OIA 13-332

11 MAR 2014

Ross Withell
President
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Dear Mr Withell

OFFICIAL INFORMATION ACT REQUEST

I refer to your official information request of 16 February 2014 relating to the terms of reference for investigation into changes in the benthic habitat in Tasman and Golden Bays.

The investigation referred to in the consultation document is being undertaken by NIWA, with some support from other agencies and businesses.

A copy of a document that introduces this project is attached.

Feel free to contact NIWA directly if you would like more information about the research it is doing into the benthic habitat in Tasman and Golden Bays.

Yours sincerely

James Stevenson-Wallace
Director, Fisheries Management

Information on drivers of shellfish fisheries production in Golden and Tasman Bays and knowledge gaps: A review summary to inform the development of a plan to rebuild shellfish fisheries.

Working draft prepared for iwi and stakeholders for the Rebuilding Shellfish Fisheries Workshop, 15th of August, Nelson.

Information on drivers of shellfish fisheries production in Golden and Tasman Bays and knowledge gaps: A review summary to inform the development of a plan to rebuild shellfish fisheries.

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1 Introduction

At their peak, wild fisheries for scallops, oysters, and mussels in Tasman and Golden Bays had combined revenues of about $90M per annum, and provided significant socio-economic benefits to non-commercial stakeholders such as customary and recreation fishers, and to iwi. These fisheries have declined to low levels over the last decade and commercial fishing has all but ceased. The causes of the observed decline are unknown, but are likely to be a combination of man-made and environmental effects.

NIWA has been asked to assist stakeholders with potential approaches to help restore the sustainable production of shellfish fisheries in Golden and Tasman Bays. As a first step, a workshop was held in Nelson on the 2nd of March 2012 with fisheries stakeholders and iwi. The workshop aimed to develop an initial understanding of what iwi and stakeholders' value and what want from the Tasman and Golden Bays shellfish fisheries. The workshop provided an opportunity for participants to share their knowledge of factors affecting the shellfish fisheries in the bays, to consider if and how scientific research may help rebuild these fisheries, and to discuss possible ways forward. Details of the workshop were circulated to iwi and stakeholders, and outcomes from this workshop were:

- There was good discussion and engagement from all participants, and consensus to start a process to investigate and address issues that may be affecting shellfish production and ecosystem health in Golden and Tasman Bays.
- The workshop participants' shared vision was: 'To maintain healthy, productive, and sustainable fisheries for commercial, recreational, and customary use in Tasman and Golden Bays'.
- NIWA agreed to carry out a review to determine what is known about the drivers of shellfish production in Golden and Tasman Bays, what may be affecting production, and identify information gaps. The review would aim to summarise relevant understanding, research, monitoring information. NIWA was to co-ordinate input from other research and monitoring agencies, the fishing industry, and other relevant groups.
- NIWA has developed a web-based data portal for the region to provide access to its data (and any other data that participants any wish to make publically available).
- NIWA agreed to co-ordinate a further workshop in Nelson to present the review and portal.

Several potential drivers of shellfish production were identified by iwi and stakeholders for the review:

- Land use including the effects of sediment loadings in waterways, toxins and pollutants, forest harvesting and deforestation
- The effects of harbour dredge spoils
- The growth of aquaculture, oil prospecting and mining
- Biosecurity effects of introduced marine plants, animals, and pathogens
- The effects of bottom fishing (shellfish dredging, Danish seining, and bottom trawling) on benthic habitats
- Climate change and its potential to increase storm frequency
- Changes in the location of freshwater springs, benthic sediments, and their effects on benthic communities

Iwi and stakeholders were concerned about the impacts these potential drivers would have on decreased water quality, habitat change, and the ability to exercise customary rights to harvest kaimoana in Tasman Bay due to health concerns arising from declining water quality and environment degradation. Frustration was also expressed over the inability of research to identify the core issues, the lack of understanding around standards, monitoring, and compliance programmes run by councils, and the timing and priorities of district plan changes, political apathy and the one size fits all approach.

Concerns were also expressed about the fishing industries limited ability to fund research and monitoring through cost recovery, the effects of cumulative stressors on ecological systems, and multi catchment issues. There was a desire from iwi and stakeholders for ecosystem approaches to management and to better understand ecosystem function.

The workshop participants also identified a list of potential activities and actions, and agreed on the next steps. We have circulated a summary of the March workshop for comments and expanded the list of participants. There was no feedback on the content of this workshop summary. This report summarises the main outcomes of the review that we will present to iwi and stakeholders on the 15th of August in Nelson. The remaining potential steps identified for the future are to develop a strategic research plan (based on the review), and to identify potential funding sources.

1.1 The review

Workshop participants agreed that a review to determine what is known about the drivers of shellfish production in Golden and Tasman Bays, what may be affecting production, and information gaps is a first and important step forward. We limited the focus of this review on rebuilding shellfish fisheries for scallops, oysters, and green-lipped mussels. This review is a work in progress, and summarises our knowledge of these fisheries, the environments from which they are fished, and drivers of shellfish production. As part of summarising this information, we have attempted to identify critical knowledge gaps in the information available. The review still needs to better incorporate fishers' and customary knowledge. As such, we present a summary of the information gathered to date. We will take back further feedback from the August workshop and incorporate further information in to a more comprehensive technical review document that will be peer reviewed and published.

1.2 Where to next?

We are mindful that iwi and stakeholders have requested a strategic research plan, a list of potential sources of funding, and research to support ecosystem approaches to fisheries. To this end, the August review meeting will discuss options on how to progress these requests. Research solutions are best explored in the context of iwi and stakeholder visions and goals for the fisheries and the environment. Research priorities for complex ecosystem approaches require careful consideration to ensure that research effort and funding is best placed where it can provide most benefit to meet iwi and stakeholder management objectives. A process that fully engages iwi and stakeholders in evaluating the benefits of various research options will provide for more effective co-ordination of research activities and collaborations amongst research providers and with industry, and maximise the benefit and uptake of the research outcomes. An agreed way forward will also improve the ability to source funding for research.

2 Scope

The scope of this review is limited to factors potentially affecting shellfish production in Golden and Tasman Bays (GBTB). We have not included the Marlborough Sounds at this stage. Scientists with research experience in GBTB have provided summaries of their information and expert opinion. The review has also incorporated information from similar reviews by Bradford et al (1994), a recent review by Morrison et al (2009, A review of land-based effects on coastal fisheries supporting biodiversity in New Zealand), and an unpublished report of the Challenger scallop fishery (Williams and Triantafillos).

The review summarises information for three shellfish fisheries, scallops (SCA7), oysters (OYS7), and green-lipped mussels (GLM7), what we know of their life histories, and on potential drivers of their production. We have summarised research information from Golden and Tasman Bays separately where possible and have focused on what we know and how well we know it. Key information from the national and international literature is also included, especially where information from GBTB is not available. The review includes requirements for successful shellfish production and their drivers that include the roles of sediments, water circulation, primary production, benthic communities, the effects of fishing, disease, and toxins and pollutants. We expect that there will be interactions between drivers of shellfish production, and that the significance of these interactions will vary over space and time.

The objective of this review was to pull together information and data on these subjects, but not to undertake any further analysis, or attribute the significance of each potential driver.

3 Summary of methods

This review summarises relevant understanding, research, and monitoring information gathered to date. NIWA has co-ordinated and worked with the Cawthron Institute and Landcare Research, the Tasman and Nelson District Councils, the Challenger Scallop Enhancement Company, the Challenger Oyster Management Company, the Challenger Finfisheries Management Company representatives, and other groups who hold relevant information to assist with the review.

We have summarised information from the literature and expert opinion. An inventory of metadata (information about data) available for further analysis has been compiled. A web-based portal to display information from Golden and Tasman Bays has been developed and some of the summaries of information are linked for display. Software tools have been developed to provide stakeholders with the capability to overlay their own confidential data with that contained in the portal, for their own use. We will make many of the original reports summarised in this review publically available through this portal.

4 Status of scallop, oyster, and green-lipped mussel fisheries

4.1 Overview

Historical information on shellfish fisheries in Golden and Tasman Bays (GBTB) mainly comprises various surveys to assess the size of scallop and oyster populations in the bays; these have been undertaken since 1959 and 1961 respectively. Survey designs generally focused on commercial fishery areas, and these designs are not as well suited to describing the distribution of scallops and oysters as are other survey designs. Scallop surveys have been relatively consistent since 1994, and were mainly focussed on enhanced areas until 1998. Oyster surveys have been carried out concurrently with scallop surveys since 1996, however, these survey designs were not optimised for oysters. Data on the relative abundance of green-lipped mussels are from bycatch data recorded from scallop and oyster surveys.

Survey data and fishery landings data show significant declines in GBTB green-lipped mussels, oysters, and scallop populations since 1976, 1996, and 2002 respectively. The cause of these declines is unknown, and we investigate potential drivers in this summary.

There are insufficient fisheries data, specifically fine spatial scale catch and effort data from dredge and trawl fisheries in GBTB to investigate the responses of shellfish populations, sediments, and benthic communities to fishing; and interactions amongst fisheries. Research investigating spatial differences in seabed communities and sediments found some of the differences can be attributed to shellfish dredging and bottom trawling.

Scallop and oyster enhancement has been successful in GBTB, and is used in fisheries elsewhere in the world to increase shellfish density and to rebuild fisheries. Enhancement strategies worked best with structured rotational fishing. There is insufficient data to investigate the interactions between bottom trawl fisheries and areas enhanced with scallop spat or waste shell for oyster enhancement, however anecdotal evidence suggest the effects of bottom contact gears in the first couple of years in areas that have been enhanced are detrimental. Future enhancement strategies in the bays may need to consider appropriate site selection or habitat restoration before enhancement, and coordination between fisheries to protected enhanced areas until they have been fished.

4.2 Scallop fishery

Trends in the abundance of scallops from surveys (Figures 1, and see Figures 5 & 6) and from commercial landings data (Figure 2) show significant declines from 2002; note that the surveys pre1998 didn't survey all the fishery area, but focussed on enhanced areas. Scallops also show decadal cycles in abundance with highs from 1970–1980, and again 1990-2002. Catch effort data are available since 1959, but are reported differently over time. A fine scale spatial description of the scallop fishery is only possible for 2009 and 2011, when tow by tow records of dredge tracks and daily catch data are available.

Surveys show the highest abundance of scallops are generally found in the inner eastern half of Golden Bay in depths of 10–20 m and occasionally to depths to about 35m, and the inner western half of Tasman Bay in depths 10–20 m (Figures 3–6). Landings data reported by sector concur with the distributions of scallop abundance from surveys. The core distribution of scallop abundance through time is likely to lie within the influence of sediment plumes from major rivers in GBTB: the Motueka (conformed by the Integrated Catchment Management study), Waimea, and Marahau river plumes in Tasman bay, and the Wainui, Takaka, and Aorere rivers in Golden Bay.

Both GBTB were productive for scallops. Large numbers of pre-recruit sized scallops were sampled from both GBTB in 2000 suggesting high natural recruitment in 1998 or 1999. These scallops grew to legal size in Golden Bay in 2001 and 2002, but remained pre-recruits in Tasman Bay (stunted growth). The abundance of scallops, mainly pre-recruits declined from 2003 to 2007, and has been very low since. The abundance of recruit-sized scallops in Golden Bay declined 2002 to 2004, but good natural settlement detected in 2004 led to an increase in abundance peaking in 2006, then declining to low levels by 2011.

The cause of these declines in scallop abundance is unknown. Natural settlement to fishery areas has been low since 1999 in Tasman Bay and 2006 in Golden Bay. There are too few data on catch and effort at a fine enough scale to investigate the response of these populations to scallop and other bottom fishing. There are data from scallop larval and spat monitoring programmes, length frequency data and length-weight data, growth and survival from tagging studies, and meat yield data that with other environmental data could be further explored to investigate these declines. Fishers' personal data and observation could also contribute to understanding these declines.

4.2.1 Scallop enhancement and rotational fishing

A scallop enhancement programme was developed in the early 1980's to provide some commercial catch in years following those with low natural recruitment to the commercial fishery areas from poor scallop spat settlement and low post-settlement survival. Enhancement comprises the capture of wild spat on artificial collectors (spat bags), and the release of spat and translocation of those spat that had fallen off the bags to commercial fishery areas. Enhanced scallops first contributed to part of the annual commercial catch in 1986 and large-scale enhancement in GBTB began in the late 1980s and continued in the 1990s (Figure 7). In addition to enhancement, harvesting of scallops was to be conducted on a three-year rotational basis in these areas. Enhancement and rotational fishing practices have changed over time. Rotational fishing practice began to change around 1999, and some areas were fished more frequently that the planned 3 year rotation; some areas were fished continuously for eight years without a break.

In the 1990s, about 90% of scallops sampled from seeded areas during surveys were attributed to enhancement. A bio-economic model was developed for the scallop fishery, but there are no reports of biological or economic performance of enhancement. Without formally designed investigations of the effectiveness of scallop spat enhancement, modelling approaches were used in an attempt to explain the observed variation in pre-recruit and recruit scallop densities in survey catches in relation to enhancement history, fishing, and environmental factors.

The analysis of fishery and survey data estimated that scallop enhancement contributed significantly to survey catches in enhanced areas, comprising about 50%–70% of the catch. The contribution of enhancement to commercial catches will depend on how much of the fishery in a particular year took place in enhanced areas. Enhancement has tended to be less effective in Tasman Bay compared to Golden Bay. Within Golden Bay, enhancement was detectable in catches of recruits (harvestable size), with primary enhancement two years prior to the survey showing a linear relationship with catch. This two year lag between settlement to the seabed and recruitment to the fishery (at 90 mm shell length) is consistent with recent estimates of average growth rate for Golden and Tasman Bay scallops. While an enhancement effect was also detected for Tasman Bay, the overall catch rates were lower than for Golden Bay. In Tasman Bay, enhancement had a detectable effect on the catch of recruits, although with a four year lag (compared to two years for Golden Bay).

Many factors are likely to contribute to the success of scallop enhancement. The retention of larvae from the three or more spawning events, about a month apart, will be important to the availability of larvae to settle in spat bags. Scallop larvae have a planktonic larval life of about 21–28 days, and mean residence time of the water mass in Golden Bay was estimated to be 11 days. The first two spawning cohorts grow to larger sizes in the spat bags and have higher survival and growth than later cohorts of smaller seeded spat. The survival and growth of seeded scallop spat is spatially and temporally variable and likely to depend on site specific habitat characteristics. These factors are poorly understood.

4.3 Oyster fishery

The fishery comprises oyster populations in Tasman Bay, Golden Bay, and parts of the Marlborough Sounds. The fishery has been mainly based in Tasman Bay, with small landings from Golden Bay. Dredge oysters have been exploited in the region since 1845. From 1963 to 1981 oysters were landed mainly as bycatch, firstly by the green-lipped mussel dredge fishery and subsequently by the scallop fishery. In 1981 the Challenger scallop fishery was closed and commercial dredge operators started targeting green-lipped mussels and oysters.

Catch effort data are available since 1980, but are reported differently over time; weekly for Golden and Tasman Bays combined from 1980, then by the Nelson-Marlborough scallop reporting areas from 1992. There are no data available to investigate the responses of the oyster populations and habitats to different levels of fishing. In 1999, the oyster season that ran from 1 March to 31 August was changed to allow oyster to be landed throughout the year. Landings peaked in the 1980s as large numbers of vessels targeted green-lipped mussels and oysters as the scallop fishery was rebuilding, and again prior to 1996, reportedly as an attempt by fishers to establish catch history for the allocation of quota before the fishery was introduced in to the Quota Management System (QMS) in 1996 (Figure 8)

Targeted surveys of oysters have been carried out are in 1961, 1969–75, 1984–86, and 1989; and as concurrent surveys with scallops in 1996–2008. The results from the early surveys are not directly comparable, and later [scallop] surveys did not sample commercial oyster fishery areas well. Oysters occurred in greater densities on gravel and calcareous gravel substrates. Fishers noted that the distribution of oysters in Tasman Bay has changed over time from being two to three relatively discrete, dense beds off Nelson to being a more widely distributed and in much lower densities. Oyster surveys and fishery landings data show significant declines from 1996. While recruit-sized (legal-sized) oysters show a consistent downward trend, pre-recruit oysters show a highly fluctuating trend that may reflect the mortality of three years old oysters detected during oyster enhancement trials, and may be due to disease mortality. The population size and distribution of oysters is not well estimated by the most of the recent surveys because of low and poorly targeted sampling effort. Sampling effort increased and the definition of oyster survey areas reportedly improved in 2012.

The distribution of oysters in 1996 (Figure 9) overlapped with scallops in both Golden and Tasman Bays, and was extensive through to 1999 (Figure 10). By 2000, oyster densities were declining with very low densities in Golden Bay. Oysters were mainly confined to outer areas of Tasman Bay until 2007, after which they declined to low levels by 2009 (Figures 11 & 12). Sampling effort for oysters in Tasman Bay was sparse in 2009–2012.

Oyster survey data since 1999 are held on the scallop database. A number of other data sets that are not currently compiled and documented could contribute to future oyster research including: oyster survey data pre-1996; enhancement data on oyster larval and spat sampling, settlement, post-settlement mortality and tagging data on growth and survival, and data from processing and fisher's data.

4.3.1 Oyster enhancement

The oyster fishery in Tasman Bay lacks dense aggregations of oysters and this has been attributed to a scarcity of suitable settlement surfaces. A large habitat enhancement trial that deployed waste scallop shell on the seabed as settlement substratum increased oyster density. Within five months, 82% of the shell was covered by other benthic animals and sediments, reducing available settlement surfaces. The timing of shell deployments to enhancement areas should be done immediately prior to oyster settlement to maximise the availability of settlement surfaces.

Spat settlement on enhanced habitat plots was 200 to 400% greater than on adjacent seabed control plots with no shell. The increase in spat densities was offset by high post-settlement mortality, only about 10% of spat survived the first year following settlement. Survival of oysters recruited to enhanced habitat was generally very low, and varied greatly among experimental sites and through time. After 3+ years, oyster survival among sites ranged from 0% to 0.04%. At sites where survival was highest, the relative density of legal-sized oysters increased from ~0.01 m^2 prior to enhancement, to ~0.14 m^2 at the end of the experiment, above the threshold for commercial fishing of 0.02 m^2. Mortality peaked for oysters less than one year old, and less than three years old. The cause of mortality is unknown.

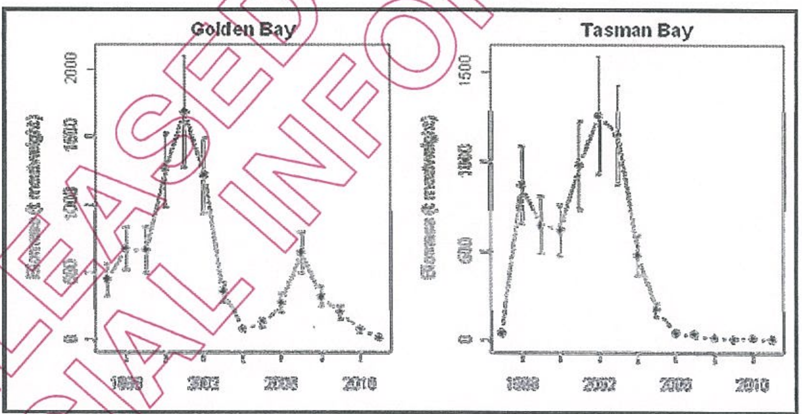

Figure 1: Trends scallop biomass (t meat weight) from surveys by region, 1997–2011.

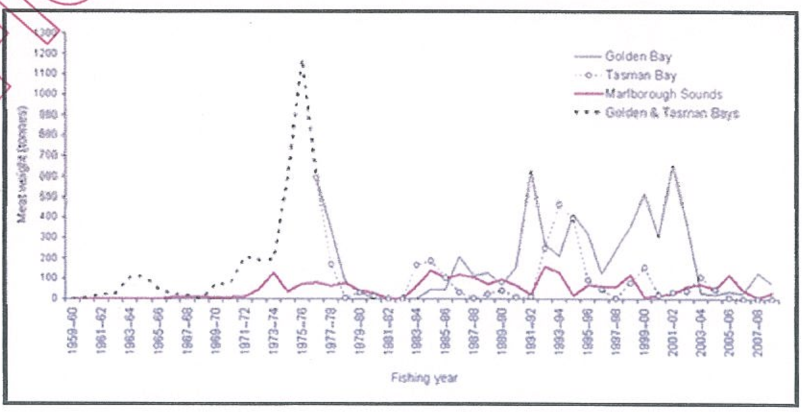

Figure 2: Annual landings by region and fishing year 1959/60–2010/11.

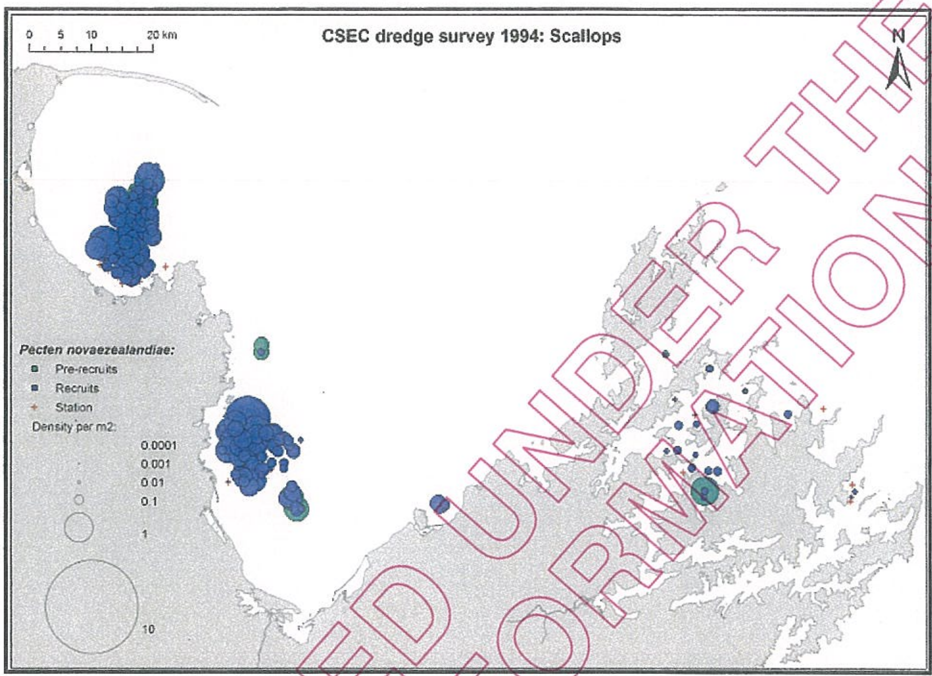

Figure 3: Survey distribution of recruit-sized and pre-recruit scallops in 1994, mostly from enhancement areas. Circle area is proportional to scallop density.

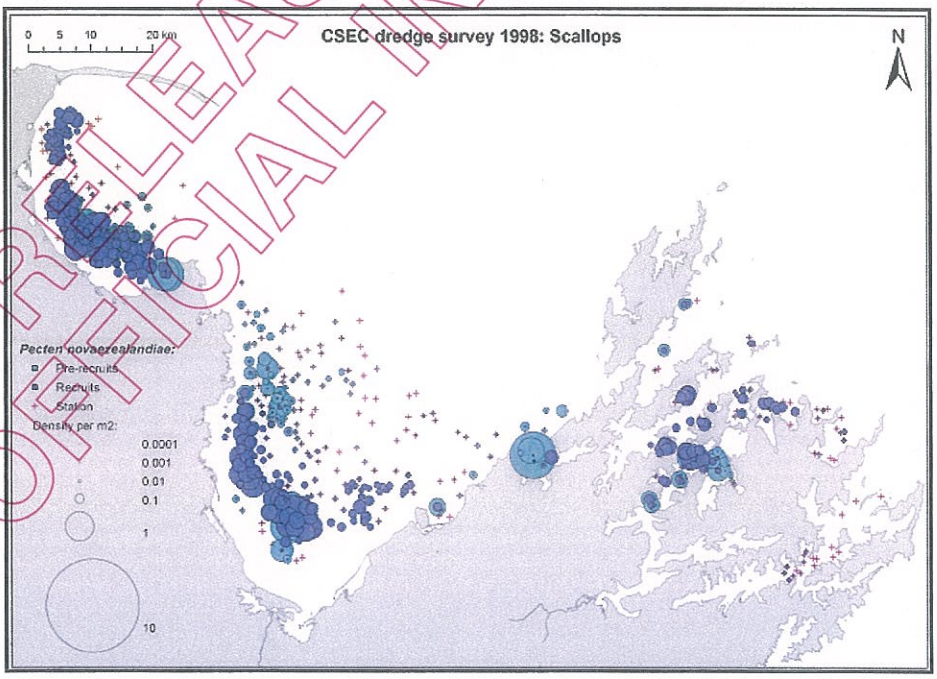

Figure 4: Distribution of recruit-sized and pre-recruit scallops, 1998. Circle area is proportional to scallop density.

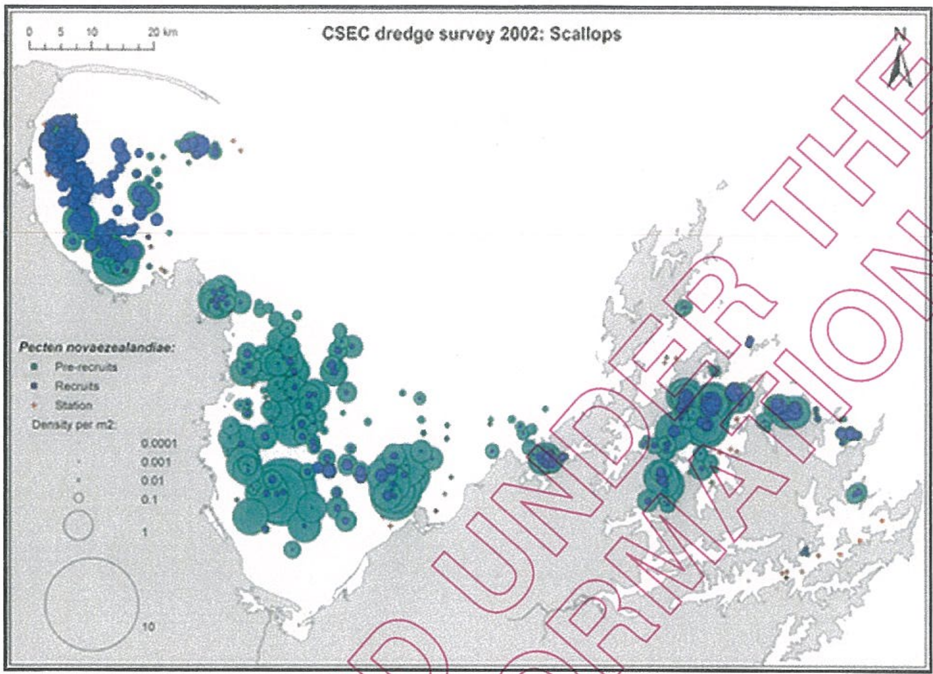

Figure 5: Distribution of recruit-sized and pre-recruit scallops, 2002. Circle area is proportional to scallop density.

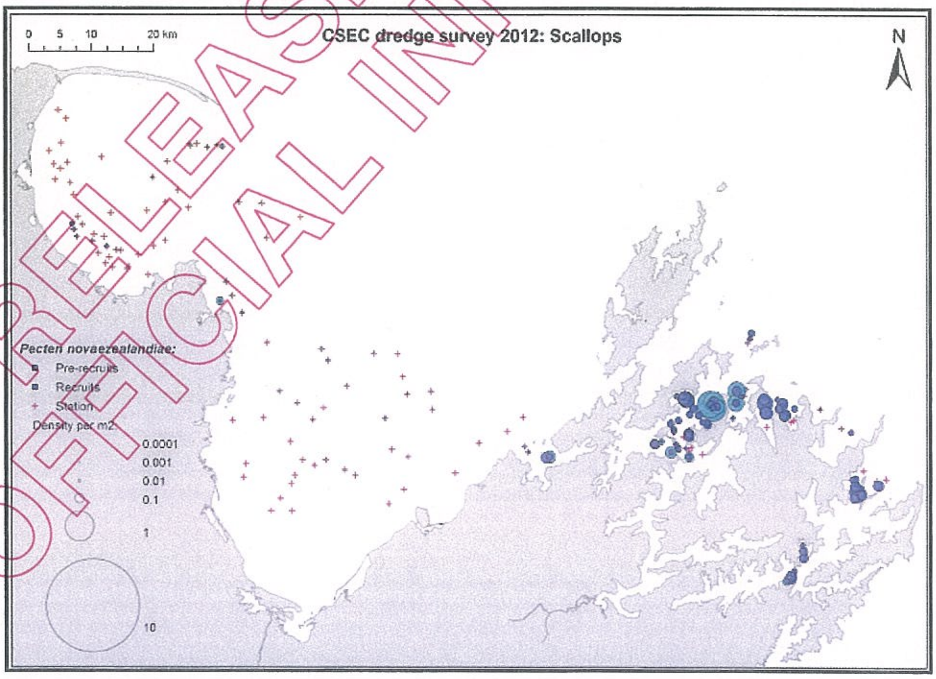

Figure 6: Distribution of recruit-sized and pre-recruit scallops, 2012. Circle area is proportional to scallop density.

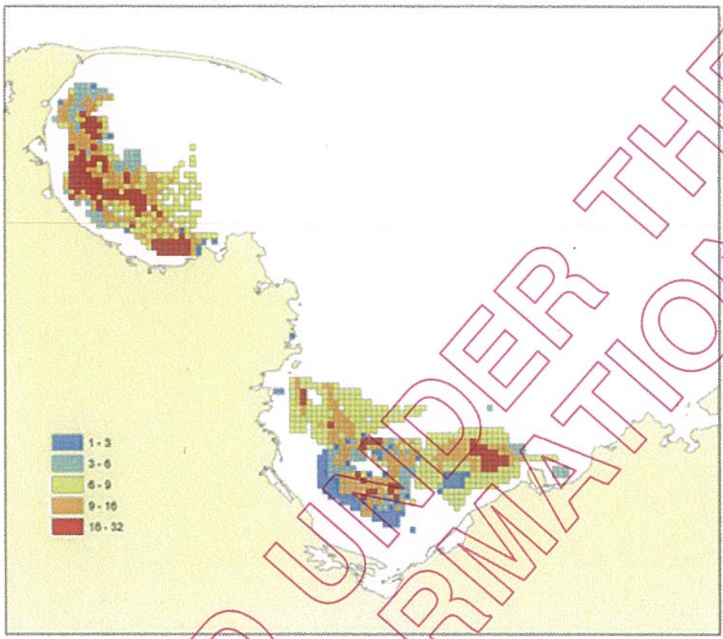

Figure 7: The areas seeded with scallops and cumulative level of spat enhancement 1992–2006.

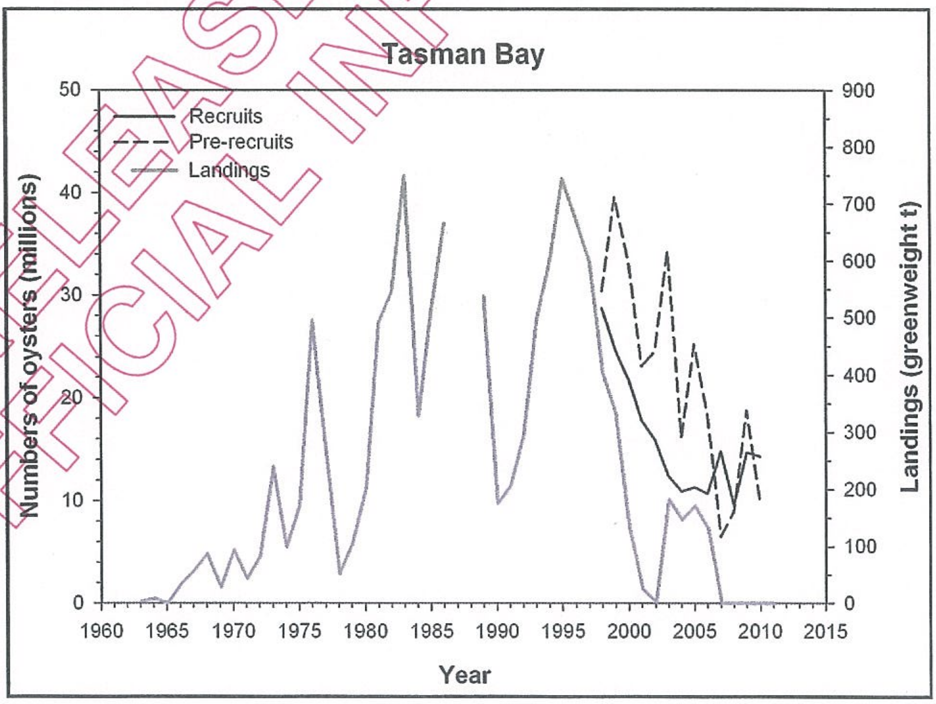

Figure 8: Trends in the oyster population size of recruits and pre-recruits (millions), and landings (greenweight, t).

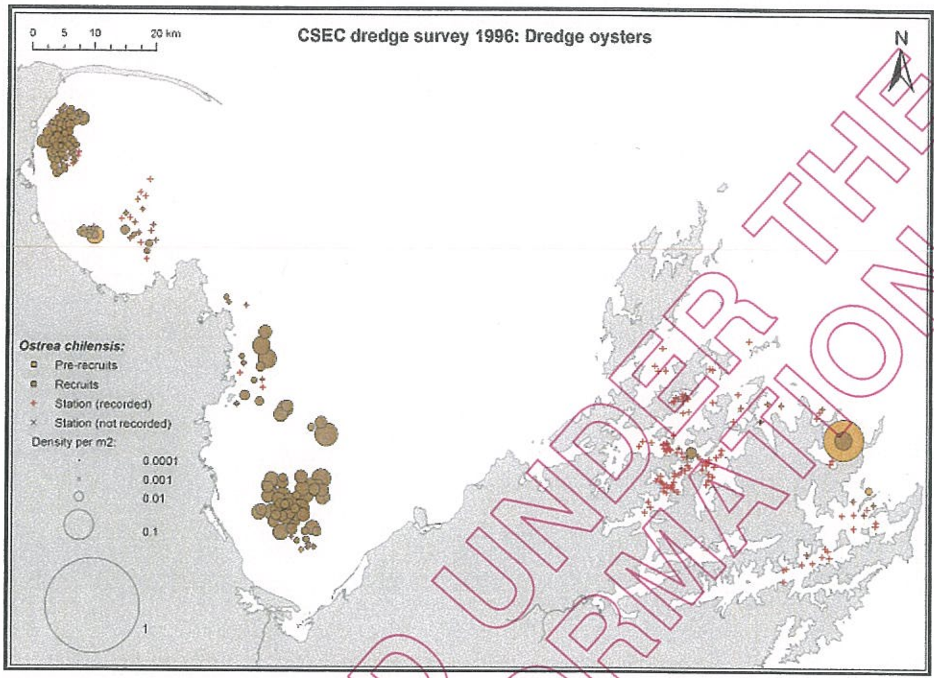

Figure 9: Distribution of oysters in 1996.

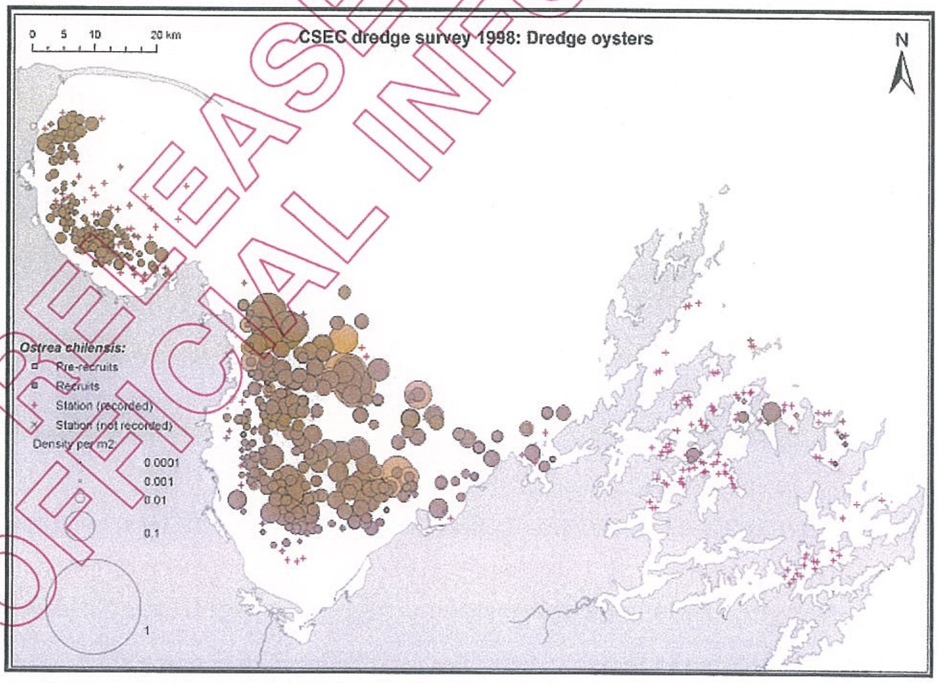

Figure 10: Distribution of oysters in 1998.

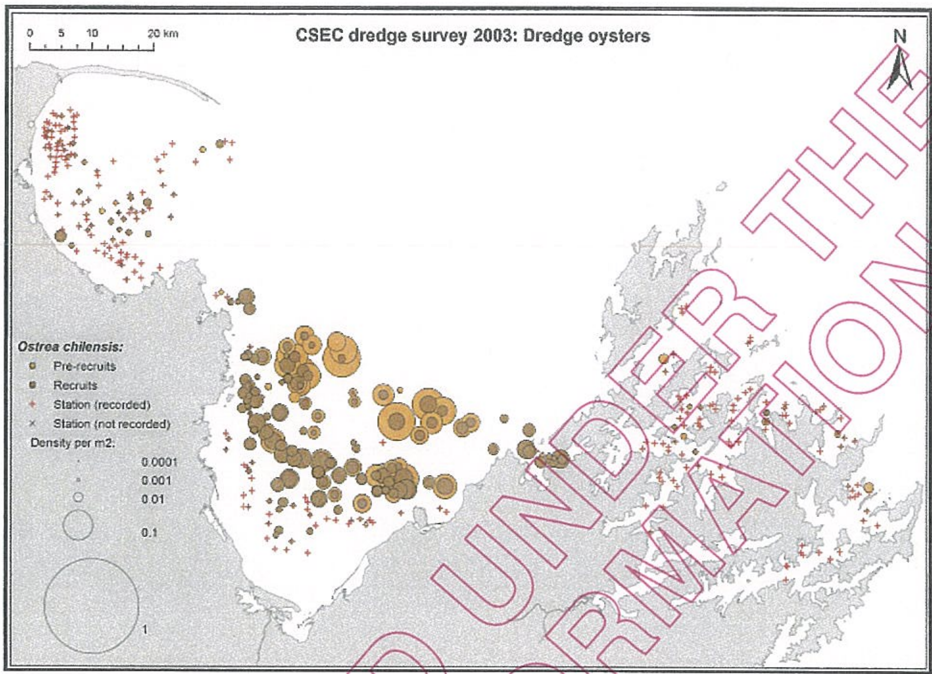

Figure 11: Distribution of oysters in 2003.

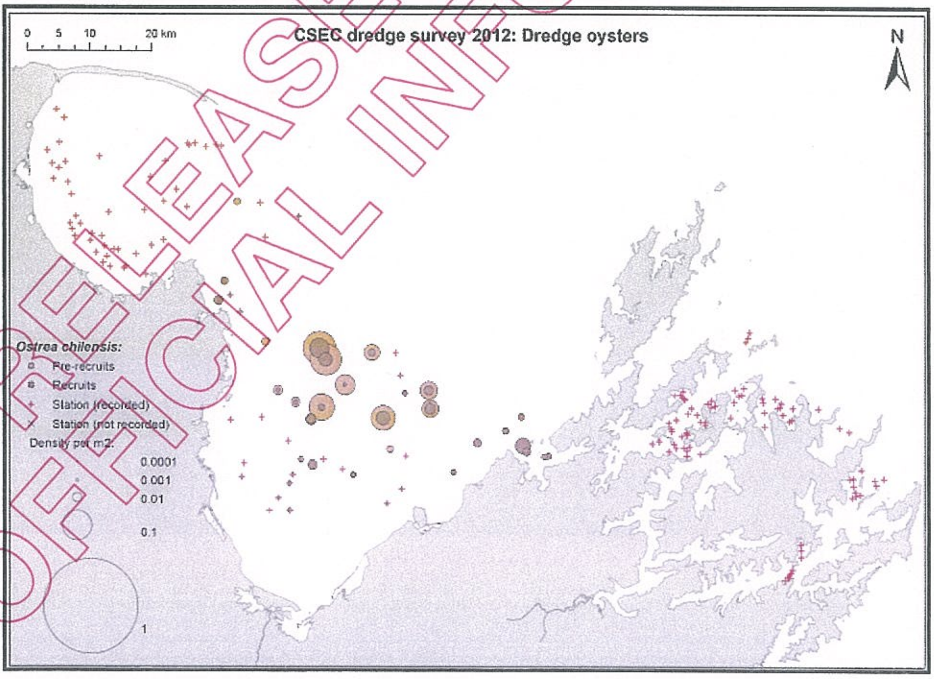

Figure 12: Distribution of oysters in 2012.

4.4 Green-lipped mussels

Early accounts indicate that mussel beds were present at the entrance to Nelson Harbour in 1862. A survey in 1959–60 found green-lipped mussels abundant over the greater part of the dominant "fine silty mud" substratum of Tasman Bay, with some patches in great abundance. Two dense mussels beds were reported in 1962, the largest directly offshore from the Boulder Bank between 10-30 m depth, and another smaller bed at about 10 m depth offshore from Kina Peninsula.

Historical newspaper accounts and catch-landing statistics indicate populations of mussels in Nelson/Marlborough region have been over-exploited potentially twice; in the late 1800's and again between 1960 and 1982 when an estimated 20,534 tonnes were landed (Figure 13). Tasman Bay mussel beds have since failed to recover.

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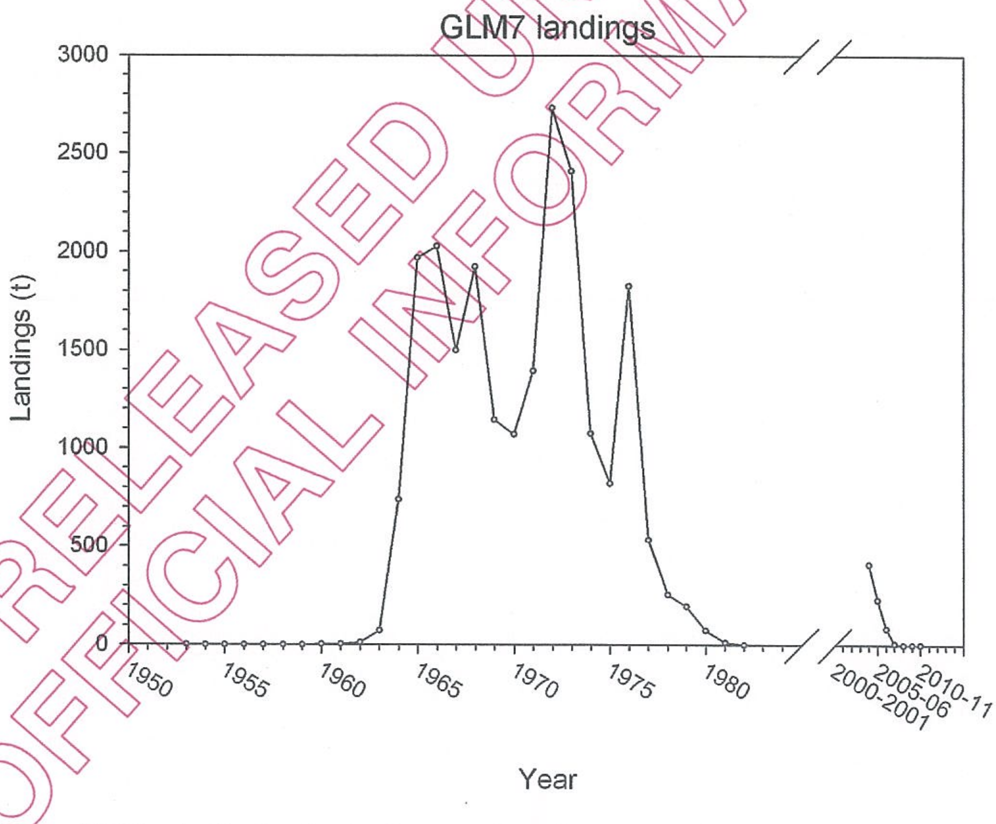

Figure 13: Standardised estimates for green-lipped mussel landings for the Nelson/Marlborough region (GLM7). Landings 1953–82 converted from sacks, and for the fishing years 2004–2005 to 2010–2011 from Ministry for Primary Industries data.

Early fishing of mussels in the 1800's was based on inshore beds accessible at low tide, with some dredging in Tasman Bay. These shallow water beds no longer exist, and over time the fishery has worked grounds progressively further in out in deeper water.

Some data on the relative abundance and distribution are contained within bycatch records from scallop and oyster surveys. Little other data is available for green-lipped mussels in GBTB, and there are no data on biological parameters. Other data sets that could contribute to future mussel research include mussel larval and spat sampling data, mussel counts from scallop spat bags, and fishers' data.

Green-lipped mussel landings peaked in the mid 1970s as did scallop and oyster landings, and these landings coincided with the highest number of vessels (~250) and highest numbers of days fished. Landing for all three fisheries declined rapidly to low levels in 1980.

Bycatch data from scallop surveys suggest the distribution of mussels have declined between 2004 and 2012 (Figures 14 & 15), but these data partly reflect low sampling effort in 2012 in areas were mussels were abundant in 2004, especially in Tasman Bay.

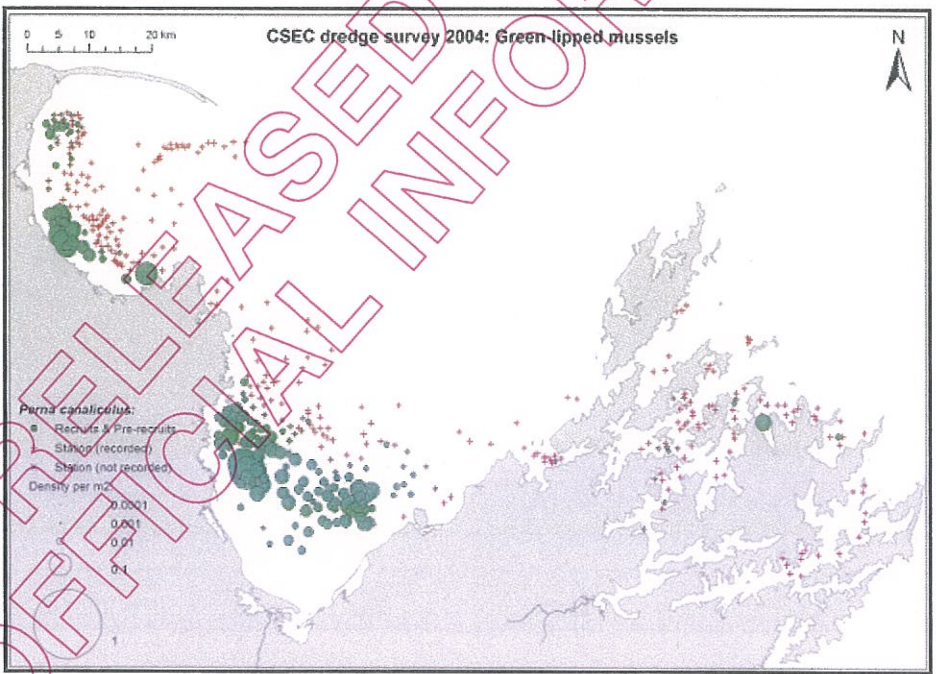

Figure 14: Distribution of green-lipped mussels in 2004.

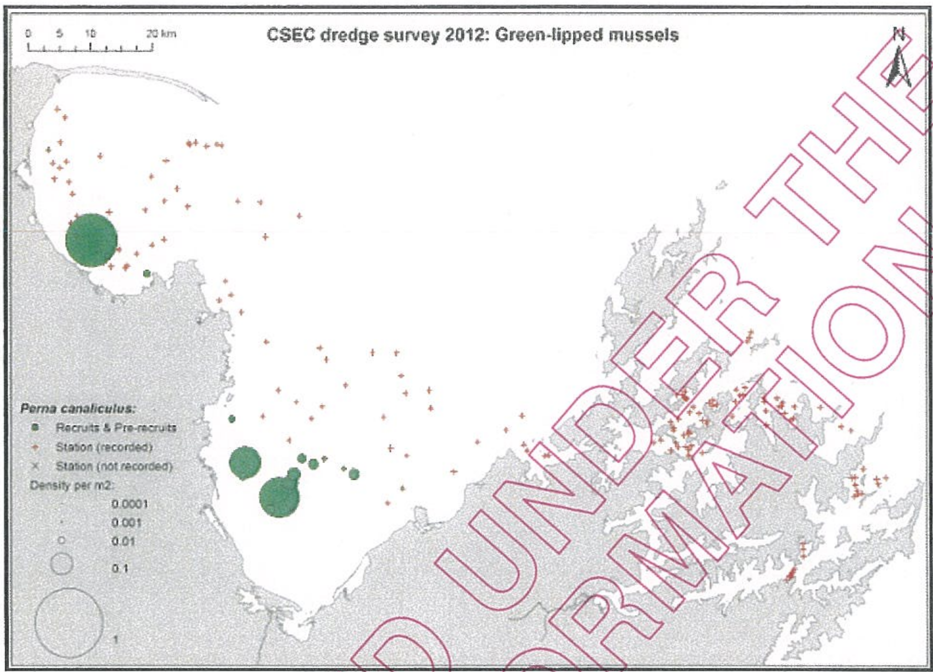

Figure 15: Distribution of green-lipped mussels in 2012.

What we know

All three fisheries for scallops, oysters, and green-lipped mussels have declined to low levels.

The population size of pre-recruit sized scallops is low, and a significant recovery within three years is unlikely.

Rebuilding of the oyster fishery is likely to be limited by low population densities.

Enhancement strategies to increase scallop and oyster densities have been successful.

Declines in all three shellfish fisheries in the 1970s occurred at a time when the numbers of vessels fishing and fishing effort was high.

What we don't know

What are the current distributions of oyster and mussel densities, especially in Tasman Bay?

What are the fine-spatial scale patterns of fishing and how much overlap is there in activities between the different bottom contact fisheries in the bays?

Do enhanced areas closed to dredging get fished by other bottom contact methods?

5 Life history stages important to successful shellfish production

It is rare that different life stages such as spawning, larval development and survival, larval retention, settlement and survival of spat, good growing condition and high survival are optimal and lead to high shellfish production. Many factors can affect the life history stages of bivalve shellfish and these can be responsible for the fluctuating or cyclic trends in population size. This variability is best characterised by scallop populations. These factors can affect different life history stages, and different shellfish species differently, especially reproductive stages. We should therefore expect variation in abundance, especially in fast growing, relatively short live species such as scallops.

5.1 Spawning, larval development and survival, and larval retention

Spawning biomass and spawner densities are important to fertilisation success and larval densities for scallops, oysters, green-lipped mussels and other shellfish. There are no data on spawner densities or spawning biomass needed to maintain larval production of shellfish, and whether larval production in the three main species has been compromised by low spawning stock biomass. Overseas studies have found fertilization success is likely to be low at low spawner densities. It would appear that the Golden Bay scallop population is not constrained by spawner densities. Large numbers of scallop spat were caught on spat catching gear over the 2011/12 summer, suggesting the low biomass of spawning size scallops surveyed in the 2011 and 2012 surveys of Golden Bay were above critical thresholds to maintain larval production. However it is not known how extensive the distributions of scallop larvae were, or whether there are spawning populations of scallops in deeper or shallower water beyond the current biomass survey boundaries contributing to larval abundance. In Tasman Bay, oyster spat settlement density was strongly related to background adult oyster density, and recruitment to the fishery likely to be limited in part by the low oyster densities there.

With a repetitive spawning and highly productive shellfish such as scallops, a very high level of energy reserves is needed for reproduction. Low-energy reserves in spawning adults can affect the size and viability of spawning, and can result in reduced success in the development of spawned eggs and subsequent survival of the larvae. The timing and magnitude of phytoplankton and benthic micro-algal production can vary dramatically from one year to the next or from one growing area to another. These fluctuations in food supply play an important role in the timing and success of spawning, larval survival and settlement of scallops. Thus, they are often considered to be a major cause of variability in scallop stocks. Meat weight indexes may be a good proxy for energy reserves as they reflect feeding success.

Research into scallop reproductive biology, to underpin the development of a scallop enhancement programme between 1983 and 1986 found:

- There were detectable changes in gonad indices to signal spawning events, the appearance of larvae shortly afterwards, larval growth, and subsequent settlement on collectors.
- Highly synchronised spawning in bivalves in Golden bay, Tasman Bay, and Croisilles Harbour that included scallops, oysters, green-lipped mussels, fan or queen scallops, horse mussels, and numerous other species of bivalves.
- Spawning generally began November and continued through to a final spawning out in March, with spawning events at near monthly intervals.
- The concentration of larvae and plankton near boundary layers when the water column is vertically stratified at about 10-15 m depth.

In Tasman Bay a peak period of oyster reproductive activity begins in late spring (September) and continues through summer (March) when seawater temperatures are constantly increasing. Trends in larval settlement closely tracked brooding patterns, and oyster settlement in Tasman Bay was greatest between November and January, and low in winter.

Most bivalves including scallops and green-lipped mussels in GBTB are broadcast spawners, and their larvae will drift in the water mass until settlement, generally within 21 to 28 days depending on temperature. In order for commercial populations to be maintained, they required regular features such as eddies to retain larvae over commercial populations or the regular delivery of larvae from distant spawning populations. Mean residence time of the water mass in Golden Bay was estimated to be 11 days, and 29 days for Tasman Bay, suggesting the entire production of an individual spawning could be lost from commercial fishery areas.

Oysters brood their larvae within their shells or about 21 days before settlement. Fully developed oyster larvae are released from the parent and tend to settle within a few hours after release, but are capable of remaining viable to metamorphose and settle for several days.

There are several causes of larval mortality including poor maternal provisioning as a result of low spawner energy levels, disease mortality, and predation. Carnivory in bivalves is well documented. Cultured species especially green-lipped mussels with their high pumping rates are effective predators of bivalve larvae in the plankton. Green-lipped mussels were a significant part of the benthic community in Tasman Bay, but are now cultured in GBTB. The potential for bivalves to reduce the availability of larvae of commercial species for settlement, in GBTB is not known.

5.2 Settlement

Many species can delay settlement, the transition between a pelagic life in the plankton and life on the seabed. This is known to occur in some scallop species, mussels, and oysters. Scallops and mussels will attach to settlement surface by fine threads or byssus, and some species can detach in unfavourable circumstance, move, and reattach. Oysters will attach (cement) their left (cupped) valve onto settlement surfaces and not be able to move. Biofilms can increase shellfish settlement, especially in high current areas.

Scallop larvae settle and attach themselves with byssus threads to filamentous materials such as seagrass debris, filamentous and other algae, sea fans (hydroids), horse mussels, and shell fragments. Scallops are reported to avoid settlement on fine muddy sediments. Scallops remain attached up to sizes of 2 – 5 mm in length. Many free swimming scallop spat 2 mm in length and greater have been observed on the seafloor. Scallop spat are known to settle on a range of artificial surfaces. The recruitment of scallops in Golden Bay may be limited by the lack of available settlement surfaces and subsequent survival, and not the availability of larvae.

Oyster spat will settle on scallop, oyster, and mussel shell, and are also known to settle on a range of artificial surfaces. Experiments which deployed shell to areas in outer Tasman Bay showed that oysters will not settle on soft sediments, but will readily settle on waste shell and fibreboard settlement plates.

Green-lipped mussels require filamentous substrata (e.g. hydroids and benthic algae) for primary and secondary settlement surface. There is little information on adult dependent settlement, where green-lipped mussel spat may actively seek mussel beds to settle in. This conspecific settlement occurs in other mussels species.

5.3 Growth

The amount of energy shellfish obtain from feeding is determined by the abundance and quality of food available, and the ability to feed. The levels of energy from feeding have direct effects on a number of life history stages. These include energy for successful reproduction; maternal provisioning that determines the energy reserves provided to larvae and their ability to survive until they settle and begin feeding themselves, energy for growth, and energy to tolerate stress and disease. Reduced food availability or the ability to feed effectively can reduce growth, reproductive success, and survival.

Scallops are active suspension feeding bivalves which rely on suspended detrital organic material and phytoplankton as their food source. Several studies have shown that benthic algae suspended from the seabed by complex boundary currents near the seabed are an important component of scallop diet in the Nelson bays, especially in the mid-summer to early-winter months. Detritus can make up 80-90% of stomach contents. Pelagic phytoplankton species are also important; phytoplankton blooms within the upper and mid water column that occur in late winter-early spring are particularly important for the growth and condition of scallops in the bays. In years when these diatom dominated blooms do not occur, or are of short duration, and during summer when planktonic food sources have become scarce, a large part of the diet is thought to come from benthic microalgae, and these algae can be abundant in shallower waters (< 30 m) when light to the seabed is not limited.

If feeding conditions are good, scallops can grow rapidly to a commercial size and be in good condition. Scallops can grow to 100 mm in length in eighteen months in Croisilles Harbour, and two years in the Marlborough Sounds and Golden Bay. Growth rates can be lower in scallops from water deeper than 30 m, and where there is a lack of food or suspended sediments reduce feed efficiency.

Decreased growth leading to stunting has been observed in enhanced scallops in GBTB, suggesting either density dependent growth, or the effects of seeding fished plots too early.

Further, scallop condition has been observed to drop after several days of fishing on enhanced plots.

5.4 Mortality

The are many potential causes of mortality in shellfish including post-spawning mortality, predation, diseases, parasites, toxic and non-toxic algal blooms, incidental mortality from fishing, and environmental stressors. We do not have good estimates for any of these sources of mortality or understanding of their interactions.

Suspended silt increases mortality in scallops, and reduces pumping and feeding, and oxygen uptake. Juvenile scallops are more prone to silt than adults. High levels of turbidity can cause mortality of spat, depress growth rates in adults, and change the metabolism of glycogen stores through forced anaerobic respiration. We do not have any quantitative data on the sediment composition, concentrations, or durations of exposure that lead to mortality in different species and sizes of shellfish in GBTB.

Post spawning mortality, also known as winter mortality, occurs when energy is transferred from the adductor muscle and other soft tissues to the gonad, and following spawning, high levels of mortality among spawned out adults can occur. The latter event has been blamed for mass mortalities recorded among scallops in intensively farmed areas in Japan in the late 1970s.

A number of predators of scallops have been identified from studies including a wide variety of fish, seastars and volutes, starfish, and, octopuses. Predation can be higher at sites regularly seeded with scallop spat compared to unseeded sites because this increase in prey density also increases predator numbers. Habitats exposed to fishing disturbance had significantly fewer elements of benthic structure, and predation rates on scallops can be significantly higher in fished compared to unfished habitats. Absolute levels of predation are not known.

The significance of disease mortality in GBTB shellfish is not known. OsHV1 causes mortality in larvae and spat while bonamia mainly in large oysters spawning as females. Intense infections of Rickettsias have been widespread and intense.

The survival of seeded scallops has been investigated through regular dive surveys of seeded areas. Mortality in the first three months after seeding was greater than 70%, and less than 30% mortality over the following two year period. Scallop spat released at a larger size had greater survival, scallop spat greater than 20 mm in length seeded from spat bags (primary spat) and spat greater than 30 mm in length dredged from under spat catching gear (secondary spat) had significantly greater survival than smaller spat. When conditions were good, the survival rates for seeded spat could be as high as 50%. Large mortalities occurred during the winter months and some may have been caused by large flood events.

What we know

Recruitment to the scallop fishery is not primarily limited by larval supply.

Variation in scallop larval supply, and potentially recruitment are likely to be linked to annual variability of wind driven water circulation.

Low scallop densities in Tasman Bay may limit scallop larval availability if larvae are not sourced from distant populations.

Growth in scallops in some areas of Tasman Bay can be slow, and may take twice as long to commercial size or, never attain commercial size because of stunting.

High localised densities of oysters are important to oyster recruitment

We can rebuild recruit-sized oyster densities through translocation and shell enhancement.

The settlement of scallop, oyster, and mussel larvae is low, and or post settlement mortality is high.

There are many diseases present in shellfish in the bays with the potential to cause high mortality.

What we don't know

How do wind direction and strength determine water circulation patterns and water mass residence times, and how do these affect larval retention?

Where do larvae that settle in commercial fishery areas come from?

What are the primary factors driving differences in growth, how do food availability, the ability to feed, density dependent growth, and other stressors interact?

Is fertilisation success limited by low shellfish spawner densities?

What is the cause of high mortality in newly settled oyster spat and why did such a large numbers of 3 year old oysters die in enhancement trials?

What are the lethal thresholds of different combinations of sediment composition, concentration, and duration of exposure to shellfish spat?

If disease related mortality is significant at shellfish population levels in the bays, what is the contribution of non-lethal stressors such as suspended sediments to disease incidence?

Do food availability and or ability to feed contribute most to heightened winter mortality in GBTB?