Zooplankton and the processes supporting them in Greater Western Cook Strait

Prepared for Trans-Tasman Resources Ltd

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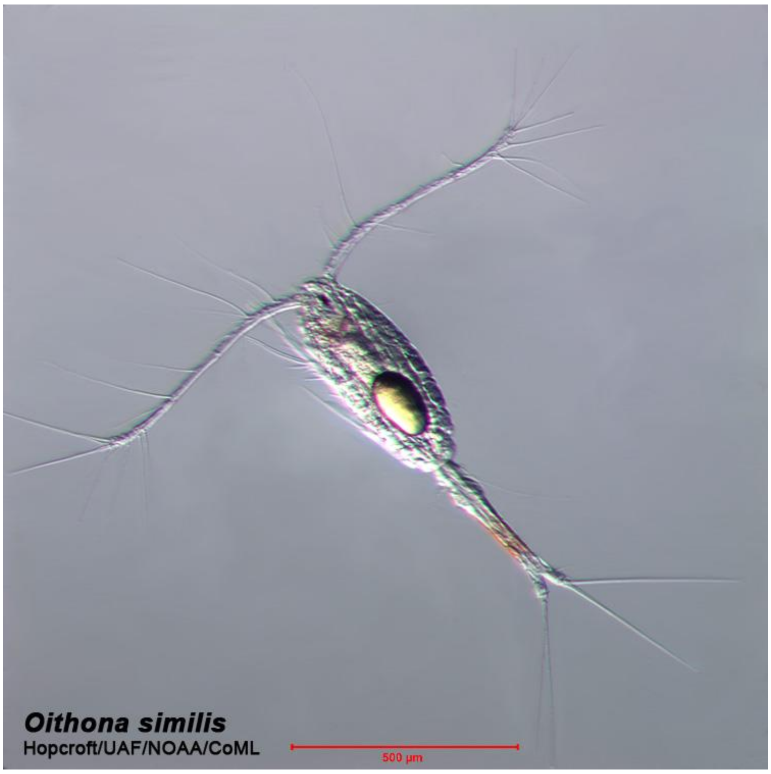

Authors/Contributors:
Janet Bradford-Grieve
Catherine Stevens

For any information regarding this report please contact:

Alison MacDiarmid
Principal Scientist
Marine Ecology
+64-4-386 0300
a.macdiarmid@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
301 Evans Bay Parade, Greta Point
Wellington 6021
Private Bag 14901, Kilbirnie
Wellington 6241
New Zealand

Phone +64-4-386 0300
Fax +64-4-386 0574

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Cover image: The copepod *Oithona similis*, one of the most abundant mesozooplankton species in the South Taranaki Bight. Image courtesy Hopcroft/UAF/NOAA/CoML.

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Reviewed by Alison MacDiarmid

AB MacDiarmid

Approved for release by Julie Hall

Julie Hall

Executive summary

Trans-Tasman Resources Ltd (TTR) proposes to extract iron sands from the seabed in the South Taranaki Bight (STB), approximately 15-40 km offshore in water depths of 25-45 m. Dredging seafloor sediments, and deposition of tailings will produce down-current plumes of suspended sediments. This has the potential to alter water clarity, with implications for primary production and higher trophic levels. Zooplankton (small invertebrate animals and fish larvae carried by currents in the water column), as abundant mid-level grazers and predators in marine systems, may be affected.

We reviewed the available information about the zooplankton, and the processes supporting it, in the Greater Western Cook Straight (including the STB, Tasman and Golden Bays, and bounded by Cook Strait Narrows), as this larger area influences zooplankton populations in the STB. This review indicates the following:

- Four major classes of pelagic water occur in the Greater Western Cook Strait region. These have been previously defined in the New Zealand Marine Environmental Classification (MEC), based on physical variables as: Class 124 – very shallow near-shore waters (mean depth of 8 m) where orbital velocities are high; Class 64 – coastal waters with mean depth of 38 m where orbital velocities are moderately high and the annual amplitude of sea surface temperature (SST) is high; Class 60 – these waters comprise the bulk of Greater Western Cook Strait with mean depth of 112 m, moderate annual solar radiation, and moderate winter SST; and Class 58 – the Cook Strait Narrows where strong tidal currents dominate.

- The STB comprises mainly Class 124 and Class 64 waters and the eastern fringes of Class 60 waters.

- Zooplankton has been sampled at 90 stations in the STB over a period of 13 years in the 1970s and 1980s. Zooplankton biomass data were collected at 62 stations and zooplankton species composition data were collected at 79 stations. Most of the sampling stations (83%) were in Class 60 waters in depths > 50 m. About 17% of zooplankton sampling stations were in Class 64 waters and none were in Class 124 waters.

- Little is known of the seasonal cycle or inter-annual variability of plankton. The existing data has been mainly collected in summer.

- The Greater Western Cook Strait region is impacted by several large-scale, highly variable, physical phenomena that structure the distribution and biomass of zooplankton, mediated by the pattern of distribution of phytoplankton biomass and its primary production. These large-scale physical processes include the Kahurangi / Cape Farewell upwelling plume, tidal mixing, river plumes and surf beach processes. Of these the Kahurangi/Cape Farewell upwelling plume is the best understood in terms of plant nutrient renewal which impacts primary production and dynamics and its downstream impact on the zooplankton.

- Upstream in the plume, near Cape Farewell, although nutrients were high there was evidence of low breeding activity among copepods and zooplankton food requirements were not being met. Omnivorous copepods were numerically dominant. But the reverse applied downstream, extending towards the STB. There, nitrate levels decreased, ammonia levels increased, and concentrations of copepod nauplii, herbivorous copepods, and developmental stages of krill *Nyctiphanes australis* were much higher than at the plume origin.

- As this assemblage was transported north-eastwards, further oceanic copepod species were entrained which produced high species richness, but two omnivorous copepods *Acartia ensifera and Oithona similis* were present in very large numbers. Further east the proportion of herbivorous copepods, species diversity and zooplankton biomass increased. These are the populations that extend into MEC Class 64 waters in the STB.
- The zooplankton populations of Class 64 water in the STB, when not dominated by salps, are likely to be dominated numerically by the copepod *Oithona similis*, and moderately large numbers of *Acartia ensifera*, *Clausocalanus jobei*, *Paracalanus c.f. indicus* and copepod nauplii. That is, omnivorous copepods should dominate (66%) with 34% herbivores and 0.1% carnivores.
- Zooplankton species composition in the STB is typical of coastal waters found around North Island, New Zealand.
- The Manawatu River appears to impact phytoplankton biomass and production near shore. Nutrient recycling on Waitarere Beach, south of the Manawatu River, is probably related to the measured high productivity of surf diatoms.
- We have no knowledge of zooplankton assemblages close to shore in Class 124 waters that have a mean depth of 8m and are dominated by very high orbital velocities.

Information relating to TTR's additional scientific work undertaken since 2014 has been provided and the conclusions is this report remain valid.

1 Introduction

Trans-Tasman Resources Ltd (TTR) proposes to extract iron sands from the seabed in the South Taranaki Bight (STB), approximately 15-40 km offshore in water depths of 25-45 m. Dredging seafloor sediments, and deposition of tailings will produce down-current plumes of suspended sediments (Hadfield 2012). This has the potential to alter water clarity, with implications for primary production and higher trophic levels. Zooplankton, as abundant mid-level grazers and predators in marine systems, may be affected.

Zooplankters, small invertebrate animals and fish larvae carried by currents in the water column, respond very strongly to the physical and chemical dynamics of the continental shelf water column. The Greater Cook Strait region[1] (Figure 1-1), including the STB, is impacted by several large-scale physical phenomena that structure the distribution and biomass of zooplankton, mediated by the pattern of distribution of phytoplankton biomass and its primary production. These large-scale physical processes include the Kahurangi / Cape Farewell upwelling plume, tidal mixing, river plumes, and surf beach processes. Most of these processes result in plant nutrient renewal which impact primary production and dynamics (e.g. Bradford et al. 1986 and references therein; Talbot et al. 1990) and, in turn, have a downstream impact on the zooplankton.

During the lead up to the installation of the Maui production platform physical and biological oceanographic studies were made of the Greater Western Cook Strait region by Auckland University and associates (e.g. Kibblewhite et al. 1982). They revealed the dynamic nature of the physical environment in the region that influences on the distribution of phytoplankton biomass and production. This work was extended by investigations conducted the Division of Marine and Freshwater Science, DSIR.

Quite a lot is known about the distribution and biomass of mesozooplankton (0.2-20 mm) during summer in the Greater Western Cook Strait Region (e.g. Bowman et al. 1982; Foster & Battaerd 1985; Bradford & Chapman 1988), but very little is known about microzooplankton (< 0.2 mm) and macrozooplankton (> 20 mm). Very little is known about the community composition or seasonal cycle of zooplankton immediately adjacent to the shore in the STB.

The dynamics of summer phytoplankton biomass and production and its response to the Kahurangi / Farewell Spit upwelling plume and also tidal mixing (e.g. Bowman et al. 1982; Bradford et al. 1986) is reasonably well known, but there is no local information about surf beach primary production processes along the STB coast. Most previous work has not extended into the shallowest water adjacent to the proposed mining site.

In this report we survey the available published information to: 1) define the classes of pelagic water present in the STB and the Greater Western Cook Strait region; 2) summarise what we know about phytoplankton nutrient renewal in summer (upwelling plume, tidal mixing, river input, surface beach dynamics); 3) describe the summer response of the phytoplankton to these processes; 4) evaluate mesozooplankton populations and their response to the upwelling plume; and 5) discuss implications for the STB region. This

[1] Greater Western Cook Strait is defined here as the area including Tasman and Golden Bays, and South Taranaki Bight and bounded by Cook Strait Narrows.

information will contribute background information to an overall assessment of the impact of the proposed iron sand extraction activities on the STB.

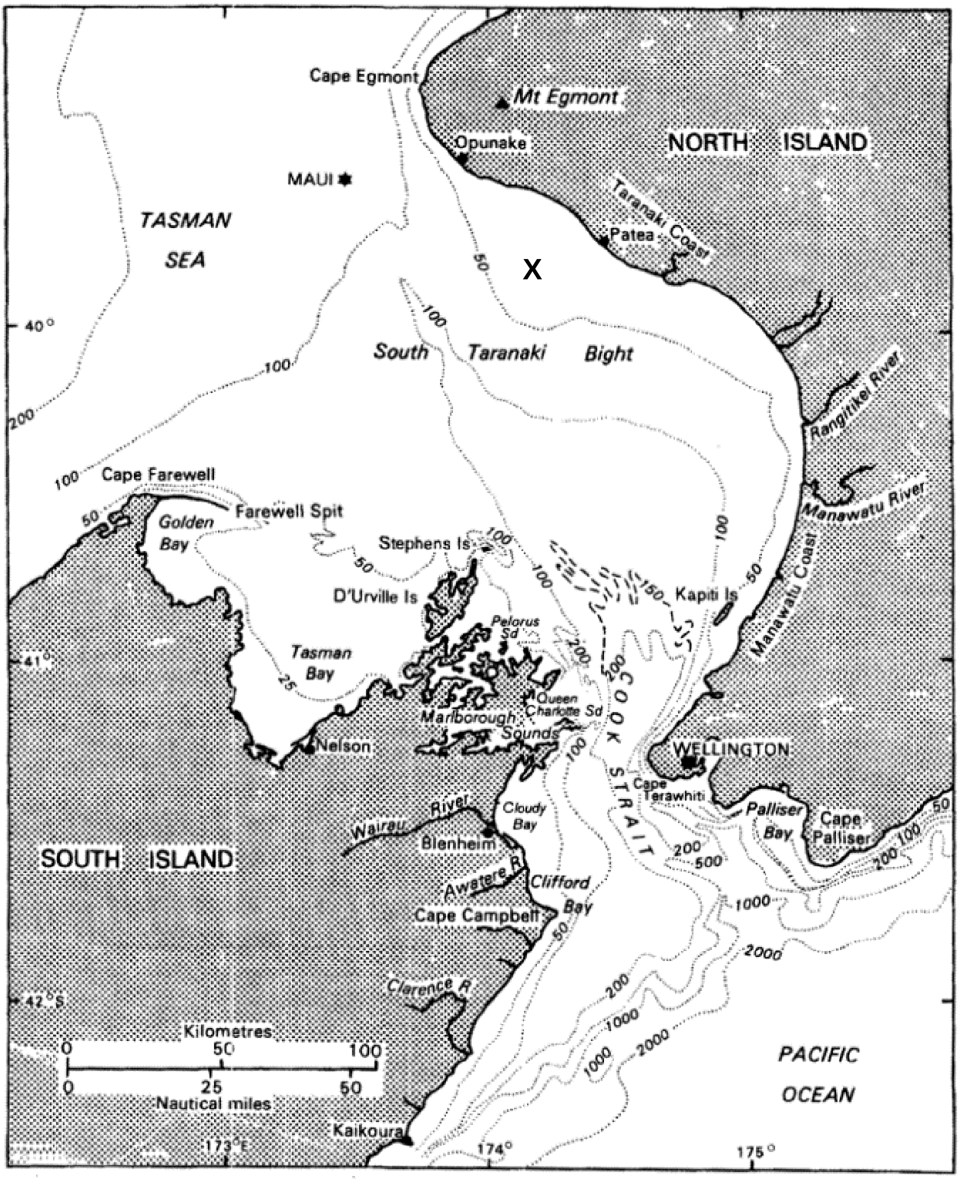

Figure 1-1: Map of Greater Western Cook Straight showing the bathymetry (m) and geographic names mentioned in the text. X indicates the approximate location of the proposed mining site. From Bradford et al. (1986).

2 Classes of pelagic water in the South Taranaki Bight

Four major classes of pelagic water occur in the Greater Western Cook Strait region. These have been previously defined in the New Zealand Marine Environmental Classification (MEC), based on physical variables (Snelder et al. 2007), as Class 124 (inshore), Class 64 (coastal), Class 60 (off-shore), and Class 58 (Cook Strait proper) (Table 2-1).

Class 124 is in shallow water (mean depth = 8 m) and is dominated by very high orbital velocities. Because it is a very narrow band close to shore this class does not show up in Figure 2-1.

Class 64 is deeper (mean depth = 38 m) than Class 124 (Figure 2-1, Figure 5-1). Seabed slopes are low but orbital velocities are moderately high and the annual amplitude of sea surface temperature (SST) is high. Chlorophyll a reaches its highest average concentrations in this class.

Class 60 is extensive, occupying deeper shelf waters (mean depth = 112 m) with moderate annual solar radiation, moderate winter SST, and moderately high Chlorophyll-a concentrations (Figure 2-1, Figure 5-1).

Class 58 is of relatively restricted extent occurring in deeper shelf waters (mean = 117 m) around the northern tip of the North Island and in Cook Strait (Figure 2-1). Strong tidal currents are the dominant feature of this class.

Thus, the pelagic waters of the STB comprise Classes 124, 64 and the eastern fringes of Class 60. Zooplankton sampling carried out in the STB is described in Section 5.0 below in relation to these classes of pelagic water.

Table 2-1: Average values for each of the eight defining variables for the four environmental classes occurring in the Greater Western Cook Strait. Data are from Snelder et al. (2007). EEZ = Exclusive Economic Zone, SST = sea surface temperature.

MEC Class	EEZ Area (km^2)	Depth (m)	Slope (cm m^{-1})	Orbital velocity (ms^{-1})	Annual solar radiation (W m^{-2})	SST amplitude (°C)	SST gradient (°C km^{-1})	SST winter (°C)	Tidal current (ms^{-1})
124	68	8	0.4	836	13.4	2.3	0.02	12.7	0.0
64	2,689	38	0.3	272	14.2	2.9	0.02	12.6	0.19
60	4,084	112	0.3	21	14.4	2.5	0.02	13.2	0.26
58	394	117	0.7	57	14.7	2.2	0.03	13.0	1.09

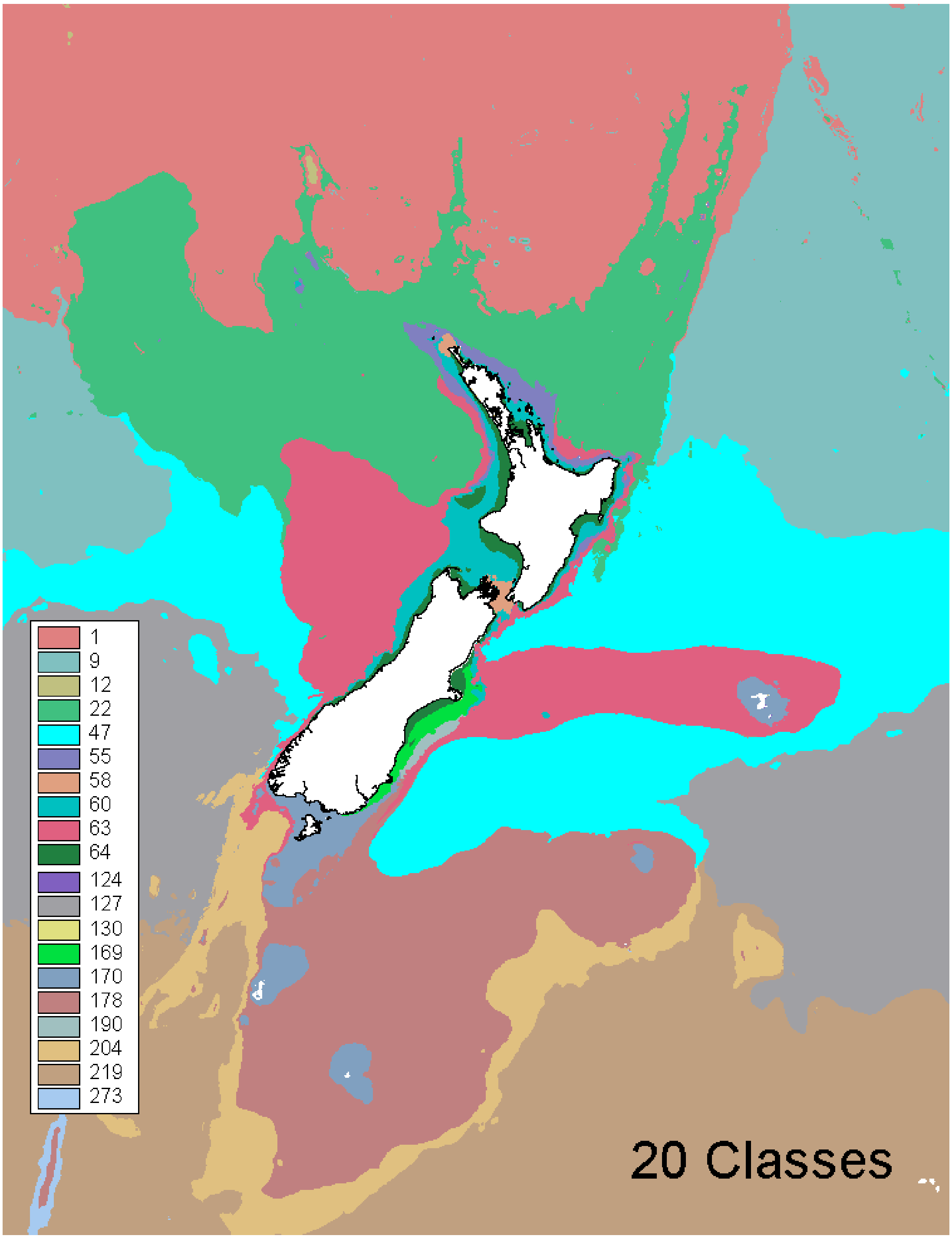

Figure 2-1: A New Zealand marine environment classification at the 20-class level. From Snelder et al. (2007).

3 Summer phytoplankton nutrient renewal processes in Greater Western Cook Strait

In summer, in the absence of mixing, the water in Greater Western Cook Strait stratifies as it is heated by the sun. This stratification has positive and negative effects on phytoplankton production. A positive effect is that phytoplankton is able to remain in the sunlit surface waters and therefore can continuously photosynthesise during the day time. As phytoplankton uses chlorophyll *a* to produce more organic matter, dissolved plant nutrients such as nitrate, ammonia, phosphorus, and silica are consumed. In the absence of mixing, dissolved inorganic nutrients are soon used up in near surface waters and primary production declines along with phytoplankton biomass as zooplankton graze down the phytoplankton.

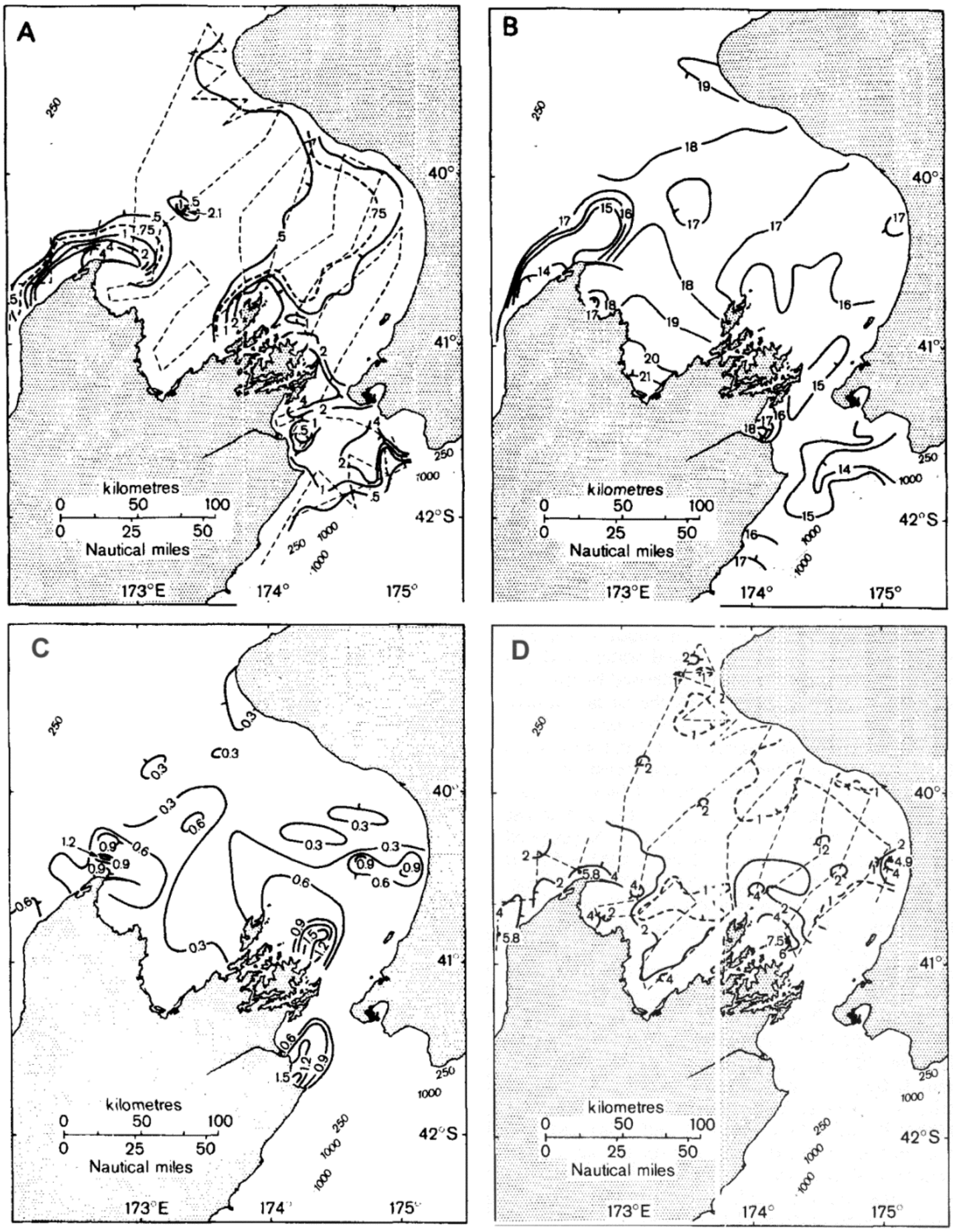

Figure 3-1: Distribution of surface water properties 11-19 January 1980. A, nitrate-nitrite nitrogen (µmol l^{-1}); B, temperature (^{o}C); C, chlorophyll *a* (mg m^{-3}); D, potential primary production (mgC $m^{-3}h^{-1}$). Ticks directed towards regions of low values. From Bradford et al. (1986).

In contrast, there are some regions of Greater Western Cook Strait where mixing enriches surface waters with plant nutrients. Well-mixed water, with elevated dissolved inorganic nutrients, has been observed at the surface off Kahurangi/Cape Farewell, off Pelorus Sound and in Cook Strait narrows (Figure 3-1A) (Bowman et al. 1982; Bowman et al. 1983b, c). Tidal mixing is the reason for well-mixed waters with moderate nutrient concentrations off Pelorus Sound and in Cook Strait narrows.

A different process is operating off the north-western South Island. Off Cape Farewell, unstratified, cool, high salinity, dissolved inorganic nutrient-rich water, (Figure 3-1A, B) has been found on several occasions and extends, sometimes as isolated patches, in a north-easterly direction into Greater Western Cook Strait and the STB (Stanton 1971; Bowman et al. 1982; Bowman et al. 1983b; Bradford et al. 1986). Mesoscale eddies are shed particularly during spring tides in the wake of the Kahurangi Shoals (Bowman et al. 1983a; Chiswell 1983) to bring nutrients closer to the surface with concentrations of nutrients being related to the depth from which upwelling occurs. The trends in distribution of nitrate (NO_3) and ammonia (NH_4), and particulate nitrogen (PN) show that the greatest NO_3 concentrations are found in the western, upstream part of the upwelling zone, whereas NH_4 has a reverse distribution downstream (Viner & Wilkinson 1988) resulting from the metabolic processes of grazing animals.

North of Kapiti Island, close to the coast, elevated dissolved reactive silica has been recorded in conjunction with dilute salinities (Bradford et al. 1986). It was deduced that the Manawatu River was responsible for the injection of silica into the ocean. Also, in many parts of the world, surf diatom blooms occur (e.g. McLachlan & Lewin 1981) indicating there are beach-generated recycling of nutrients (e.g. Cockcroft & McLachlan 1993). We do not know how far away from the coast nutrient recycling from bottom sediments influences the water column.

4 Phytoplankton biomass (chlorophyll *a*) and primary production

4.1 Biomass

In Greater Western Cook Strait the patterns of distribution of chlorophyll *a* in summer and autumn (Figure 3-1C) are related to the features described in Section 3 above which renew phytoplankton nutrients in the region (Bowman et al. 1983; Bradford et al. 1986; Viner & Wilkinson 1987). In January 1980 maxima in surface chlorophyll *a* were located near Farewell Spit, off Marlborough Sounds, and off the Manawatu coast.

Tidal mixing influences chlorophyll *a* distribution off the Marlborough Sounds (Figure 3-1C) (Bradford et al. 1986), with maximum concentrations found in the more stable water adjacent to the well mixed region.

Upwelling against the north-west coast of South Island and the north-eastwards shedding of cold nutrient-rich water into Greater Western Cook Strait is associated with greater concentrations of chlorophyll *a* than the surrounding water. The pattern of chlorophyll *a* distribution is similar with maxima north and east of Cape Farewell (Figure 3-1C).

The only historical in situ chlorophyll *a* data from the STB was collected 11-19 January 1980 (e.g. Bradford et al. 1986 and references therein). Chlorophyll *a* values were low (< 0.3 mg m^{-3}) similar to the general background values for Greater Western Cook Strait.

An area of maximum chlorophyll *a* off the Manawatu River in conjunction with elevated dissolved reactive silica and a salinity minimum suggests river water is implicated in the localised accumulation of phytoplankton biomass (Bradford et al. 1986). Such accumulations of diatoms have also been noted at Waitarere beach by Cassie and Cassie (1960).

4.2 Primary production

Patterns of surface primary production also approximately followed the processes renewing plant nutrients (Figure 3-1D) with maxima (> 4 mgC m^{-3} h^{-1}) in the Kahurangi/Cape Farewell upwelling plume, Marlborough Sounds tidal mixing and off the Manawatu River (Bradford et al. 1986). Nevertheless, absolute levels of primary production were probably overestimated as Viner (1990) showed that in such productive coastal waters there is a high potential for heterotrophic dark uptake (by non-photosynthetic microbes) of carbon. The most elevated rates of non-photosynthetic carbon uptake were generally associated with the warmer, more mature parts of the upwelling plume. Here, both bacteria and phytoplankton used NH_4 (Viner 1990). Bacteria also transformed NH_4 into NO_3 (nitrification) and may have supplied about 40% of phytoplankton requirements for NO_3 (Priscu & Downes 1985).

Highly productive surf diatoms (20-400 mgC h^{-1} m^{-3}) have been recorded in New Zealand waters at Waitarere Beach south of the Manawatu River (Cassie & Cassie 1960). Toheroa and other shellfish are often plentiful where blooms of these diatoms take place. Here we cannot separate the possible effects of river runoff and processes which recycle nutrients on sandy beaches.

5 Mesozooplankton biomass and populations

5.1 Available data

Zooplankton samples were taken at 90 stations in the STB over a period of 13 years in the 1970s and 1980s (Battaerd 1983, Bradford 1977, 1978, 1980, Bradford et al. 1993) (Figure 5-1). Zooplankton biomass data were collected at 62 stations for all species and for two key species at an additional four stations. Zooplankton species composition data were collected at 79 stations including 55 of the stations at which biomass data were collected. At one station, the Maui A platform, zooplankton species composition data were collected four times over a period of 10 months in 1981 and 1982 (Battaerd 1983).

Most of the sampling stations (83%) were in MEC Class 60 waters (Figure 2-1) in depths > 50 m. About 17% of zooplankton sampling stations were in MEC Class 64 waters and none were in MEC Class 124 waters.

5.2 Biomass

Biomass, as wet weight, may be elevated in summer in the STB compared with other near-shore regions around New Zealand (Bradford and Roberts 1978; Bradford 1980). Biomass measurements ranged from 100 to > 8000 mg m^{-3} in mid-January 1980 (Bradford et al. 1986)

(Figure 5-2), 50 to > 300 mg m^{-3} in March 1983 and 50 to > 200 mg m^{-3} in April 1983 (Bradford-Grieve et al. 1993). In mid-January 1980 the highest zooplankton biomasses in the STB occurred in MEC Class 64 waters east of the proposed mining site and were dominated by salps (*Thalia democratica*).

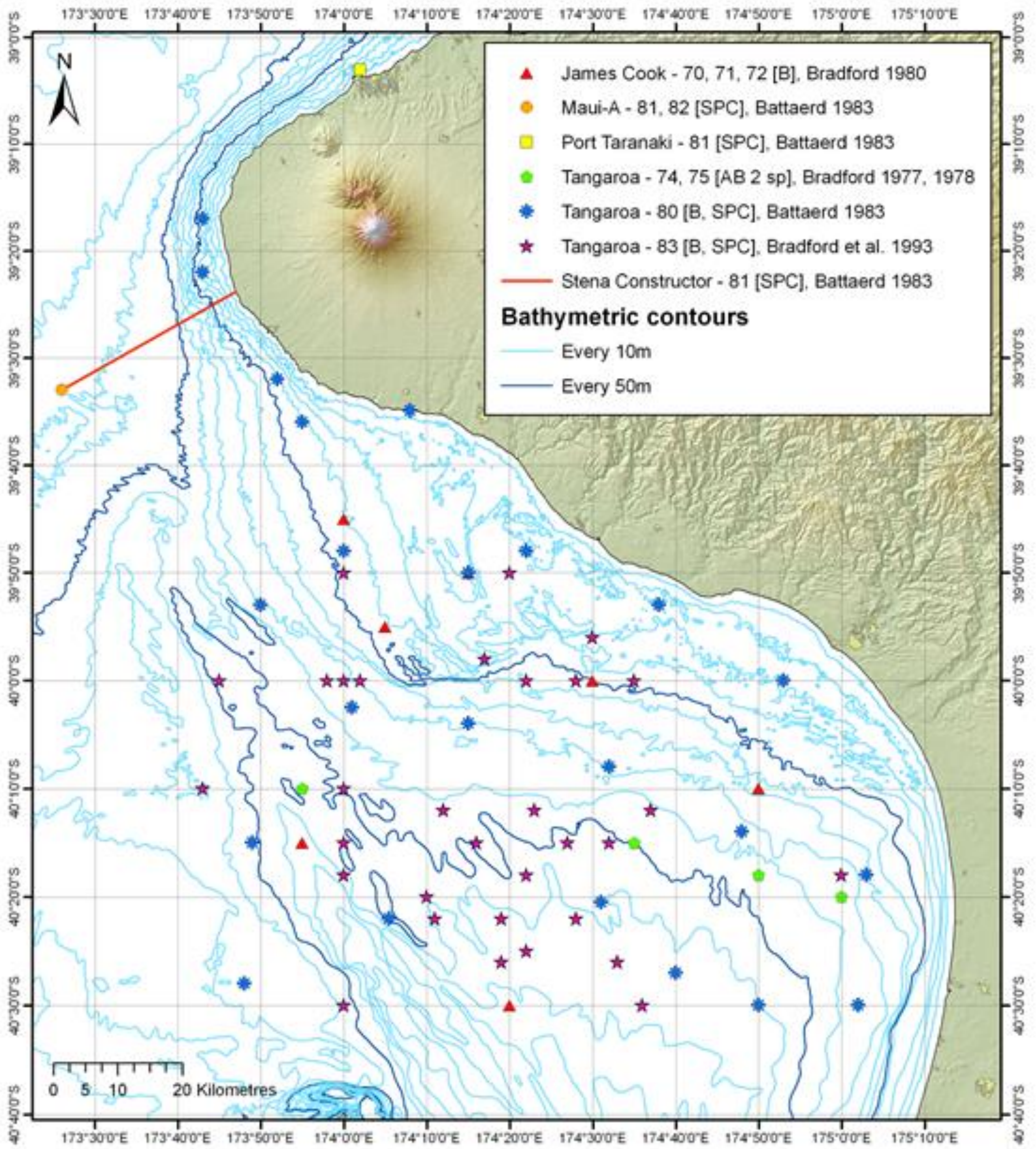

Figure 5-1: Locations in the South Taranaki Bight where mesozooplankton sampling has been conducted. The legend shows the vessel or location, followed by the year of sampling and the reference. Codes refer to the types of samples that were collected where B=biomass, SPC=species composition, and AB 2 sp=abundance data for 2 individual copepod species. A total of 23 stations were sampled along a transect from Oaonui to the Maui-A gas platform (Stena Constructor).

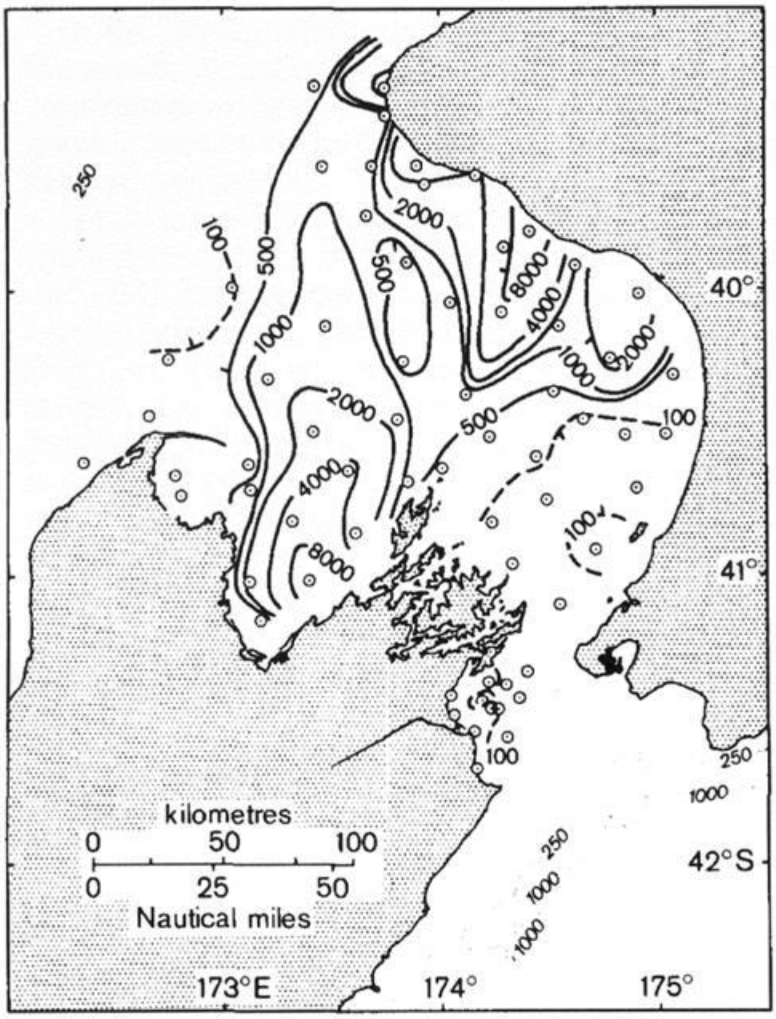

Figure 5-2: Integrated (from surface to near seafloor) zooplankton wet weight (mg m^{-3}) 11-19 January 1980. Ticks directed towards regions of low concentrations. From Bradford et al. (1986).

5.3 Species composition

The mesozooplankton community in Greater Western Cook Strait (Figure 5-3) is typical of the nearshore zooplankton communities found round the North Island, New Zealand (e.g. Bradford-Grieve et al. 1993). The dominant species found at all sampling sites (Maui-A platform, STB proper and Port Taranaki) were *Oithona similis* (reaching 15,000 m^{-3}) and *Paracalanus* c.f. *indicus* (reaching 1200 m^{-3}) (Battaerd 1983; Foster and Battaerd 1985; Bradford-Grieve et al. 1993). Other species and groups that were frequently abundant were copepod nauplii (a developmental stage), the copepods *Microsetella rosea*, *Clausocalanus* spp., *Acartia ensifera*, *Corycaeus aucklandicus*, *Euterpina acutifrons,* and *Temora turbinata* (Battaerd 1983; Bradford-Grieve et al. 1993). A number of other species were consistently present but in small numbers. Gelatinous zooplankton such as appendicularians (*e.g.*, *Oikopleura* spp.) and salps (*e.g.*, *Thalia democratica*) were sometimes dominant.

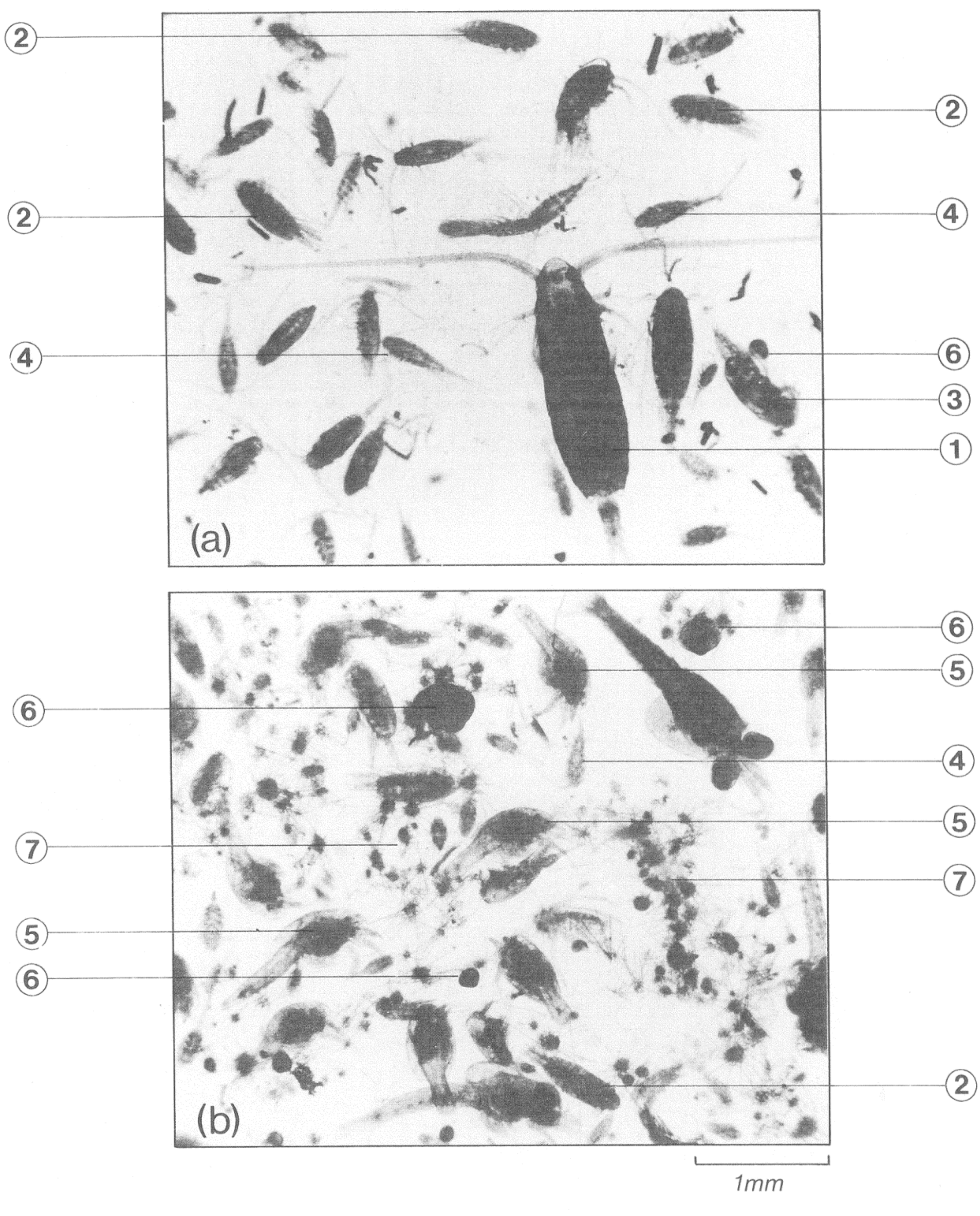

Figure 5-3: Samples of zooplankton from Greater Western Cook Strait. (1) Calanus australis; (2) Paracalanus c.f. indicus; (3) Clausocalanus spp. (4) Oithona similis; (5) calyptopsis of Nyctiphanes australis; (6) bivalve larvae; (7) acantherian protistans. From Bowman et al. (1982).

6 Discussion

A limitation of the available data about plankton communities and related geophysical processes in the Greater Western Cook Strait is that they are from the 1970s and 1980s, are mainly from the warmer months, and very few of the oceanographic studies included results from the shallowest regions of the STB. That is, most (about 83%) of the zooplankton data were for MEC Class 60 water offshore of the proposed iron sand extraction site (Figure 2-1, Figure 5-1). About 17% of the data were for MEC Class 64 waters that includes the proposed extraction site and coastal waters shallower than about 50 m. None of the zooplankton sampling stations were located near-shore in the long, narrow, and shallow MEC Class 124 waters that includes the surf zone.

The Greater Western Cook Strait region, including the South Taranaki Bight (STB), is impacted by several large-scale, highly variable, physical phenomena that structure the distribution and biomass of zooplankton, mediated by the pattern of distribution of phytoplankton biomass and its primary production. These large-scale physical processes include the Kahurangi / Cape Farewell upwelling plume, tidal mixing, river plumes and surf beach processes. Of these the Kahurangi/Cape Farewell upwelling plume is the best understood in terms of plant nutrient renewal which impacts primary production and dynamics and its downstream impact on the zooplankton. A high degree of year-to-year and season-to-season variability in these processes and consequent patterns of plankton distribution and biomass is to be expected. Ten-year satellite observations of sea surface chlorophyll (Pinkerton et al. 2013), show impacts of summer upwelling off the Kahurangi Shoals and winter influence of near shore process including river inputs. Importantly, Pinkerton et al. (2013) found no evidence of long-term (decadal) trends in phytoplankton biomass suggesting that the plankton observations from the 1970s and 80s provide insights relevant today.

The upwelling of cold nutrient-rich water off Kahurangi Point and its transport north-eastwards past Farewell Spit affects the zooplankton fauna in the STB, especially those in MEC Class 60 waters, a number of ways. First, there is evidence of passive entrainment effects on zooplankton assemblages. This takes the form of oceanic species being carried inshore upstream in the upwelling plume then north-eastwards (Bradford-Grieve et al. 1993). Other species may be entrained from Tasman and Golden Bays in the westerly or south-westerly flows between the upwelling plume and Farewell Spit (e.g. *Euterpina acutifrons, Temoria turbinata*, and *Corycaeus aucklandicus*).

Second, there is indirect evidence that *in situ* processes structure zooplankton populations through the growth and consumption patterns of the species involved. Although the Kahurangi/Cape Farewell upwelling plume, rich in inorganic nutrients, promotes phytoplankton growth above background levels (Bradford- et al. 1986; Viner & Wilkinson 1987), at the beginning of the upwelling plume primary production is not great enough to match zooplankton food requirements. Minimum breeding activity was indicated by low numbers of copepod nauplii and calculations showed that zooplankton ingestion exceeded potential phytoplankton production (James & Wilkinson 1988). The reversed applied downstream in the upwelling plume. Nitrate levels decreased, ammonia levels increased, and concentrations of copepod nauplii were an order of magnitude greater than in the Kahurangi Point area as were the developmental stages of the krill *Nyctiphanes australis* (Bradford-Grieve et al. 1993; Bradford & Chapman 1988).

There were several stages in the development of copepod assemblages along the upwelling plume (Bradford-Grieve et al. 1993). Upwelling near Kahurangi Point resulted in an assemblage of high average biomass, relatively rich in copepod species, including oceanic species, although the omnivore *Acartia ensifera* was numerically dominant. The upwelling reduced the proportion of copepod herbivores and favoured omnivore species (*Acartia ensifera, Oithona similis*) which are possibly best equipped to survive in a situation where zooplankton grazing was overtaking phytoplankton production (James & Wilkinson 1988). As this assemblage was transported north-eastwards, average biomass fell and further oceanic copepod species were entrained which produced high species richness, but two omnivorous copepods *Acartia ensifera* and *Oithona similis* were present in very large numbers. Further east the proportion of herbivorous copepods, species richness and zooplankton biomass increased. These are the populations that extend into MEC Class 64 waters in the STB.

In shallow coastal MEC Class 64 waters <50 m deep, even though tidal mixing occurs along STB (Bowman et al. 1983b), it does not result in nutrient renewal in January as the thermocline lies below the depth to which near shore waters are mixed. The phytoplankton chlorophyll *a* results we have for this class of water (Figure 3-1C, D) are usually low (< 0.3 mg m^{-3}), patchy and probably influenced by river runoff or sandy beach nutrient recycling processes. We do know, on at least one occasion, that a huge biomass of the fast growing, gelatinous salps (*Thalia democratica*) were present in the STB (e.g. Figure 5-2) and may have been responsible for the low chlorophyll *a* measured on this occasion (Figure 3-1C).

The zooplankton populations of Class 64 water in the STB, when not dominated by salps, are likely to be dominated numerically by *Oithona similis* (16,000 individuals per 0.25 m^2), and moderately large numbers of *Acartia ensifera, Clausocalanus jobei, Paracalanus c.f. indicus* and copepod nauplii (Bradford-Grieve et al. 1993). That is, omnivorous copepods should dominate (66%) with 34% herbivores and 0.1% carnivores.

We have no direct knowledge of how such communities change closer to shore in Class 124 waters that have a mean depth of 8m and are dominated by very high orbital velocities. It is possible that, in higher turbulence waters, zooplankton feeding rates decrease and some species might try to avoid high turbulence levels (e.g. Visser & Stips 2002). We might expect shallow near-shore zooplankton assemblages to include more groups that are more common in estuaries and low salinity waters than in water offshore, e.g. cladocera and the planktonic larval forms of benthic and intertidal animals (crabs, echinoderms, molluscs, fish, barnacles etc.) which might be seasonally common (e.g. DeLancy 1987). A special case of Class 124 waters is the surf beach. Primary productivity measurements by Cassie and Cassie (1960) at Waitarere beach showed how productive this type of environment might be. It is likely that this class would be modified by buoyancy imparted by freshwater and additional riverine nutrients.

Information relating to TTR's additional scientific work undertaken since 2014 has been provided and the conclusions is this report remain valid.

7 Acknowledgements

We thank Alison MacDiarmid for reviewing an earlier draft of this report.

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