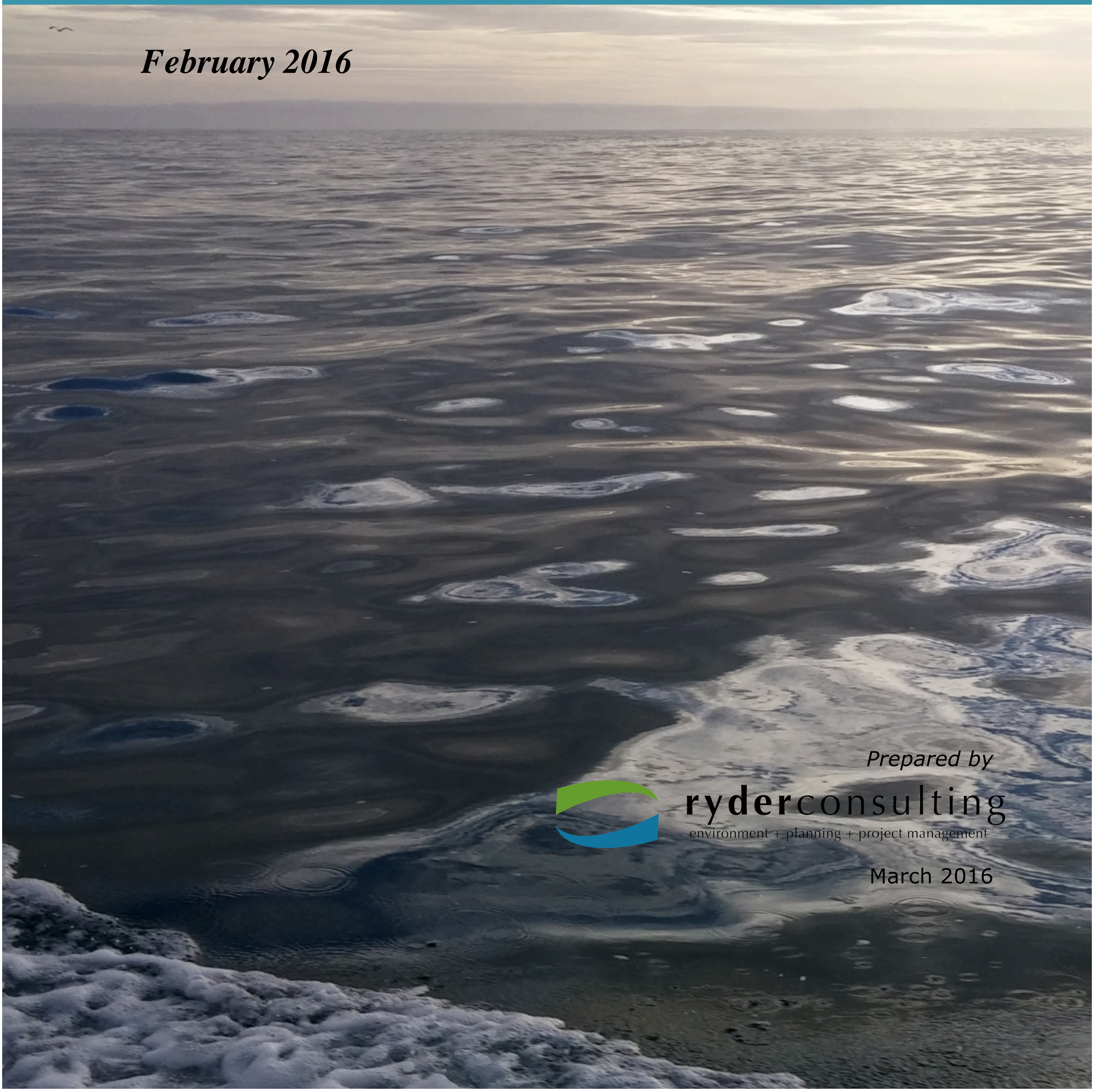
TAHUNA WASTEWATER TREATMENT PLANT OUTFALL – Discharge Consent 2002.623 OFFSHORE SEDIMENT SURVEY:

February 2016



Prepared by

ryderconsulting

environment + planning + project management

March 2016

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Prepared for

Dunedin City Council

By

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March 2016

Cover Photo: Off the coast at the Tahuna outfall – Brian Stewart

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EXECUTIVE SUMMARY

- Benthic marine communities and sediment metal concentrations were measured along a 4000 metre transect parallel to the coastline and centred on the offshore wastewater outfall from the Tahuna Wastewater Treatment Plant and at a single control site.

- This study is the seventh since the commissioning of the outfall and can be compared with earlier baseline studies.

- The transect lies along sandy seabed, with occasional shelly areas. Rocky reef was apparent to the west of the outfall but did not fall within any of the survey sites.

- Sediment metal concentrations were low and well below ANZECC (2000) guidelines.

- Invertebrate communities were patchily distributed, of relatively low abundance and relatively species poor, results that are consistent with nearby areas and with previous surveys.

- No rare or exceptional species or communities were observed in the vicinity of the location of the outfall.

- There are no apparent adverse effects on benthic communities either side of the outfall that may be attributable to the wastewater discharge.

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1. Introduction

1.1 General overview

As a part of the upgrade of the Dunedin City Council's wastewater treatment plant at Tahuna, a permit was granted to discharge wastewater from a new extended coastal outfall 1100m offshore from the Tahuna WWTP site (refer to the Tahuna AEE, 2002 for details) consisting of a 1000m closed pipe culminating with a 100m long diffuser. The extended outfall became operational on 23 January 2009.

This survey is the seventh since the commissioning of the outfall. It is intended to provide a comparison with baseline surveys carried out in 2002, 2004, 2005 and 2006, all of which provided information on the area of the then proposed outfall. This survey serves two purposes:

1) to assess the current environmental state in terms of the presence of unique or outstanding features.
2) to provide data against which past and future studies can be compared to assess any changes that may result from the wastewater discharge.

Other surveys of areas adjacent to the outfall site (Key 1998, Gibbs *et al*. 2003) have also been assessed for comparison.

1.2 Soft-shore sub-tidal benthic biology

1.2.1 Overview

The marine environment in the vicinity of the outfall is predominantly comprised of soft sediment (mainly sand and broken shell), with occasional rocky reefs (AEE, 2002). In marine soft sediment environments the animal communities are based on algae growing on the sediment surface, organic detritus falling from the water column, and organic detritus in the sediments. The benthic (bottom-living) animals present live both on the sediment (epifaunal animals) and within the sediment (infaunal animals). These animals belong to a variety of taxonomic groups including crustaceans (crabs, cumaceans, isopods, amphipods and shrimps), annelids (predominantly polychaete worms), molluscs (including gastropods and bivalves), nemertean worms, ascidians (sea tulips, sea squirts) and echinoderms (sea urchins, starfish) (Figure 1).

Soft shore marine communities tend to have relatively low densities of animals reflecting the low productivity of those settings. Disturbance of sediments in the sub-tidal zone by wave action and currents also tends to reduce animal density and diversity (the number of different species present).

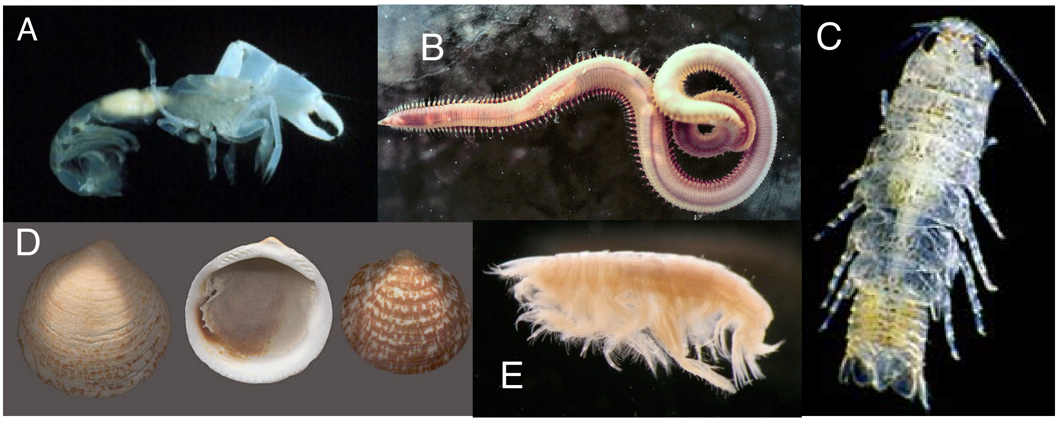

Figure 1. *Typical animals found in marine soft shore benthic communities A) ghost shrimp B) polychaete worm C) isopod D) bivalves and E) amphipod.*

1.2.2 Studies in New Zealand

There have been relatively few studies of soft-shore sub-tidal communities in New Zealand. Those studies that have been carried out have tended to be in situations that are estuarine, rather than strictly marine (e.g. Knox and Kilner 1973, Davidson and Moffat 1990, Davidson and Brown 2000, Robertson *et al*. 2002) or in coastal harbours (e.g. Pridmore *et al*. 1990, Turner *et al*. 1995). These settings are distinct from offshore sites in that the dominant influence is tidal. Of the studies published for offshore settings, the majority have examined the effects of wastewater discharges, including those on the North Otago coast (Robertson 1990, Loveridge 1998, Thompson and Ryder 2001, 2002a, 2002b, Stewart 2004, 2005, 2007, 2008), Hawke Bay (Knox and Fenwick 1981), Gisborne (Roper *et al*. 1989), and Tauranga (Roper 1990).

The communities described from New Zealand soft-shores have generally been variable, both in space and time (Robertson 1990, Roper 1990, Loveridge 1998, Thompson and Ryder 2001). The dominant groups described from soft-shore communities have been the crustaceans (predominantly ostracods, cumaceans, amphipods and decapods), polychaete worms, and molluscs. This appears to differ from the situation overseas (e.g. Clarke and Warwick 1998 in Europe, Jong-Geel *et al*. 2000 in Canada) where annelids (predominantly polychaete worms) are the dominant group.

A number of studies concerning the effects of wastewater discharges have been carried out in the immediate area of this study. Key (1998) surveyed benthic communities in the vicinity of the Lawyers Head wastewater outfall. This area is to the east and inshore of the Tahuna outfall (Figure 2). A number of studies have been carried out in the vicinity of the Green Island discharge (e.g. Stewart 2005, 2010). In overview, all of these studies have characterised the benthic communities in this area as relatively species poor, patchy, and probably most strongly affected by physical disturbance. In general, species that are considered intolerant of pollution have been found to be absent, but this is thought to reflect the high-energy nature of the coast and resulting significant movement of sediment, rather than due to effects from pollution.

In 2002 a survey was carried out by Gibbs *et al.* (2003) on an area inshore of this study area, adjacent to the Tahuna area, but including a control site to the northeast (at Victory Beach) (Figure 2). Compared to previous surveys this study used different sampling techniques (dredging and grab-sampling), was at a slightly different time of year (late autumn compared to late summer), but used the same sieve size (0.5mm). Density in the Gibbs *et al.* (2003) survey was extremely variable (range of densities = 31-330 individuals/core), but, despite these differences, Gibbs *et al.* (2003) came to the same conclusion as previous investigators: that the area was characterised by low diversity and a patchy distribution of animals, reflecting the harsh physical environment.

1.2.3 Impacts of pollution and indicator species for pollution

Communities of benthic (bottom-living) marine animals are known to be good indicators of the presence of pollutants in the environment (Warwick *et al.* 1990). Patterns of species abundance (numbers), composition (which species are present), and variability, have been widely used to try and assess the effects of pollution (Warwick 1993). These effects may be due to eutrophication (nutrient-enrichment) or to the presence of toxins in, for example, effluent.

Research on the effects of effluent outfalls on soft-sediment fauna has generally shown toxic effects closest to the outfall, then a zone with few species but very high abundance (eutrophic zone), followed by a zone where number of species increases but number of individuals decreases (Table 1).

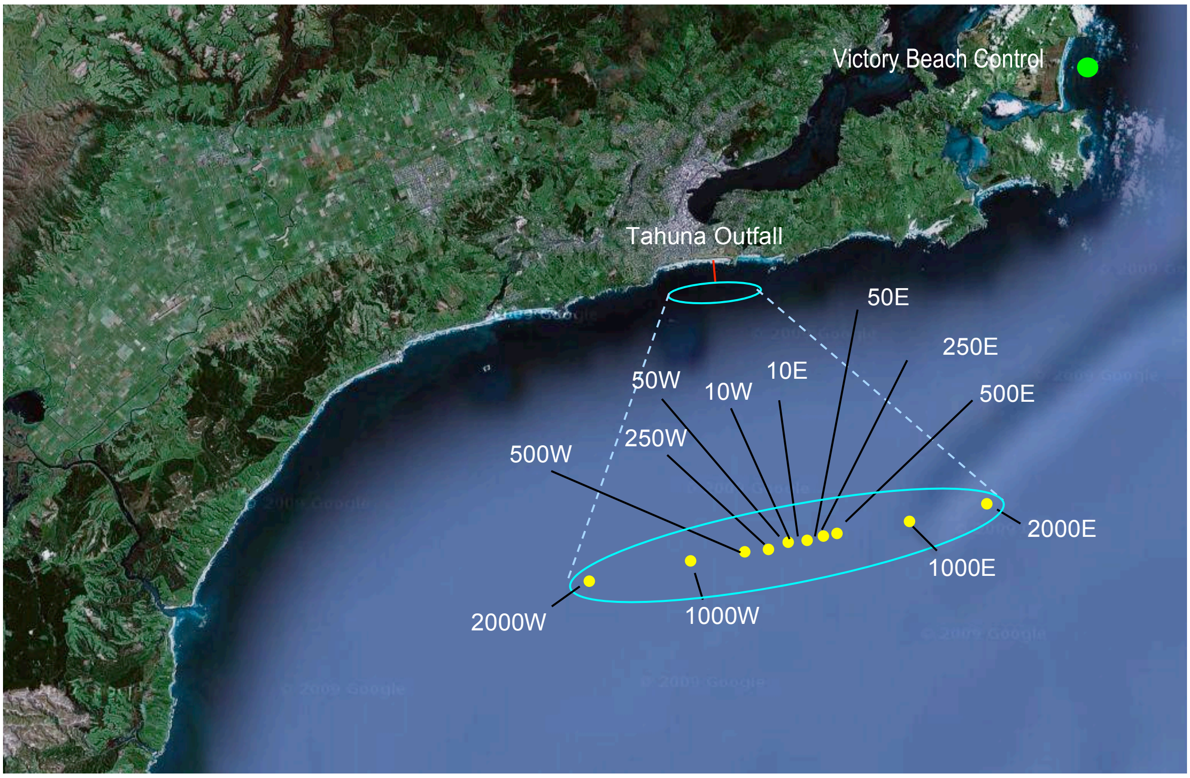

Figure 2. *Locations of survey areas and control site for Tahuna wastewater outfall.*

Table 1. *Summary of trends in benthic marine communities observed around wastewater outfalls in New Zealand and overseas. (Adapted from Pearson and Rosenberg 1978).*

Biological indicator	**Proximity to outfall**		
	Close	**Intermediate**	**Distant**
Number of species	Low	Moderate	High
Number of animals	Low	High	Moderate
Community variability	Low	High	Moderate
Pollution intolerant species	Absent	Reduced numbers	Present

Interpretation of the results of soft-sediment benthic sampling is made more complex by a lack of knowledge of the tolerance to pollution for some taxonomic groups (e.g. Orbiniidae). At a broad level, some families and groups are known to be less tolerant to pollution (Table 2), although we know of no New Zealand studies that directly assess different species' tolerance to organic pollution. There is some doubt as to whether the European Annelid Pollution Index (Dean *et al*. 1988) can meaningfully be applied outside Europe. Investigations of pollution tolerance within polychaete families have highlighted some variability (Belan 2000), but the most significant European conference to date on the issue concluded that family level taxonomy is sufficient to measure the effects of pollutants on marine benthic fauna (Austen *et al*. 1989, Warwick 1988).

Table 2. *Taxonomic families of soft-shore sub-tidal benthic invertebrates. For families whose tolerance to pollution has been hypothesized (Pearson and Rosenburg 1978; Thrush and Roper 1988; Roper 1990), tolerance is shown with asterisk; * tolerant, ** moderately tolerant, *** intolerant. [??] indicates unknown tolerance.*

Group	Family	Group	Family
Polychaetes	Amphictenidae***	Isopods	All families[??]
	Ariciidae***	Echinoderms	Holothuria[??]
	Capitellidae*	Bivalves	All families[??]
	Magelonidae**	Nemerteans	All families[??]
	Malanidae***		
	Nereidae***		
	Nephtyidae*		
	Serpuliidae***		
	Spionidae**		
	Other families[??]		
Ascideans	All families[??]		
Amphipods	All families[??]		
Cumaceans	All families***		

2. Methods

2.1 Sub-tidal monitoring sites

Samples were obtained from a transect running parallel to shore in the depth range of 14-21 m (Figures 2 and 3). This depth was chosen as being representative of the depth at which the sewage outfall lies (18 – 20 m at Tahuna). At some sampling sites this depth lay slightly greater or less than 1100m offshore but it is considered that, for the purposes of this survey, depth rather than distance from shore is more critical in determining community composition. Samples were taken 10m, 50m, 250m, 500m, 1000m, and 2000m either side of the effluent outfall along the transect (Figure 3). In addition, samples were taken from a single location at Victory Beach to the northeast (Figure 2) to function as a control. All sampling sites were located using a global positioning system (GPS) located on the tender boat. These positions are listed in Appendix One.

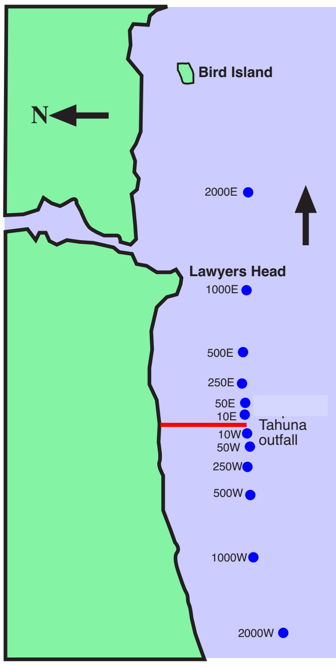

Figure 3. *Sampling locations (blue dots) around the Tahuna wastewater outfall (shown as a red line). The predominant current direction is shown with a black arrow.*

2.2 Sample Collection and Processing

All samples were collected by OSH-accredited divers operating from a boat. All sampling was carried out in a way that was consistent with the Health and Safety Plans of Ryder Consulting Ltd. and New Zealand Diving and Salvage Ltd.

2.2.1 Benthic macrofauna samples

The methods used in 2016 are broadly similar to those employed in previous offshore surveys (Robertson 1995, 1997; Ryder 1999, 2000, 2001, Thompson and Ryder 2002, 2003, Stewart 2004, 2005, 2006, 2010a, 2011 - 2015). At each sampling location divers entered the water and descended to the bottom. The divers noted the immediate characteristics of the seabed, estimated visibility, and took note of any other significant features. Three samples of the substrate were taken for benthic community analysis, and involved inserting an 85 mm diameter core sampler approximately 250mm into the substrate (Figure 4). A core of sediment was extracted, capped, and place in a catch-bag for return to the surface.

At the surface the samples were sieved through a 0.5 mm diameter mesh Endicott® sieve and all animals retained placed into pre-labelled plastic jars. Upon return to the laboratory the samples were preserved in 70% ethanol for identification and enumeration.

Figure 4. *Core sampler used during offshore sampling.*

A number of community values were gained for each sample:

Species diversity: the number of different 'types' of animals found in each sample.

Invertebrate abundance: the total number of animals found in each sample.

Community structure: the way in which the total number of invertebrates is distributed across the different species in each sample.

Variability: the amount of variation in community structure between the samples at a location.

2.2.3 Metal samples

A sediment sample for heavy metal analysis was collected at each site using labelled clean 200 ml screw-top plastic containers. Each container was 'scooped' horizontally along the surface to take a sample to a depth of approximately 2 – 5 cm, then sealed underwater. Samples were refrigerated prior to being delivered the next day for analysis at Citilab, Dunedin. Each sample was analysed for aluminium, cadmium, chromium, copper, lead, nickel, silver and zinc after a nitric/hydrochloric acid digestion.

2.2.4 Statistical analysis

For the analysis prior to the building of the outfall, the primary aim was to ascertain whether there are underlying differences between locations that might act to obscure patterns in the future. Post commissioning results were analysed to answer three main questions:

1. Do benthic communities differ significantly between control sites and sites around the outfall in terms of; species richness, total numbers, variability and overall community structure?
2. Do benthic communities change moving closer to the outfall in terms of species richness, total numbers, variability and overall community structure?
3. Is there any relationship between heavy metal concentrations, the outfall, and benthic invertebrate communities?

2.2.5 Analysis of biological communities

Simple measures of species diversity (number of different 'types' of animals per sample) and animal abundance (number of animals per sample) were calculated from the collected data. A diversity index was also calculated using the Shannon-Weiner method (Zar 1996). A higher diversity index indicates high diversity in the community. Such indices provide a ready method for comparing diversity at sites from year to year. For other community analyses the data were transformed (fourth root) to meet the statistical requirements of the tests used.

Effects of distance from outfall on diversity and abundance

To compare the species diversity, total abundance and variability in invertebrate communities at each sampling location, two-factor analysis of covariance was used. This tested for an effect of distance from the outfall (in metres), and direction from the outfall (up-current or down-current) (Figure 3). The test then analysed the interaction between distance and direction. A significant result for this test indicates that the patterns in diversity or abundance with distance from the outfall differ between the up-current and the down-current samples.

To interpret analysis of covariance results, look at the 'p' value. If this value is less than 0.05, then the two groups of data are significantly different from one another.

Effect of distance from outfall on invertebrate community structure

Differences in invertebrate community structure were analysed in a number of ways. To test whether the benthic invertebrate communities were different at each location, multivariate techniques were used. Multivariate techniques have been shown to be the most useful indicators of community responses to environmental pollutants (Bayne *et al*. 1988).

Variability was measured using the Index of Multivariate Dispersion (IMD) (Warwick and Clarke 1993). Higher values of the IMD indicate higher variability. IMD values were calculated for the invertebrate samples at each location and compared visually.

Ordination was used to 'graph' the invertebrate communities. In these plots, how close the cores appear to each other reflects how similar they are in terms of species composition and abundance patterns.

Although the statistics underlying multivariate analysis are complex, interpretation of the results is simple. An ordination is just a picture that shows how similar the communities from each core are to each other. If sites are very similar then they are close to each other in the picture.

Analysis of similarities was used to test whether there were significant differences between the invertebrate communities at different locations. This procedure is like drawing a circle around each group of data, (for example around all of the samples from 2000E of the outfall, and all of those from 10E) and comparing the amount of variation within each circle to the variation between circles.

To interpret analysis of similarities results, look at the 'R' value. A value of 0 means the groups are indistinguishable; a value of 1 means that *all* similarities within groups are less than *any* similarity between groups. i.e. the closer the number is to 1, the more different the groups are.

Comparison between communities at impact and control sites

To compare the communities around the outfall with those from the control sites, analysis of similarities was used to test whether there was a significant difference between communities up-current of the outfall, down-current of the outfall, and at Victory Beach. The species that were responsible for differences between the groupings were identified using similarity percentages (Warwick and Clarke 1994).

Similarity percentages express how similar the distribution of animals across species is between two locations. A value of 100% would indicate that the communities at two locations are identical in terms of species present and the number of animals in each species.

2.2.5 Analysis of metal data

To compare the concentrations of each of the metals at different distances up-current and down-current of the outfall, a two factor analysis of covariance (ANCOVA) was used. This analysis compares the average levels each side of the outfall, and ascertains whether they are significantly different from one another, then tests to see if differences at different distances from the outfall are statistically significant. Finally, an analysis is carried out to test whether the patterns of concentrations on each side of the outfall with distance are the same.

To interpret analysis of covariance results, look at the 'p' value. If this value is less than 0.05, then the two groups of data are significantly different from one another.

A 'p' value of 0.05 or less means that there is at most a 5% chance that the statistical differences between the two groups of data could be false. Or, put another way, there is a 95% chance that the two groups of data are statistically different.

Relationships with metals data

To look at the relationship between metal concentrations and invertebrate communities the ordination of the communities had overlain on it the sediment chemistry data. Therefore, cores that were different in terms of both communities and metal concentrations could be identified.

3 Results

The survey was undertaken on 11th February 2016. Weather conditions were fine with a light, but strengthening, north easterly breeze. Sea conditions at the time were light, with a swell of approximately 2 m. Water visibility was approximately 5 - 8 m.

3.1 General observations

Benthic sampling sites were dominated by sand that was largely devoid of surface material (Table 3). Shelly material evident at sites close to the outfall last year was once again present this year. Depths ranged from about 21 metres at 500E to 13 metres at the Victory Beach site (Table 3).

Table 3. *General characteristics of sites sampled in February 2016*

Location	Depth	Substrate
2000E	15.0	Clean mobile sand
1000E	20.0	Clean mobile sand
500E	21.0	Clean mobile sand
250E	20.0	Clean mobile sand
50E	20.5	Clean mobile sand
10E	20.0	Clean mobile sand
10W	20.0	Clean mobile sand
50W	20.0	Clean mobile sand and abundant shell material
250W	18.0	Shelly material
500W	17.5	Clean mobile sand
1000W	18.0	Clean mobile sand
2000W	17.0	Clean mobile sand
Victory	13.0	Clean mobile sand

3.2 Heavy Metals

Heavy metal results are presented in Table 4 and Figure 5. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) establish guidelines for sediment quality. These are based on recognition that sediments are an important sink for contaminants, that may then impact on benthic communities. The ANZECC guidelines propose two levels; a trigger value, which when exceeded requires further investigation, and a 'high' value, which suggests an immediate and chronic problem. As there is a general lack of information on toxicity of metals in sediment in Australasia, these values are largely derived from overseas work (Long *et al*. 1995). The trigger values are recognised by ANZECC as being conservative values, and are the values that we have chosen to use here, adopting a precautionary approach against ecological damage.

None of the metals measured exceeded the ANZECC (2000) low trigger values, with concentrations for cadmium, chromium, copper, lead, nickel, silver and zinc being considerably lower than the relevant ANZECC guideline concentrations (Figure 5). There are no specific guidelines that are applicable to aluminium. This years results are consistent with those reported for relatively "clean" coastal marine environments in New Zealand (Robertson 1997). Overall, mean values were similar to what they have been in previous survyes and lower than those observed last year. For silver and cadmium values, levels at most sites were below the laboratory detectable limits (Table 4).

Table 4. *Metals concentrations in sediments at survey sites sampled in February 2016. Units are mg/kg dry weight. BDL = below detectable limits.*

Site	Al	Ag	Cd	Cr	Cu	Ni	Pb	Zn
Vict	3900	BDL	BDL	5.7	3.2	5.5	2.5	17
2000E	2300	BDL	BDL	2.9	1.9	3	1.69	10.6
1000E	2500	BDL	BDL	3.8	1.6	3.6	1.67	10.1
500E	2300	BDL	BDL	2.9	2	3.1	1.88	10.6
250E	1860	BDL	BDL	2.6	1.7	2.7	1.57	8.6
50E	2400	BDL	BDL	3.5	1.8	3.2	1.88	10.3
10E	2400	BDL	BDL	3.5	1.8	3.4	1.75	9.9
10W	2400	BDL	BDL	3.3	1.8	3.2	1.75	10.5
50W	3600	BDL	0.038	5	3.5	5.2	3	15.4
250W	1800	BDL	0.024	2.7	2	3.3	1.82	8.4
500W	2300	BDL	BDL	3.3	2	3.4	1.83	10.9
1000W	2200	BDL	BDL	2.7	2	3	1.7	9.8
2000W	2300	BDL	BDL	3.1	2	3.3	1.78	12.3

As in previous surveys, values for aluminium and nickel show a degree of variability (Figure 5), but there is no clear pattern of higher or lower values upstream or downstream of the outfall.

When the results were analysed to test for an effect of proximity to the outfall and for direction (up-current or down-current) relative to the outfall, with the control site included, just cadmium showed any significant interaction for direction, largely due to the fact that cadmium was undetectable at all eastern (downstream) sites (Table 5). If Victory Beach data are removed, the interaction for cadmium is no longer significant for "distance" (Table 5). This differs from the 2015 round where silver was noted to have significant interactions with both distance and direction. However, it is much the same as for 2014 and 2013 results when no significant interactions were found. Such fluctuations are likely the result of natural variability.

It should be remembered, however, that the levels of metals in the sediments, both east and west of the outfall, are so far below the ANZECC guidelines as to be biologically insignificant (Figure 5).

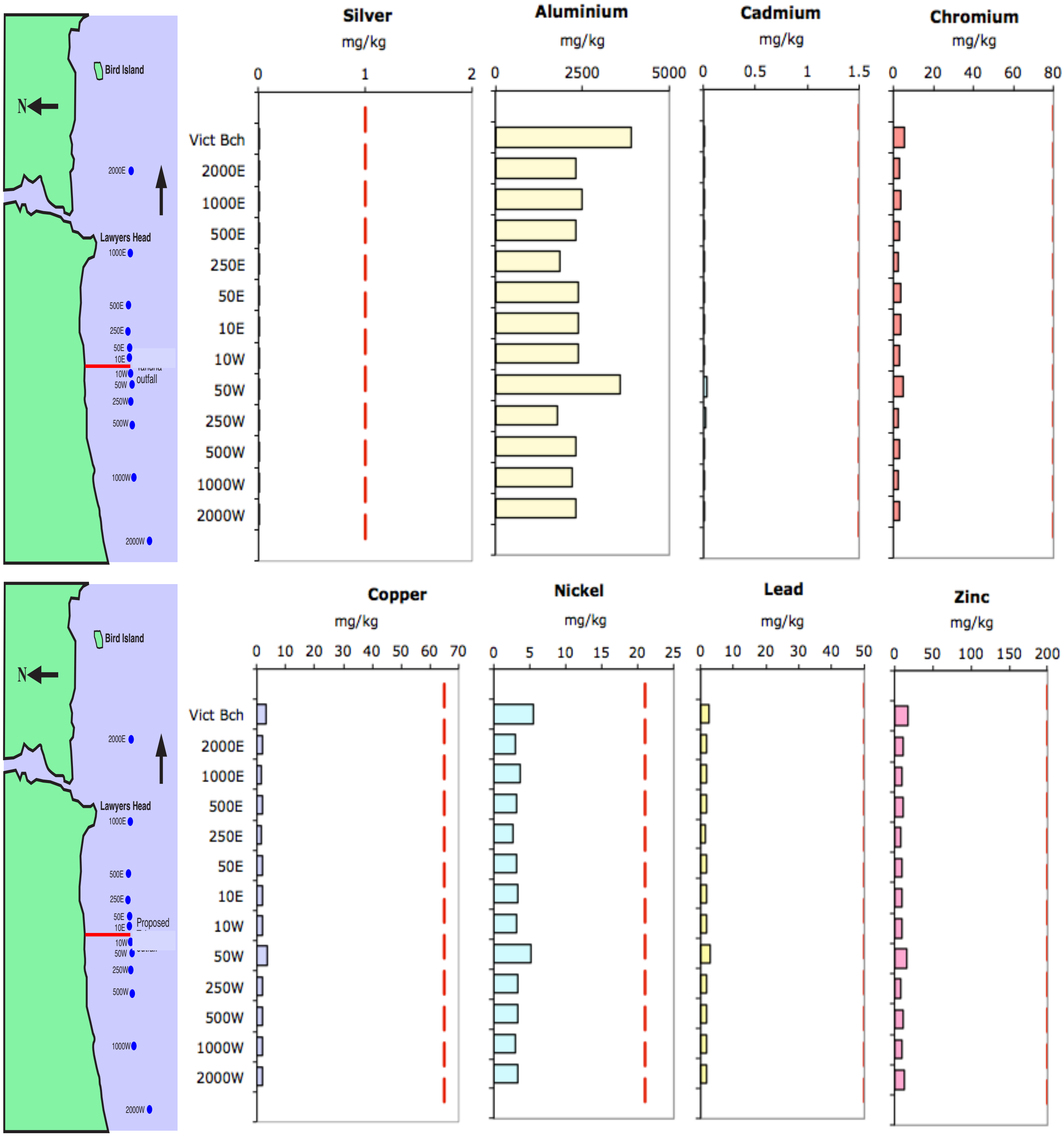

Figure 5. *Mean metal concentrations (mg/kg dry sediment) for February 2016 sediment samples around the Tahuna outfall, and at the controls. Trigger values for possible environmental effects (ANZECC 2000) are marked with a dashed red line.*

Table 5. *Results ('p' values) of an ANCOVA testing for an effect of distance from the outfall (in metres), direction from the outfall (up-current or down-current). A 'p' value of less than 0.05 is regarded as being a statistically significant result and is shown in bold.*

	All sites			Control site removed		
Metal	**Distance**	**Direction**	**Dist/Direction Interaction**	**Distance**	**Direction**	**Dist/Direction Interaction**
Silver	1.00	1.00	1.00	1.00	1.00	1.00
Aluminium	0.089	0.276	0.192	0.641	0.441	0.525
Cadmium	0.142	**0.049**	0.125	0.488	0.089	0.284
Chromium	0.064	0.285	0.140	0.807	0.537	0.590
Copper	0.094	0.073	0.181	0.641	0.156	0.502
Nickel	0.051	0.105	0.119	0.671	0.235	0.488
Lead	0.106	0.116	0.158	0.749	0.240	0.520
Zinc	0.251	0.256	0.548	0.767	0.380	0.822

3.3 Benthic invertebrates

3.3.1 Overview

Data for macrofauna found in sediment core samples that were collected from each site are presented in Table 6. As with previous surveys (Gibbs *et al*. 2003, Thompson and Ryder 2002, 2003, Stewart 2004-2014), crustaceans (e.g. amphipods, shrimps etc.) and polychaetes (marine worms) were the visually dominant animals. However, when examined under the microscope, forameniferans (*Polystomella* spp.) and tiny bivalve molluscs were present at moderate abundances in some samples (Table 6).

The most commonly occurring groups were the amphipods, polychaete worms and forameniferans, which were present in 32, 35 and 25 samples respectively out of 39 cores. The most diverse group were the polychaetes with 11 species overall, but with no more than six taxa present at any one site. The total number of species present (32) was slightly higher than last year, and also higher than in 2014 (31) and 2013 (29), and considerably higher than the 21 observed in 2012. In 2011 there were 26 species, 25 in 2010 and 31 recorded in 2006 (Stewart 2005, 2006). As found in all previous surveys (Stewart 2004 - 2015) the species were patchily distributed, with the greatest species richness being eleven, encountered in the Victory Beach 'c' core (Table 6).

Animal densities varied from 529 to 6696 animals per m^2, with the mean being 2047 per m^2. This is very slightly lower than in last years survey, but is comparable to previous surveys. Core samples contained between 4 and 38 animals with a mean number of 12 per sample, the same as was observed last year.

No rare or exceptional taxa were encountered at any of the sites. However, six ophiuroids were recovered, four at 500E, and one each at 1000E and 500W. This is the sixth survey in which ophiuroids have been observed. A number of taxa considered sensitive to pollution were present. Such taxa include the polychaete families nereidae and spionidae (see Tables 2 and 6). Patterns of occurrence and abundance of these species provide a useful indicator of any potential effects associated the outfall.

3.3.2 Effects of distance from the outfall on diversity and abundance

Mean diversity was highest at Victory Beach, and then at 50W and 500E sites (Table 6, Figure 6). Variability in diversity along the coast was slightly higher than last survey, but similar overall to previous surveys. Diversity still appears to be closely correlated with abundance (number of individuals), with the sites having highest diversity also having the high overall abundance (Table 6).

There were no consistent patterns for diversity with distance from the outfall site ($F_{5,6} = 5.98$, $p = 0.002$) or with direction ($F_{1,10} = 1.08$, $p = 0.322$). This is shown quite clearly in Figure 6. It would be expected that if the discharge was having any significant effect on community diversity it would be apparent as lower diversity observed near the outfall, with diversity increasing as one moved further away. As can be seen in Figure 6, diversity is slightly lower near the outfall, but is also lower at 100W and 200W, both upstream of the outfall.

There is no obvious reason for the higher diversity observed at the Victory Beach, 500E and 50W sites, and it may be simply a reflection of the patchiness of species distribution and abundance, or substrate type. There was no clear relationship with the location of the now defunct Lawyers Head outfall, which is situated landward of the 1000 East sampling site. This site has moderately low diversity and low abundance this year, but is comparable to sites that are located up-current of, or distant from, Lawyers Head (e.g. 2000W, 1000W).

Values for animal abundance (i.e. animal density) were patchy, with relatively high densities at Victory Beach and 50W. The lowest densities were at the 10E and 50E (Figure 6). The statistical tests found no significant effect for direction from the outfall with respect to abundance ($F_{1,10} = 0.138$, $p = 0.717$), or for distance ($F_{5,6} = 1.17$, $p = 0.419$). This is differs from last year, and 2012, 2004 and 2006 surveys (Stewart 2004, 2006), which found significant effects. However, it reflects the 2014, 2011, 2010 and 2005 surveys (Stewart 2005) when no significant difference was observed.

As there is no obvious relationship of density to the position of the outfall through time, such changes in density through time are likely attributable to natural variability.

Mean number of animals per m^2 west of the outfall was 1723 while to the east the mean was 2056. Both figures are very similar to the preceding surveys. Variability in animal abundance over all sites and within sites is high. Overall, the existence of the current outfall off St Kilda Beach appears to have no effect on animal abundance this year with numbers to the east being very similar to numbers observed to the west (Figure 6).

Table 6. *Invertebrates found at a transect off the Tahuna WWTP outfall and at a control site, February 2016. Codes indicate site (TAH = Tahuna), distance from the outfall (in metres) and replicate (A, B or C). Presence/39 indicates how many samples the species was present in.*

Order/family present	Vict A	Vict B	Vict C	TAH 10 E A	TAH 10 E B	TAH 10 E C	TAH 50 E A	TAH 50 E B	TAH 50 E C	TAH 250 E A	TAH 250 E B	TAH 250 E C	TAH 500 E A	TAH 500 E B	TAH 500 E C	TAH 1000 E A	TAH 1000 E B	TAH 1000 E C	TAH 2000 E A	TAH 2000 E B	TAH 2000 E C	TAH 10 W A	TAH 10 W B	TAH 10 W C	TAH 50 W A	TAH 50 W B	TAH 50 W C	TAH 250 W A	TAH 250 W B	TAH 250W C	TAH 500 W A	TAH 500 W B	TAH 500 W C	TAH 1000 W A	TAH 1000 W B	TAH 1000 W C	TAH 2000 W A	TAH 2000 W B	TAH 2000 W C	Total number	Presence/39
Polychaetes																																									
Arenicolidae																			1																					1	1
Capitellidae	1	1	2										1			1				1					3	1	2				1	1								15	11
Glyceridae	9	6	6																		3			1	7	4	5				2	2								45	10
Lumbrineridae		1																								1	1													3	3
Nephtyidae	1	1	2	1			1	1	2			1		1			1			3	1		2		3	1	2	3		1	1	1					1			31	21
Nereidae			1		1	1		1		2		5	1	2	2		1	1		2			1		2	1		1	1											26	17
Nereididae												1																		1										2	2
Opheliidae												1																		1										2	2
Orbiniidae			1																																					1	1
Pectenariidae		1																																						1	1
Spionidae	1		3										2	2	1	2						1			14	6	12				2	1	1			2		1		51	15
Enteropneusta																											2													2	1
Crustaceans																																									
Haustoridae	2	1	2	1	2		1		1	1	3	1	1	2	1	2	2	1	3	3		1		2										3	1	1	3	3	2	46	26
Oedicerotidae									1							1													1											3	3
Phoxocephalidae	2	3	3	2	2	1	2		2	2	2	2	2			1	4	1	3	5	2	3	3	4	3				3		1			6	5	2	2	10	3	86	30
Unknown ostracod												1		1										1	2	3	1													9	6
Bodotriidae																													1											1	1
Anomura																			1																					1	1
Callianassidae										1																														1	1
Stomatopoda		1												1																										2	2
Asellota											1														3															4	2
Serolidae						1					3								1	1	1									1										8	6
Molluscs																																									
Borniola spp					1				1	3	1	1	1	2			2		2	1											2	1	2			1				21	14
Nucula																							1		1			1	2											5	4
Dosinia			1										1																											2	2
Nucula spp												1			1			1	1																					4	4
Paphies subtriangulata											1											1																		2	2
Gari lineolata														1																										1	1
Zethalia	1	2	3	1									1	1		1	2		2	2																		1		17	11
Foraminifera	1	2	2					2	1	3	3	2	4	4	3		4	4	1		1		4	3		2	4				2	1		2		1		2	2	60	25
Waltonia (brachiopod)																								1			1	2	2	3										9	5
Ophiuroidea											1		2	1	1			1													1									7	6
Number of animals	18	19	26	5	6	3	4	4	8	12	14	16	14	17	8	8	16	8	15	18	8	6	11	11	38	19	29	5	8	4	11	7	3	11	6	7	6	17	7		
Number of animals/sq m	3172	3348	4581	881	1057	529	705	705	1410	2114	2467	2819	2467	2995	1410	1410	2819	1410	2643	3172	1410	1057	1938	1938	6696	3348	5110	881	1410	705	1938	1233	529	1938	1057	1233	1057	2995	1233		
Number of taxa	8	10	11	4	4	3	3	3	6	6	7	10	9	10	5	6	7	5	9	8	5	4	5	5	9	8	8	3	5	4	7	6	2	3	2	5	3	5	3		

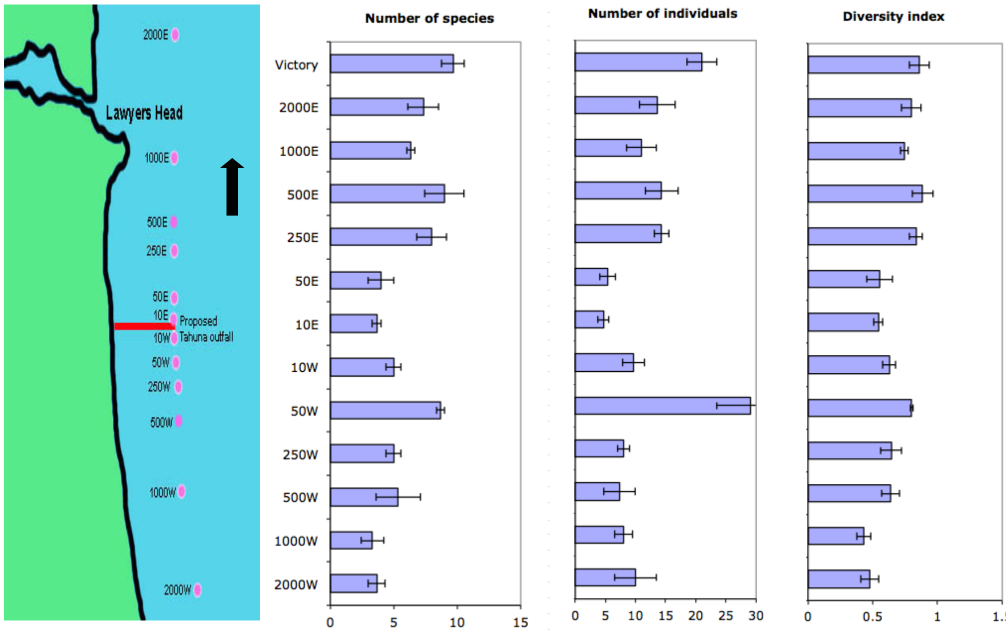

Figure 6. *Number of infaunal species, number of individuals and diversity index for samples from along the Otago coast, February 2016. (All are means ± 1 SD).*

There are no clear trends for abundance, diversity or diversity index through time as one moves in either direction from the Tahuna outfall (Figure 6), although it could be argued that abundance is slightly lower nearer the outfall. However, this trend is discernible both upstream and downstream of the outfall. Overall diversity, as indicated by the diversity index (H') is significantly different this year to the H' values calculated in previous surveys ($F_{9,126}$ = 9.56 *p* = <0.001), due largely to the lower diversities encountered in 2010, 2011 and 2012. Diversity indices for this year, however, show a much closer correlation with diversity indices from the 2013, 2014 and 2015 surveys, and there is no significant difference from 2015 to 2016 ($F_{1,24}$ = 2.83, p = 0.11).

3.3.2 Effects of distance from the outfall on invertebrate community structure

Consistent with previous studies, high variability in community structure was found (Figure 7). The relatively high values for the index of multivariate dispersion for the majority of sites also suggests high variability (Figure 8). Samples from a number of sites had quite similar communities, as can be seen in the way some symbols from each site are relatively closely grouped in the ordination (Figure 7), although overall spacing shows similar dispersion to last year. This echoes the results for 2015, 2014 2013 and 2012, but is less obvious than in 2010 when some symbols (Victory Beach) lay well away from other samples in a discrete cluster (Figure 7b, Stewart 2010).

Statistical tests comparing communities at the different locations found the most difference occurred between the up-current sites and the Victory Beach control site (R = 0.184) (Table 7). Victory Beach was a lot less different to down-current sites this year and this is noticeable in the result shown in Figure 7 where the symbols for Victory Beach are located within the scatter of other symbols. All other sites were more similar than last year (R = 0.115) (Table 7). However, when compared with results from previous surveys, differences among other sites fall within the variability seen through the years since surveys began.

Table 7. *Analysis of similarities in invertebrate communities between locations. Higher 'R' values (approaching 1) indicate locations that are more different to each other.*

	Up-current	**Down-current**	**Victory**
Up-current			
Down-current	0.115		
Victory	0.184	0.068	

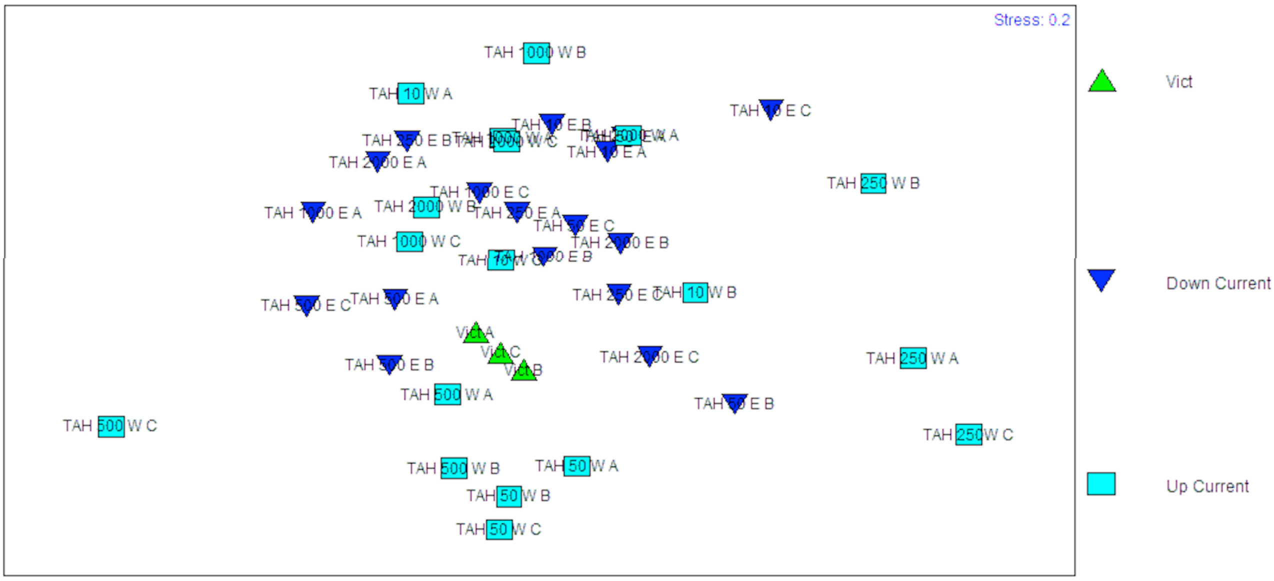

Figure 7. *Ordination of infauna communities found along a transect off the Tahuna WWTP outfall and at control site (Victory Beach) in February 2016. Codes indicate site (TAH = Tahuna), distance and direction from the outfall in metres (e.g., 10W). Sites with similar animal communities are situated closer to one another.*

There was no clear relationship between the patterns in community variability and location. The highest within-site variability was at 10W, then 250W and 500E (Table 6, Figures 7 and 8). The next most variable was 1000W, then 250W and 10E. The least variability was observed at 50W and Victory Beach. Overall, there is no clear pattern of variability that may be attributed to the presence of the outfall (Figure 8).

Variation was moderate between locations and also within up-current and down-current locations, as shown in percentage similarity tests (Table 8). Different communities within the site at Victory Beach are most similar to each other, and more similar than to those on either side of the outfall, as indicated by the values in italics in Table 8and the closeness of Victory Beach symbols in Figure 7.

Figure 8. *Variability in invertebrate communities within locations along a transect off the Tahuna wastewater outfall and at two control sites in February 2016. Higher values indicate higher variability.*

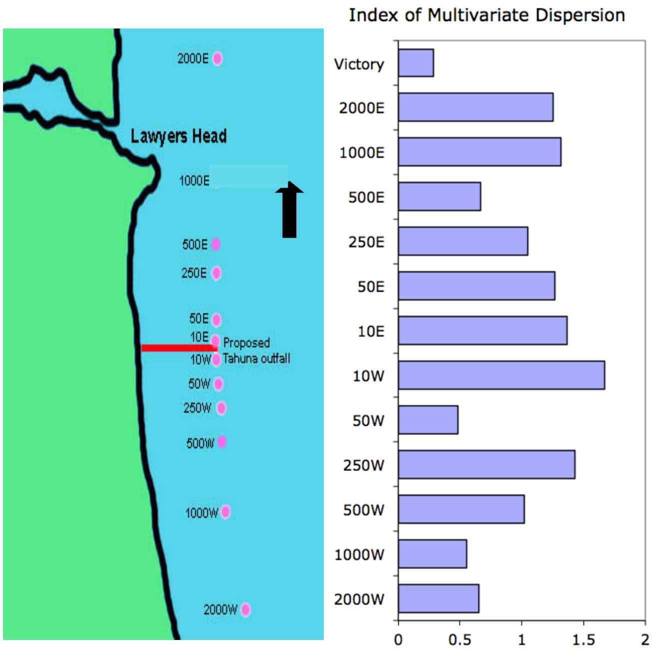

Table 8. *Percentage similarities in invertebrate communities between samples within locations (in italics) and between locations (plain text). Higher values (approaching 100) indicate locations that are more similar to each other.*

	Up-current	Down-current	Victory
Up-current	*33.16*		
Down-current	35.62	*45.47*	
Victory	41.01	44.26	*75.24*

Few animals that are considered sensitive to the effects of pollution (Table 2) were encountered during this survey. The cumaceans, found in low numbers the 2003 survey (Thompson and Ryder 2003), were once again notably absent, as in 2015, 2013, 2012, 2011, 2010 and 2006. A number of other groups that are known to be intolerant of pollution were not present at any of the locations, even those well removed from the discharge. These groups were also absent in the study by Gibbs *et al*. (2003) and from control sites on a similar shore further north near Oamaru (Thompson and Ryder 2002, Stewart 2006, 2007, 2008). It seems likely, therefore, that their absence is due to a factor such as the physically disturbed nature of the substrate (as a result of the high energy nature of the coastline), and should not be interpreted as an effect of the discharge.

3.4 Relationship between benthic communities and sediment heavy metals

In order to view the relationship between sediment heavy metal concentrations and benthic communities, the ordination of the invertebrate communities was overlain by the heavy metal concentrations (Figure 9). In these plots the size of the circle indicates the relative concentration of heavy metal present. For each metal the circles within the plot are the same scale, but circles between plots are not necessarily drawn to the same scale. It is important to note that for all of the metals present, levels were extremely low, and well below those considered likely to influence biological communities (ANZECC 2000).

Overall, there were no clear associations between invertebrate community structure and sediment metal concentrations. These results are not unexpected, given that the levels of all of the metal tested are below those that are expected to have known ecological effects (ANZECC, 2000) (Table 9).

If the concentrations of the various metals this year are compared with concentration of the same metals from previous surveys we find that there are a number of significant differences this year (Table 10), due largely concentrations of all metals at all sites in 2015 year being slightly higher than in past surveys or in this survey. This may well be due to differences in analytical techniques among Hill Laboratories and Citilab, who carried out the analyses last year.

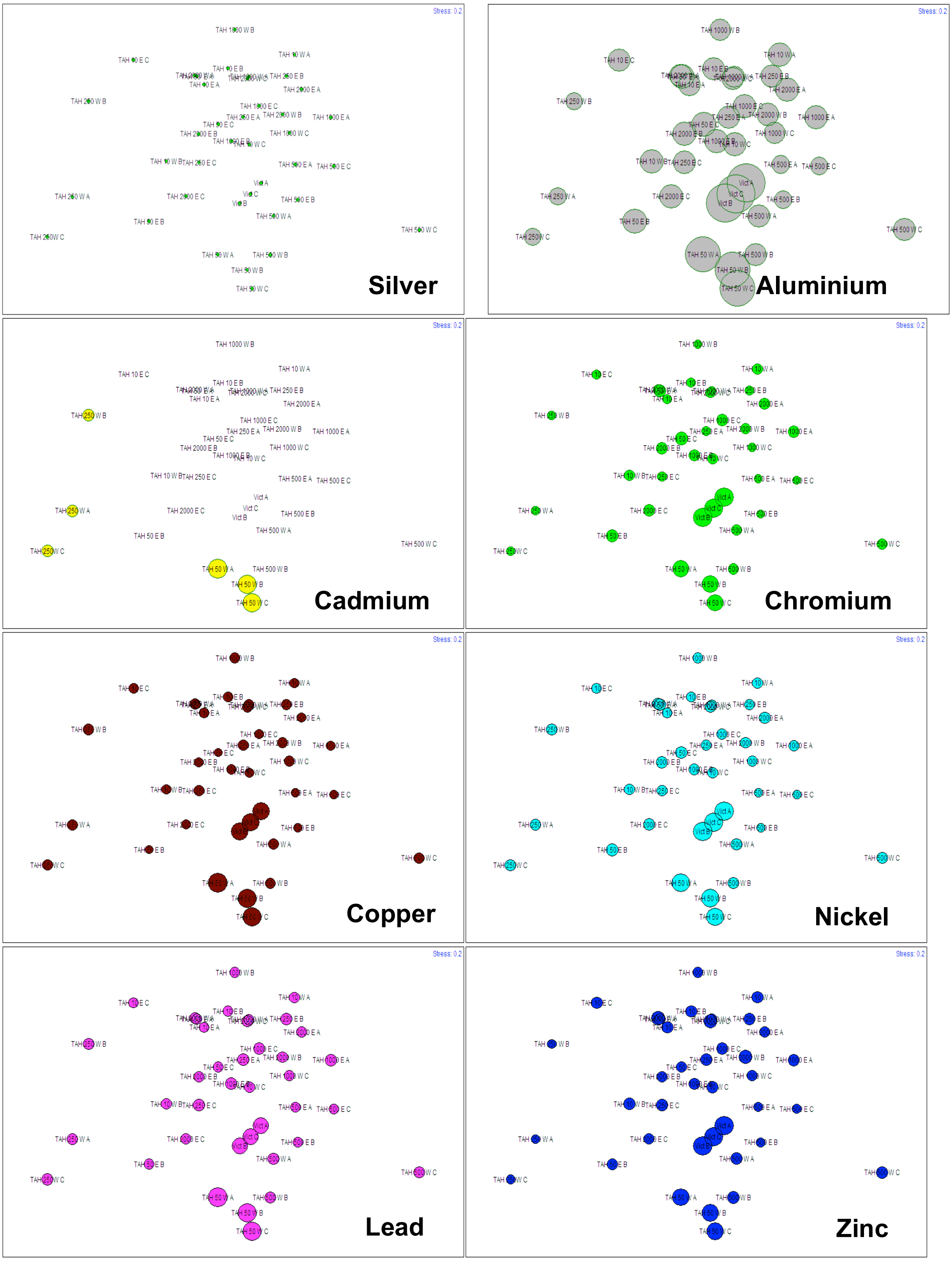

Figure 9. *Ordination of benthic invertebrate communities from February 2016. Heavy metal data (size of circles indicate relative amounts of metals) are overlain.* ***Note: Different metals are NOT drawn to the same scale.***

Table 9. *Recommended ANZECC (2000) sediment quality guidelines compared with values obtained from sampling associated with the Tahuna WWTP offshore sediment survey (February 2016). All units mg/kg dry weight.*

Site	Cadmium	Chromium	Copper	Lead	Nickel	Silver	Zinc
ANZECC Low trigger	1.5	80	65	50	21	1.0	200
ANZECC High trigger	10	370	270	220	52	3.7	410
This study	<0.001 – 0.038	2.6 – 5.7	1.6 – 3.5	1.57 – 3.0	2.7 – 5.5	<0.001	8.6 – 15.4

Table 10. *Analysis of variance (ANOVA) for metal concentrations for this year compared with previous surveys. Significant values shaded orange.*

Metal	$F_{8,243}$	p
Silver	3.02	<0.01
Aluminium	51.73	<0.01
Cadmium	1.69	0.108
Chromium	6.89	<0.01
Copper	2.65	0.01
Nickel	4.64	<0.01
Lead	2.95	<0.01
Zinc	1.62	0.128

Heavy metal concentrations in all sediment samples are well below the appropriate ANZECC (2000) sediment guidelines. Variability in sediment concentrations exists between some sites and has been the case since surveys began. However, variability within sites has, historically, always been very low.

4 Summary & Conclusions

4.1 Overview of current results

The purpose of this survey is to assess the current state of the environment at the site of the Tahuna WWTP offshore outfall, and to compare results with baseline information. It also adds to our existing knowledge of the general area (e.g. Gibbs *et al*. 2003, Key 1998). This survey was carried out using the same field techniques as previous surveys in 2004, 2006, 2010 – 2015 inclusive.

The number of species and number of individuals found in this survey are broadly similar to those found in previous surveys (Stewart 2004 - 2014). They are, however, higher than in the surveys by Key (1998) and Gibbs *et al*. (2003). Direct comparisons of species abundance and diversity data from the Key and Gibbs *et al*. surveys are not possible for a number of reasons. The surveys of both Key and Gibbs *et al*. were located closer inshore than this survey. There were differences in the sampling methodology used by Gibbs *et al*., who obtained core samples at the surface from van Veen grab samples, compared to the present method of collecting core samples directly from the seabed. Also, differences in taxonomic richness are at least partially due to the use by Gibbs *et al*. of 'morpho-species', which are informal groupings of similar looking individuals, which are not able to be repeated in this study, where more taxonomically robust groupings have been used. Finally, it is also likely that the different time of year of sampling (e.g., the Gibbs study was carried out in May whereas the current survey was carried out in January) may have introduced variation.

The small differences from previous surveys are likely due to sporadic settlement of some benthic species. Settlement of benthic organisms from the water column varies through the year and from year to year (Eagle 1975), and both seasonal variation in abundance and species richness of benthic organisms have been shown both in New Zealand waters (Davidson 1989) and overseas (Frankenberg and Leiper 1977; Calado and Lacerda 1993; Findlay and Gatling 1998).

In general, the fauna found are typical of a physically disturbed environment, with a common core of species exhibiting a patchy distribution. The group of families found in the core samples is broadly similar to that described in similar habitats (Robertson 1990; Loveridge 1998; Knox and Fenwick 1981; Roper *et al*. 1989; Roper 1990; Turner *et al*. 1997; Thompson and Ryder 2003). A number of families considered sensitive to pollution are absent from the site of the outfall and also at control sites, and have always been absent since surveys began. This is assumed to be an effect of either physical disturbance (i.e., strong currents) or geographic distribution, and care should be taken in future surveys not to assume that this is due to a wastewater effect.

4.2 Pre-existing patterns in the survey area

A number of questions were posed during the baseline surveys to assess the underlying environmental state in the area.

1: Were there differences in species diversity, total abundance and variability in invertebrate communities at different distances from the proposed outfall, before the outfall was constructed?

There was high variation in abundance, diversity and community structure of benthic communities along the coast. This high variation meant that surveys testing for an effect of wastewater discharges would need to have clear patterns across a number of adjacent sites. Results from a single sample or location could possibly be misleading.

2: Were there differences in invertebrate community structure at different distances from the proposed outfall, before the outfall was constructed?

There was high natural variability in invertebrate community structure along the coast, but this did not appear to be predictable or associated with distance from the proposed discharge site.

3: Were there differences in invertebrate communities between the control sites and the outfall location, even before the outfall was constructed?

There was evidence that some underlying differences between the outfall area and the control (Victory Beach with respect to invertebrates) exists naturally. With this in mind future surveys could not assume that differences between the Victory Beach and the Tahuna sites would be due to an effect of the discharge without clear evidence that those differences are of a greater magnitude or of a different nature than those present prior to the discharge.

4.3 Assessing environmental impacts from the current discharge

This is the seventh benthic survey to be carried out off the Tahuna WWTP outfall since the commissioning of the outfall. With regard to the possible indicators of environmental change suggested in Table 1 we need to assess whether or not there have been any changes to these parameters that were not evident in the baseline (pre-outfall) surveys.

Increased abundance and lowered species richness have been associated with effluent outfalls (Knox and Fenwick 1981; Roper *et al*. 1989). The pre-outfall sites were dominated by the effects of physical disturbance and sediment instability, and the benthic community had high natural variability. This same pattern has been evident in all of the Tahuna offshore surveys, including this latest one.

Increased variability in communities. Warwick and Clarke (1993) suggested that "at low levels, pollutant effects will first be observed in an increase in 'patchiness' of fauna and in the loss of sensitive taxa". Pre-discharge comparison between variability in communities up-current and down-current of the outfall showed high natural variability within communities in the area. The surveys since the outfall was commissioned have shown no change to this pattern. i.e. these has been high variability both within and between communities up-current and down-current of the outfall.

Loss of sensitive taxa. Pollution effects may include the loss of taxa that are intolerant of pollution ('indicator taxa'). At the Tahuna site, the cumacean crustaceans encountered in the 2002 survey would have been the most suitable indicator taxa, but they have been notably absent in most surveys conducted since. Other animal groups worth keeping note of are the spionids and nereids, but in previous surveys their occurrence has been patchy, both temporally and spatially. Spionids and nereids are present this year, but in relatively low numbers and, as usual, are patchily distributed. The general patchiness of species means that any presence or absence of animals needs to be viewed with caution.

Changes in diversity index at each site likely provides the clearest indication of changes in the benthic communities either side of the outfall. Diversity indices for this year show a close correlation with diversity indices from the 2013, 2014 and 2015 surveys, and there is no significant difference from 2015 to 2016. There is no other obvious trend in diversity in relation to distance or direction from the outfall.

The overall conclusion from the 2016 survey, taking into account variability observed in pre-outfall surveys, is that there are no adverse effects observable either up-current or down-current that can be attributable to discharges from the Tahuna WWTP outfall.

5 References

Austen, M.C., Warwick, R.M. and Rosado, M.C. 1989. Meiobenthic and macrobenthic community structure along a putative pollution gradient in southern Portugal. Marine Pollution Bulletin 20: 398-405.

Australian and New Zealand Environment and Conservation Council (ANZECC), 2000. Australian and New Zealand guidelines for fresh and marine water quality. Volume 2, Aquatic Ecosystems.

Bayne, B.L., Addison, R.F., Capuzzo, J.M., Clarke, K.R., Gray, J.S., Moore, M.N. and Warwick, R.M. 1988. An overview of the GEEP workshop. Marine Ecology Progress Series 46: 235-243.

Belan, T. 2000. Changes in benthic communities along a presumed pollution gradient in Vancouver Harbour. Report 16, Scientific Reports of the University of Vancouver.

Calado T.C. and Lacerda P.R. 1993. Vertical zonation and seasonal-variation of carcinofauna (Decapoda and Isopoda) of the steep rocky coast of Calhetas (Cabo-Pernambuco, Brazil). Aquatic Biology and Technology 36: 731-738.

Clarke, K.R. and Gorley, R.N., 2001. Primer v5: User manual/tutorial. Primer-E, Plymouth.

Davidson, R.J. 1989. The bottom fauna from three subtidal locations around Banks Peninsula, Canterbury, New Zealand. New Zealand Natural Sciences 16: 87-95.

Eagle, R.A. 1975. Natural fluctuations in a soft bottom benthic community. Journal of the Marine Biology Association of the United Kingdom 55: 865-878.

Findlay R.H., Watling l. 1998. Seasonal variation in the structure of a marine benthic microbial community. Microbial Ecology 36: 23-30.

Frankenberg, D. and Leiper, A.S. 1977. Seasonal cycles in benthic communities of the Georgia continental shelf. In: Coull, B.C. ed. Ecology of Marine Benthos. The Belle W. Baruch Library in Marine Science Number 6. Columbia, South Carolina.

Gibbs, M., Asher, R. and Forrest, B. 2003. Tahuna Wastewater Plant Upgrade: Baseline Ecological Survey. Cawthron Institute Report No. 733, prepared for the Dunedin City Council.

Jong-Geel, J.E., Belan, T., Levings, C.D., and Koo, B.J., 2000. Changes in benthic communities along a presumed pollution gradient in Vancouver Harbour. Report 16, Scientific Reports of the University of Vancouver.

Key, J.M. 1998. Environmental impacts of the Lawyers Head sewage outfall, Dunedin, New Zealand. Diploma of Science Research Report, Department of Marine Science, University of Otago, New Zealand. 47pp.

Kingsford, M. and Battershill, C. 1998. Studying temperate marine environments: A handbook for ecologists. Canterbury University press.

Knox, G.A. and Fenwick, G.D. 1981. Zonation of inshore benthos off a sewage outfall in Hawke Bay, New Zealand. New Zealand Journal of Marine and Freshwater Research 15: 417-435.

Long, E.R., MacDonald, D.D., Smith, S.L., and Calder, F.D. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management. Vol. 19(1): 81-97.

Loveridge, C.J. 1998. Marine Environmental studies along the Oamaru coastline. MSc thesis, University of Otago.

Morton, J. and Miller, M. 1968. The New Zealand sea shore. Collins, Auckland.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology: an annual review 16: 229-311.

Robertson, B. 1990. A preliminary assessment of the benthic coastal ecology in the vicinity of the North Otago wastewater outfalls.

Robertson, B.M. 1995. Green Island wastewater discharge: soft sediment monitoring. Prepared by Robertson Ryder Limited for Dunedin City Council.

Robertson, B.M. 1997. Green Island wastewater discharge: soft sediment monitoring. Prepared by Robertson Ryder Limited for Dunedin City Council.

Robertson, B.M.; Gillespie, P.A.; Asher, R.A.; Frisk, S.; Keeley, N.B.; Hopkins, G.A.; Thompson, S.J.; Tuckey, B.J. 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93p. Part B. 159p. Part C. 40p plus field sheets.

Roper, D. 1990. Benthos associated with an estuarine outfall, Tauranga Harbour, New Zealand. New Zealand Journal of Marine and Freshwater Research 24: 487-498.

Roper, D.S., Smith, D.G. and Read, G.B. 1989. Benthos associated with two New Zealand coastal outfalls. New Zealand Journal of Marine and Freshwater Research 23: 295-309.

Ryder, G.I. 1998. Green Island wastewater discharge: soft sediment monitoring. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Ryder, G.I. 1999. Green Island wastewater discharge: soft sediment monitoring. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Ryder, G.I. 2000. Green Island wastewater discharge: soft sediment monitoring. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Stewart, B.G. 2004. Tahuna WWTP proposed outfall offshore survey. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Stewart, B.G. 2005. Green Island wastewater discharge: soft sediment monitoring. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Stewart, B.G. 2006. Tahuna WWTP proposed outfall offshore survey. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Stewart, B.G. 2007. Alliance Pukeuri Meat Processing Plant – sub-tidal survey of marine benthic communities. Report produced for Alliance Group Ltd., by Ryder Consulting Ltd.

Stewart, B.G. 2008. Alliance Pukeuri Meat Processing Plant – sub-tidal survey of marine benthic communities. Report produced for Alliance Group Ltd., by Ryder Consulting Ltd.

Stewart, B. G. 2010. Tahuna wastewater treatment plant outfall – discharge consent 2002.623: Offshore sediment survey: March 2011. Prepared by Ryder Consulting

Ltd for Dunedin City Council.

Stewart, B.G. 2010a. Green Island Wastewater Treatment Plant: offshore sediment survey: January 2010 (ORC Resource Consent 97530, Condition 8). Prepared by Ryder Consulting Ltd for Dunedin City Council.

Stewart, B. G. 2011. Tahuna wastewater treatment plant outfall – discharge consent 2002.623: Offshore sediment survey: March 2011. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Stewart, B. G. 2012. Tahuna wastewater treatment plant outfall – discharge consent 2002.623: Offshore sediment survey: March 2012. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Stewart, B. G. 2013. Tahuna wastewater treatment plant outfall – discharge consent 2002.623: Offshore sediment survey: March 2013. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Stewart, B. G. 2014. Tahuna wastewater treatment plant outfall – discharge consent 2002.623: Offshore sediment survey: January 2014. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Stewart, B. G. 2015. Tahuna wastewater treatment plant outfall – discharge consent 2002.623: Offshore sediment survey: January 2015. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Thompson, R.M. and Ryder, G.I. 2002a. Green Island wastewater discharge: soft sediment monitoring. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Thompson, R.M. and Ryder, G.I. 2002b. Alliance Pukeuri meat-processing plant – sub-tidal survey of marine benthic communities. Prepared by Ryder Consulting Ltd for Alliance Group Ltd.

Thompson, R.M. and Ryder, G.I. 2003. Tahuna WWTP Proposed Offshore Outfall: Offshore sediment survey, December 2002. Prepared by Ryder Consulting Ltd for Dunedin City Council.

Thrush, S.F. and Roper, D.S., 1988. Merits of macrofaunal colonization of intertidal mudflats for pollution and monitoring: preliminary study. Journal of Experimental Marine Biology and Ecology 116: 219-233.

Turner, S.J., Funnell, G., Hewitt, J.E., Cummings, V.J. 1997. Report on the Long Bay Pilot Study. NIWA Client Report ARC70221.

Warwick, R.M. 1988. The level of taxonomic discrimination required to detect pollution effects on marine benthic communities. Marine Pollution Bulletin 19: 259-268.

Warwick, R.M. 1993. Environmental impact studies on marine communities: pragmatical considerations. Australian Journal of Ecology 18: 63-80.

Warwick, R.M. and Clarke, K.R. 1993. Increased variability as a symptom of stress in marine communities. Journal of Experimental Marine Biology and Ecology 172: 215-226.

Warwick, R.M., Platt, H.M., Clarke, K.R., Agard, J., Gobin, J. 1990. Analysis of macrobenthic and meiobenthic community structure in relation to pollution and disturbance in Hamilton Harbour, Bermuda. Journal of Experimental Marine Biology and Ecology 138: 119-142.

Wolff, W.J. 1987. Flora and macrofauna of intertidal sediments. pp 81-105 in Baker, J.M. and Wolff, W.J. (eds). Biological surveys of estuaries and coasts. Cambridge University Press.

Zar. J.H. 1996. Biostatistical Analysis (3rd edition). Prentice-Hall International.

Appendix One : Sampling Locations

	NZGD2000		NZTM	
Site	**East**	**South**	**Easting**	**Northing**
Victory	170 45.087	45 49.475	1425342	4922984
TAH 2000W	170 29.690	45 55.173	1405740	4911840
TAH 1000W	170 30.467	45 55.098	1406740	4912010
TAH 500W	170 30.855	45 55.085	1407240	4912050
TAH 250W	170 31.048	45 55.075	1407490	4912075
TAH 50W	170 31.210	45 55.069	1407699	4912093
TAH 10W	170 31.241	45 55.069	1407739	4912095
TAH 10E	170 31.257	45 55.068	1407759	4912097
TAH 50E	170 31.288	45 55.071	1407799	4912093
TAH 250E	170 31.458	45 55.075	1408020	4912093
TAH 500E	170 31.651	45 55.086	1408270	4912080
TAH 1000E	170 32.061	45 55.095	1408800	4912080
TAH 2000E	170 32.838	45 55.030	1409800	4912230