, invertebrates, and seaweeds and caused human respiratory distress. It appears to be the most toxic dinoflagellate known. Two toxic species of *Pfiesteriids* have been identified in Tasman Bay's estuaries, but are not considered an immediate risk to fish or human health given the low to moderate nutrient concentrations in the estuaries. Increases in nutrient loadings could pose an increased risk.

During the period from 1982 to 2002, eight major or 'exceptional' blooms were reported in New Zealand inshore waters, two particularly destructive blooms in 1993 and 2002. These eight blooms caused fish or invertebrate mortality, toxicity to humans, and spread across large coastal areas of New Zealand. Six out of eight of these blooms were dominated by dinoflagellates and virtually all coincided with major El Niño-Southern Oscillation (ENSO) events in the two decades from 1982 to 2002 (Figure 27).

It is clear that strengthening of winds during El Niño, leads to an increase in upwelling intensity and surface-nutrient enrichment during the summer that is normally nutrient-poor, and encourages the development of harmful algal blooms.

In the 1993/94 summer, a large algal bloom event in the Hauraki Gulf completely eliminated scallop recruitment to collectors for the first three months of that settlement season.

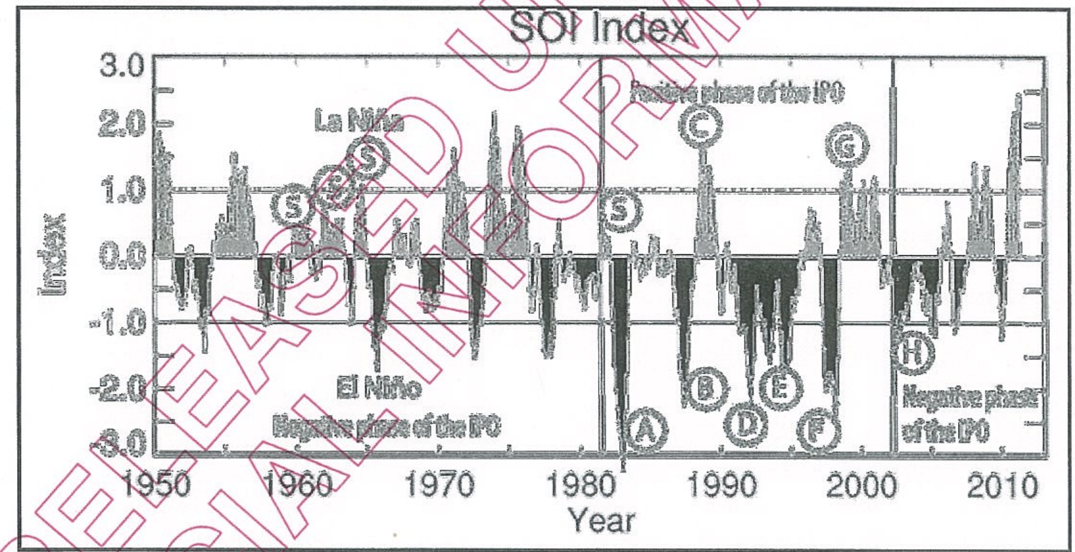

Figure 27: Major algal blooms (HAB) 1950–2010: S, nuisance 'slime' events; A–H, other major harmful algal bloom events reported in 1982–2002. El Niño-Southern Oscillation (ENSO) events and Interdecadal Pacific Oscillation (IPO).

Mucilage producing algae blooms "slime" events

Slime events are a recurring feature of Golden and Tasman Bays, and of other harbours around NZ since the 1860's. Slime events occurred in the Nelson Bays in the 1860's, 1901, 1960–62, and 1981. Early events, pre 1981 reportedly caused fish and shellfish mortalities, and in some areas affected oysters (up to 80% mortality in some areas), and green lipped-mussels more than scallops. There were both spatial and temporal differences in the distribution of slime within the bays and their effects. Strong northwest winds (El Nino) and warmer seawater temperature have been implicated in facilitating these blooms.

Amongst a number of species of plankton cultured from samples of the 1981 "Tasman Bay slime" the colonial, non-motile, mucilage producing algae (*Phaeocystis pouchetti*) was identified as the most likely cause of the bloom. The bloom was first detected in July and continued through to November. Divers observe no initial signs of shellfish mortality in oysters, scallops or green-lipped mussels, by the numbers of sites dived were few.

6.8.3 Toxins and pollutants

Heavy metal analysis of scallops from Tasman Bay has shown elevated cadmium levels in their stomachs, but cadmium does not accumulate in other parts of the body. Cadmium was thought to originate from aerial top-dressing of superphosphate fertilizer, which can get washed into waterways. An approximate 50 km^2 area around the mouth of the Motueka River is contaminated by heavy metals (nickel and chromium), thought to originate from the plume, and traced back to a natural upper catchment mineral belt. Concentrations strongly exceed sediment quality thresholds for probable ecological effects. Although the Motueka plume appears to influence sediment chemistry up to 6 km from the Motueka River mouth, analysis of shellfish did not reveal any evidence of direct terrestrial or riverine influence.

A survey of agricultural chemicals between 1986–1988 for chemicals that may have potential effects on Nelson Bays, identified Azinphos-CH3 in the Nelson Marlborough area which was used as a non-selective pesticide. It is to be phased out for use in New Zealand by 2014.

A review of intertidal shellfish depletion around Auckland concluded that chemical stressors at high levels are relatively rare and localised, with greater risk of anthropogenic contaminants in intertidal zones in enclosed estuaries compared with open coastal environments. There is however the possibility of endocrine disruption in marine invertebrates by some chemicals used as organic booster biocides in new generation antifouling paints. Further research is required to establish these effects.

There is a register of known and possible contaminated sites kept by NCC and TDC, many of which are situated on private land. As land-owners are liable for any contamination on their property, even if the contamination was caused by a previous owner, site information is sensitive, and as a result Councils are reluctant to release information on non-public sites. The way contaminated sites are managed varies. Generally sites are managed by:

- Maintaining an inventory of the status of potentially contaminated land in the District (Site Contamination Register as per Monitoring of Estuaries (MOE) guidelines).
- Restricting the range of land uses able to occur at contaminated sites.
- Capping contaminated soil to isolate the contamination from rain, wind, and people.
- Treating or removing the most contaminated soils.

Remediation at the site of the former Fruitgrowers Chemical Company (FCC) at Mapua is the most heavily studied sites adjacent to the marine environment at the top of the South Island. Soils at the site and two areas of foreshore were included in the remediation between 2004 and 2008. Three post-remediation monitoring reports have been completed. Moderate levels of nutrient enrichment were detected at East and West of the site, resulting in anaerobic conditions or changes in community composition, perhaps in response to the nutrient enrichment. Present levels of pesticides in marine sediments have not resulted in a decrease in the invertebrate community diversity or abundance. Levels of chermicals in cockles were comparable to other areas of New Zealand considered representative of contaminated sites (i.e. close to large cities or development). Levels in cockles were below the US and Canadian limits for the protection of human health. Levels of chemicals in mudflat snails were elevated west of the FCC shore, but levels fluctuated both down and up from 2009, 2010 and 2011, and levels did not correspond to an increase in contaminant levels at the site, with the reasons unknown. Recommendations for future monitoring include west FCC stream which potential recontamination in the central and upper area of this stream. Based on ongoing variability in contaminant levels at the site, continued monitoring of mudflat snail, cockle, and topshells have been recommended

Estuary state of environment (SoE) monitoring has been undertaken in four major estuaries of Tasman Bay according to a standardised protocol. The protocol includes three component parts: a preliminary description, based on existing information, in order to prioritise monitoring effort, broad-scale mapping of intertidal habitats, and fine-scale assessment of indicators of estuary condition.

What we know

Shellfish from Golden and Tasman Bays harbour many diseases, including a number that could pose significant threats to shellfish fisheries.

The toxin and pollutants section of the review is incomplete and information to date suggests:

Monitoring the effectiveness of remediation work at Mapua, the most contaminated site in the bays, show pesticide levels have not changed benthic communities when compared to non-contaminated sites and the low levels of pesticides in cockles below international health limits and similar to other harbours near high populations.

Mud snails are a good indicator of toxins in the estuary.

Effects of shellfish pollutants are thought to be more likely in shallow estuarine waters than deep well flushed bays.

What we need to know

Are these diseases causing problems in GBTB shellfish fisheries?

What are the levels of agricultural toxins in scallops, mussels and oysters?

Are the physiological effects of the toxins and metals, and their concentrations in shellfish likely to lead to increased mortality and or reduced reproductive success?

7 Further information to be included in the review

- Fishers' information
- Customary knowledge and information from iwi.
- Estuary monitoring in Tasman and Golden Bays, and information on toxins and pollutants.

8 Acknowledgements

We acknowledge the assistance of and contributions from Kelly May [1], Max Gibbs [1], Janet Bradford-Grieve [1], Matt Pinkerton [1], Caroline Williams [1], Mitch Campbell [3], Reid Forrest [2], Steve Webb [2], Ross Sneddon [2], Leigh Stevens [6], Ros Squires [4], Paul Sheldon [5], Rob Smith [4], and Tracey Osborne [7]. Thanks to Russell Cole for his editorial input.

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