Cawthron Report No. 862

Estuarine Impacts of the Land Disposal of Sewage Sludge on Rabbit Island:

2003 Monitoring Survey

Prepared for

Nelson Regional Sewerage Business Unit

March 2004

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Cover Photo: Estuary field work at Transect 9, Rabbit Island (Cawthron 2003)

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1. INTRODUCTION

1.1 Background

A biosolids land disposal programme was initiated by the Nelson Regional Sewerage Authority (NRSA), now the Nelson Regional Sewerage Business Unit (NRSBU), in February 1996. Since that time, treated sewage sludge from the Bell Island wastewater treatment plant has been applied on a semi-regular basis to designated disposal areas on Rabbit Island. Background and rationale for the biosolids disposal programme may be found in Beca Steven (1994). The history of biosolids application rates and locations, and soils and ground water monitoring results may be obtained from NRSBU.

Cawthron was retained in 1995 by the NRSA, to design and carry out a monitoring programme to identify any impacts to the estuarine environment of Waimea Inlet resulting from the biosolids applications onto Rabbit Island. The estuarine monitoring programme was designed in accordance with the requirements outlined in Sections 7.4 - 7.7 of the NRSA discharge permit application (NN940379D) to Tasman District Council.

1.2 Impact assessment

A theoretical model of the potential intrusion of biosolids leachate into coastal habitats is shown in Figure 1. As indicated by the model, nutrients and possibly trace metals originating from the application of treated sewage sludge to adjacent coastal lands would be expected to percolate through the shallow soil layer resulting, to some degree, in increased concentrations in the groundwater. Where horizontal ground water flows impinge on the intertidal environment, there is a potential for adverse effects to occur. There is also the possibility that direct surface runoff could expose intertidal habitats to contaminant effects during periods of heavy rainfall.

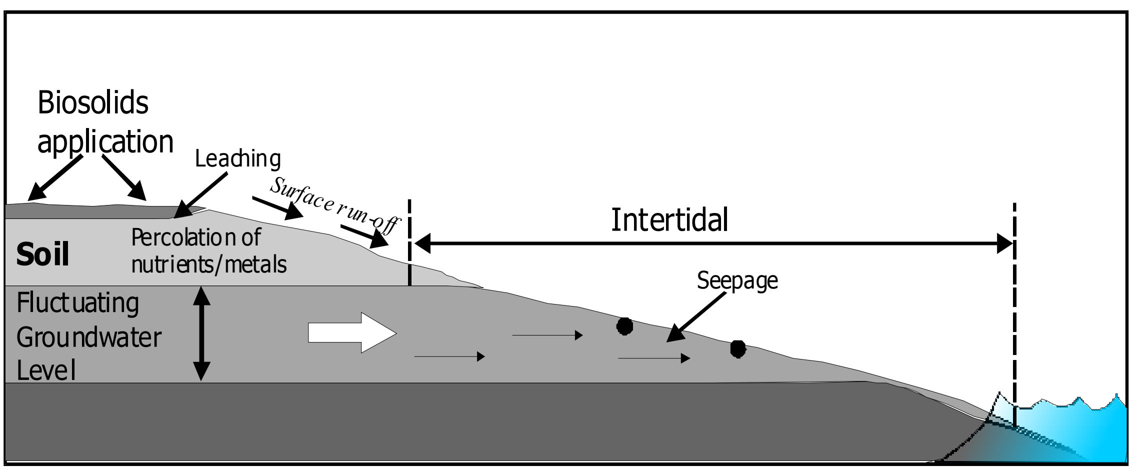


Figure 1. Schematic diagram of the potential transport of contaminants from biosolids land application areas on Rabbit Island to adjacent intertidal habitats.

Where sewage systems receive significant loadings of toxic organic compounds, these could also affect groundwater quality. Fortunately the concentrations of toxic organics in sewage sludge are nearly always low (O'Connor *et al.* 1991), and they are not likely to be of ecological significance in this instance.

Of primary concern with respect to the potential effects of biosolids application to land areas adjacent to intertidal estuarine habitats are (1) elevated sediment nutrient concentrations and related symptoms of enrichment, (2) accumulation of potentially toxic concentrations of trace metals in sediments and (3) deterioration of shellfish quality due to elevated trace metals or faecal indicator bacteria.

A pre-disposal baseline survey was carried out February 1996 in order to provide a means of detecting any significant adverse effects from the disposal programme. Biosolids applications commenced in April 1996. Follow-up visual inspections of the intertidal monitoring transects (12 in total) were carried out subsequently at approximately 6-monthly intervals, from October 1996 through August 2001. The study design and results of the baseline survey are described in Gillespie & Asher (1997) and site inspection reports and photographic records are held by Cawthron.

In this report, we evaluate the results of a full estuarine monitoring survey, carried out in April 2003, and a summary of the interim 6-monthly site inspections. The data are compared with those from the baseline survey (and other monitoring investigations in the region) in order to identify any long term changes in the intertidal seabed environment that could be attributable to the biosolids application programme.

2. METHODS

2.1 Study area

Rabbit Island forms the seaward barrier between Tasman Bay and Waimea Inlet (Figure 2). The estuarine (intertidal) environment of Waimea Inlet, including physical, chemical and biological characteristics and ecological values, is described in detail in Robertson *et al.* (2002) and Davidson & Moffat (1990). The terrestrial environment and groundwater system of Rabbit Island are described in Beca Steven (1994) and Carnus (1994).

2.2 Transect and site locations

Transect and site locations for the April 2003 survey (Figure 2, Table 1) are identical to those used for the baseline survey as described by Gillespie & Asher (1997). Transects were selected after consideration of (1) the proposed biosolids application areas, (2) the predicted direction of groundwater flow towards the inner (south western) side of the Island and (3) the apparent relative efficiency of tidal flushing. The twelve transects were therefore situated on the south western side of Rabbit and Rough islands extending perpendicular to the shore from approximately spring high water to mean low water. Transects 2-9 were situated adjacent to designated biosolids application areas while Transects 1, 10, 11, and 12 were adjacent to non-application areas, thus serving as 'non-impacted' reference locations. A measuring tape extending from the transect marker (upper end) through the lower intertidal levels was used to relate shore characteristics to position on the transect line and the monitoring sites (two per transect) were situated at points where groundwater seepage was most apparent. Only one site was selected on Transect 10 (Rough Island) because of its shorter length.

Due to the uncertainty of fine scale groundwater flow directions and the long monitoring interval, we recognise the possibility that the unimpacted 'control' sites could be compromised. For this reason, results from a variety of additional sites, previously monitored from other Waimea Inlet locations, are used for comparison (Gillespie *et al*. 2001, Robertson *et al*. 2002, Gillespie & Asher 1999).

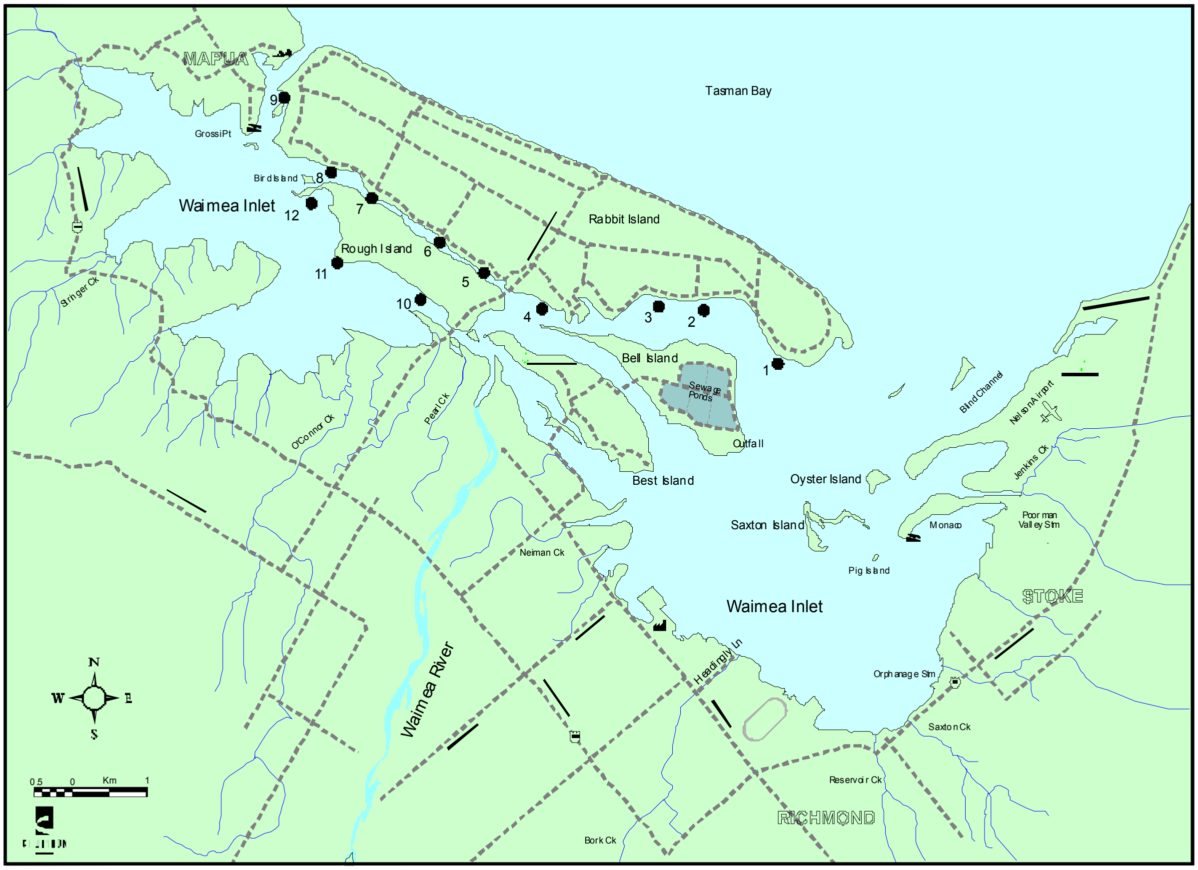


Figure 2. Study area and intertidal transect locations (numbered 1-12).

Table 1. GPS coordinates of the upper (shore) end of study transects.

Transect	Coordinates	
	E	N
1	252 5551	599 1114
2	252 4569	599 1754
3	252 4019	599 1821
4	252 2476	599 1630
5	252 1573	599 2121
6	252 0861	599 2587
7	251 9913	599 3263
8	251 9584	599 3400
9	251 8903	599 4392
10[a]	252 0627	599 1927
11	251 9646	599 2240
12	251 9146	599 3009

a. Coordinates taken at Site 19 as Transect peg missing.

2.3 Field observations

Changes in substrate type, shore topography and major biological habitats along the transects were described in general terms and more detailed quantitative descriptions were made at study sites. Photographic records are held by Cawthron. The site characteristics recorded were:

- General characteristics (including location, tidal elevation and topography). Photographs were taken for comparison with 1996 records).
- Sediment type (mud, sand, shell, *etc*.).
- Abundance of conspicuous macroinvertebrate species; *e.g.* crab holes, shellfish and surface animals (five replicate 0.1m^2 quadrats).
- Macrophyte species and % coverage. Where a significant macroalgal cover existed, the percent coverage of the sediment habitat was estimated using five replicates of a randomly placed 0.25 m^2 quadrat containing gridlines dividing it into 36 equally-spaced squares. The number of grid intersections (including the outer frame) that overlapped vegetation were counted and the result converted to percent (*i.e.* No. x 2 = %).
- Microalgae (visible mat development estimated as for macroalgae).
- Sediment profiles (62 mm diameter cores extruded, photographed and described according to stratification of colour and texture and corresponding indications of sediment anoxia).
- Obvious signs of enrichment or pollution (*e.g*. H_2S odours, bacterial growth, *etc*.)

2.4 Sediment nutrients and organic content

Sediment sampling
Sediment moisture, total organic matter and organic and inorganic nitrogen concentrations were determined on three composite samples per site. Each composite consisted of the top 1 cm of sediment scraped off five replicate, 132 mm diameter circles randomly positioned within 10 m of the site. The samples were mixed thoroughly and kept on ice while in the field. Upon returning to the laboratory, samples were frozen at -20°C for subsequent analyses.

Analyses
Inorganic forms of nitrogen (nitrate, nitrite and ammonia) were determined on 1 molar KCl extracts of the sediments using standard analytical techniques for sea water analyses (Strickland and Parsons 1968; Solarzano 1969; APHA 1999). Organic-N (Kjeldahl) determinations were according to Henrikson (1970). Sediment moistures were estimated as weight loss after drying at 105°C and total organic contents as further weight loss after combustion at 550°C.

2.5 Trace metals

Sediment sampling
Sediment samples were obtained by removing and mixing equal volumes of the composite samples (those collected for nutrients and organic content analyses) from the two sites for each transect. Analyses were carried out on whole sediments rather than fractionated samples in order to provide direct comparison with existing data.

Shellfish sampling
Cockles (*Austrovenus stutchburyi*) were collected from the vicinity of each transect, depending on availability, and put into plastic bags. All samples were frozen until the analyses were carried out.

Analyses
The sediment and shellfish samples were analysed for mercury, lead, cadmium, zinc, chromium, copper, and arsenic, according to the following analytical procedures:

- Hg (shellfish and sediments) - cold vapour atomic absorption spectrometry (AAS).
- Pb, Cd, Zn, Cr, Cu (shellfish and sediments) - perchloric/nitric acid digestion and AAS.
- As (shellfish) - Dry ashing with magnesium nitrate and hydride generation AAS.
- As (sediment) - perchloric/nitric acid digestion and AAS.

2.6 Faecal indicator bacteria

Shellfish sampling
Cockles (*Austrovenus stutchburyi*) were collected from the vicinity of each transect (*i.e.* within 10 m) and put into plastic bags. All samples were frozen until the analyses were carried out.

Analyses
Shellfish faecal coliform, enterococci and presumptive coliform analyses were carried out using standard tube dilution methods (APHA Seawater Shellfish 4th Edn., Compendium 4th EDN. 2001).

3. RESULTS AND DISCUSSION

3.1 Summary of visual transect/site inspections

All transects and monitoring sites were visited at approximately 6-monthly intervals from February 1996 through August 2001. During that period, no obvious biosolids-related changes in the enrichment status of intertidal environments were observed. Observed changes in macroalgal and microalgal coverage were thought to be primarily attributable to normal seasonal fluctuations.

Logging and vehicle disturbances to the upper intertidal regions of Transects 5 and 6 were observed in March 1999 through to March 2000 (Plate 1 and Plate 2) with gradual recovery through to August 2001. These disturbances corresponded to some increases in macroalgal cover in upper tidal channels; particularly those where drainage had been disturbed. Increased accumulations of a number of species of macroalgae in the upper drainage channel at Transect 6 (September 1999, Plate 3) may have been related to direct nutrient runoff from the adjacent biosolids application area, however this runoff would have occurred as a result of the physical disturbances and corresponding wet weather. These effects were largely reversed by a series of spring high tides that smoothed off the disturbed areas prior to the February 2001 visual assessment (Plate 4).

An improvement in the environmental condition of the Traverse (partially ponded area between Rabbit and Rough islands, see Figure 2 and Plate 5 and Plate 6) was observed during the March 1999 visit. This corresponded to the earlier re-opening of the channel at the western end which resulted in the flushing out of decomposing mats of the filamentous alga *Enteromorpha* sp. Although considerable regrowth of *Enteromorpha* was observed on subsequent visits, they were in a healthier state and gradually declined as the accumulated soft sediments were flushed out.

3.2 2003 field observations

Transect and site characteristics assessed during the 2003 monitoring survey are described in detail in Appendix A, using the same format as reported for the 1996 baseline survey. No symptoms of over-enrichment (*e.g*. excessive algal growth, sediment anoxia, H_2S odours, *etc*.) were observed. This was confirmed by observations of the sediment profiles; light to medium brown or grey colouration extending to >10 cm below the sediment surface at all sites. Typical examples of the sediment profiles are shown in Plate 7 and Plate 8. Although some changes in habitat characteristics were identified, these appeared to be largely attributable to normal variation or factors unrelated to biosolids applications.

Physical (and associated biological) changes were noted, however, along a number of transects. These were probably related to storm effects (T1) and the further disappearance of remnant *Spartina* roots (T3 & T4). Temporary degradation of environmental condition in the vicinity of the Traverse (T5 & T6) was caused by forestry operations in conjunction with periods of rain. This appeared to have resulted in periodic nutrient release that may have been exacerbated by direct runoff from the adjacent landward areas. We note, however, that NRBSU have put in place two procedural safeguards in order to prevent direct runoff from biosolids application areas. These are: (1) maintenance of buffer strips of at least 50 m between application areas and spring high water; and (2) maintenance of a minimum six-year stand-down period prior to log harvesting within a particular application area. Thus it is unlikely that the observed effects were directly related to biosolids applications. These effects were reversed after a series of spring high tides succeeded in smoothing and flushing the region. Recovery of the environmental condition of the ponded area of the Traverse channel was noted after the western end was opened to improve flushing.

Additional biological changes resulted from the expansion of Pacific oyster reefs at a number of sites (*i.e.* T3, T4 and T7, Plate 9).

Habitat characteristics at T2, T8, T9, T10, T11, and T12 were largely unchanged (1996 vs. 2003).

Plate 1. Area surrounding Transect 6 after logging operations (September 1999)

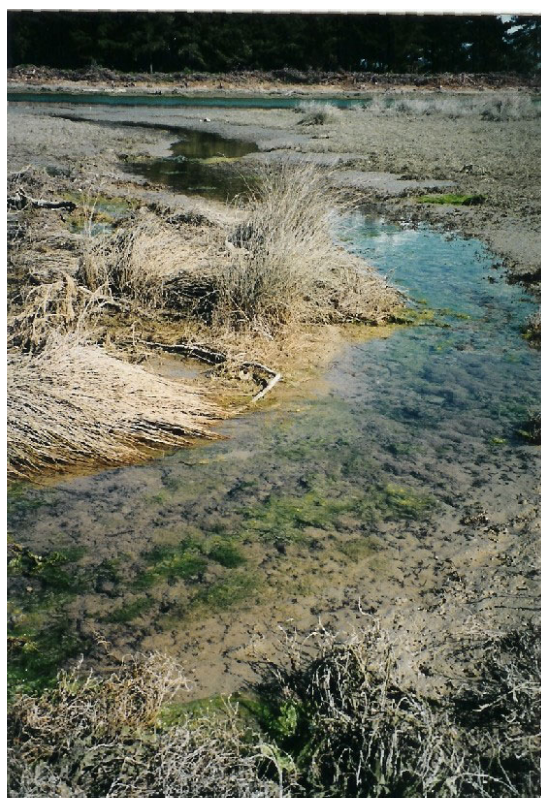


Plate 2. (left) Area surrounding Transect 6 after logging operations (September 1999)

Plate 3 (right) Macroalgae in the upper drainage channel Transect 6 (September 1999)

Plate 4. Reestablishment of estuarine conditions at Transect 6 (February 2001).

Plate 5. *Enteromorpha* mats along edge of Traverse at Transect 5 (March 1999).

Plate 6. The edge of the Traverse from Transect 5 in September 2000. Note absence of *Enteromorpha* mats.

Plate 7. Sediment core from Transect 1, Site B.

Plate 8. Sediment core from Transect 9, Site A.

Plate 9. Pacific oyster beds along channel edge at Transect 3 (March 2003).

3.3 Sediment nutrients and organic content

Sediment inorganic and organic nitrogen concentrations and total organic matter concentrations at the monitoring sites (April 2003) are presented in Table 2 and compared with baseline (1996) concentrations in Figure 3 - Figure 6. Sediment nitrate concentrations indicate some enrichment of interstitial waters with dissolved inorganic nutrients.

Table 2. Sediment nutrient and organic matter concentrations (mean ± sd) at Rabbit / Rough Island monitoring sites (April 2003). Shading highlights control locations.

Transect/ Site	NO_2-N (mg/kg)	NO_3-N (mg/kg)	NH_4-N (mg/kg)	TKN (mg/kg)	AFDW (%)
1A	<0.005 ± 0.00	0.13 ± 0.06	0.90 ± 0.11	133 ± 6	0.8 ± 0.2
1B	<0.007 ± 0.00	0.50 ± 0.08	2.13 ± 1.45	190 ± 20	1.4 ± 0.3
2A	0.01 ± 0.00	0.62 ± 0.16	5.60 ± 7.27	467 ± 202.	2.3 ± 0.6
2B	<0.015 ± 0.01	0.88 ± 0.63	10.83 ± 8.10	697 ± 333	3.2 ± 1.2
3A	<0.007 ± 0.00	1.13 ± 0.59	3.13 ± 0.47	750 ± 87	3.4 ± 0.7
3B	<0.010 ± 0.00	0.68 ± 0.27	14.63 ± 6.72	467 ± 46	1.6 ± 0.7
4A	<0.001 ± 0.00	0.63 ± 0.16	3.57 ± 0.58	967 ± 43	4.2 ± 0.2
4B	<0.010 ± 0.00	0.65 ± 0.18	22.37 ± 14.00	1467 ± 152	5.6 ± 0.7
5A	<0.008 ± 0.00	0.38 ± 0.12	8.13 ± 4.41	730 ± 45	3.0 ± 0.4
5B	<0.002 ± 0.00	0.17 ± 0.01	3.97 ± 0.70	570 ± 70	3.3 ± 0.1
6A	<0.007 ± 0.00	0.65 ± 0.11	10.97 ± 3.66	1233 ± 153	5.0 ± 0.4
6B	<0.005 ± 0.00	0.40 ± 0.21	25.67 ± 13.05	1233 ± 58	4.2 ± 0.5
7A	<0.004 ± 0.00	0.43 ± 0.03	14.10 ± 8.55	463 ± 55	1.9 ± 0.2
7B	<0.005 ± 0.00	0.22 ± 0.07	46.33 ± 35.73	790 ± 214	1.7 ± 0.3
8A	<0.005 ± 0.00	0.17 ± 0.06	57.33 ± 30.62	990 ± 359	2.9 ± 0.4
8B	<0.005 ± 0.00	0.41 ± 0.24	37.00 ± 19.67	793 ± 137	2.9 ± 0.3
9A	<0.006 ± 0.00	0.17 ± 0.02	3.23 ± 0.45	657 ± 55	3.7 ± 0.2
9B	<0.005 ± 0.00	0.23 ± 0.13	5.67 ± 0.81	523 ± 119	2.4 ± 0.5
10A	<0.005 ± 0.00	0.87 ± .20	7.10 ± 3.42	790 ± 165	3.93 ± 0.2
11A	<0.005 ± 0.00	0.10 ± 0.02	8.40 ± 3.22	1133 ± 58	5.8 ± 0.5
11B	<0.005 ± 0.00	0.98 ± 0.13	3.73 ± 1.57	607 ± 23	2.5 ± 1.0
12A	<0.005 ± 0.00	0.12 ± 0.04	12.33 ± 7.77	687 ± 21	3.6 ± 0.1
12B	<0.005 ± 0.00	0.12 ± 0.00	5.93 ± 4.39	677 ± 21	3.5 ± 0.2

At 10 of 16 sites adjacent to biosolids application areas and three of seven "control" sites, the sediment nitrate levels observed during the 2003 monitoring were more than twice those observed during the pre-disposal baseline survey (Figure 3). Although not measured during 1996, sediment ammoniacal N concentrations (2003, Figure 4) at 10 of 16 impact and one of seven control sites showed elevated levels compared to what would normally be expected for similar intertidal environments in the Nelson region (*i.e.* <10 mg/kg, Gillespie & MacKenzie 1990, Gillespie & Asher 1996). These results, in themselves, are not indicative of adverse environmental effects, however it appears that intermittent enrichment of surface sediments occurs either due to ground water intrusion or surface runoff in conjunction with periods of rainfall.

Of greater concern would be the degree to which the elevated inorganic nutrients resulted in organically enriched sediment habitats. This question was addressed partly through the 6-monthly visual assessments (Section 3.1) and the 2003 field observations (Section 3.2) during which no symptoms of over enrichment attributable to biosolids application were observed. These findings are consistent with observations of sediment organic nitrogen (TKN) and organic matter (AFDW) concentrations that were within ranges observed for other unimpacted intertidal habitats in the Nelson region (Gillespie & MacKenzie 1990). Comparing sediment TKN and AFDW concentrations, 2003 vs 1996 (Figure 5 and Figure 6), indicated slight organic enrichment at a number of sites, however a reduction in organic matter was observed at other sites suggesting that physical flushing characteristics were sufficient to prevent the development of symptoms of over-enrichment.

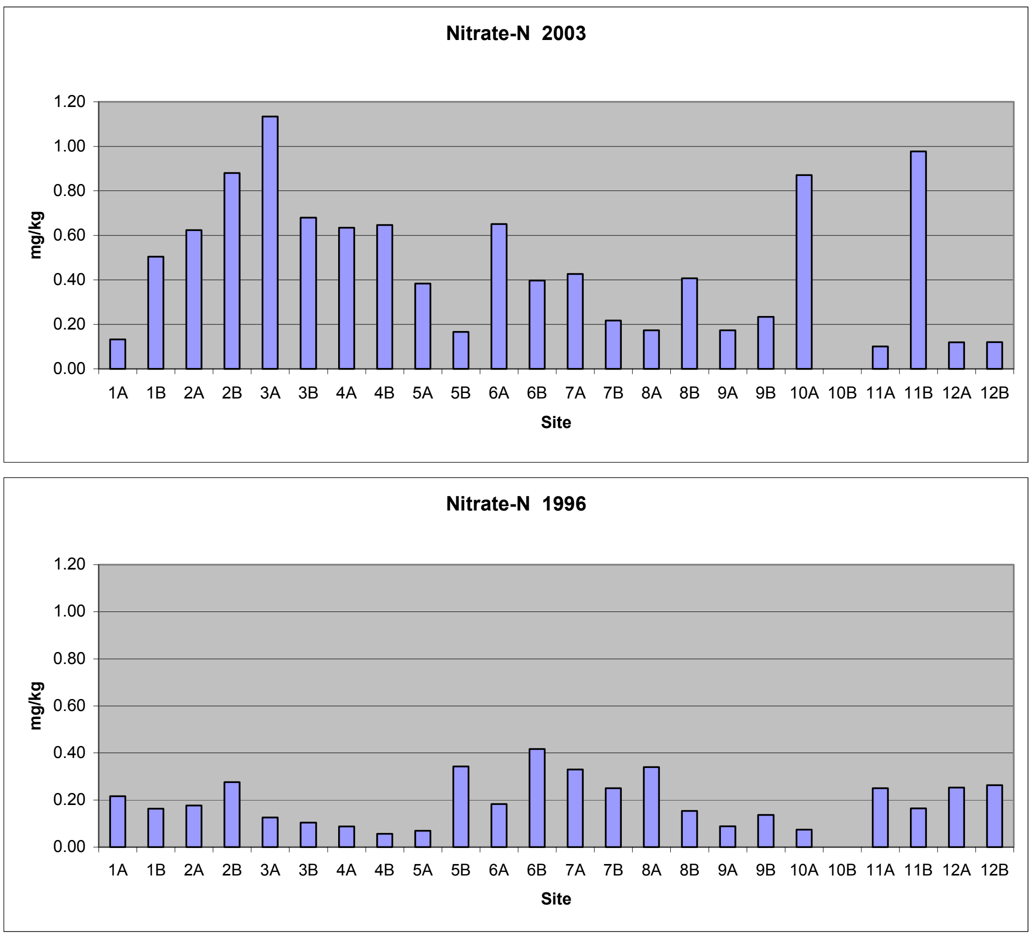


Figure 3. Variation in sediment nitrate concentrations at Rabbit/Rough Island monitoring sites (1996 vs 2003).

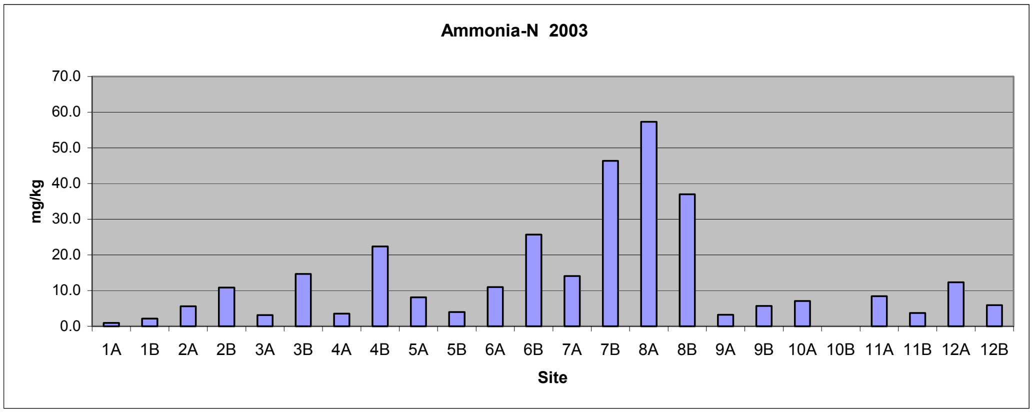
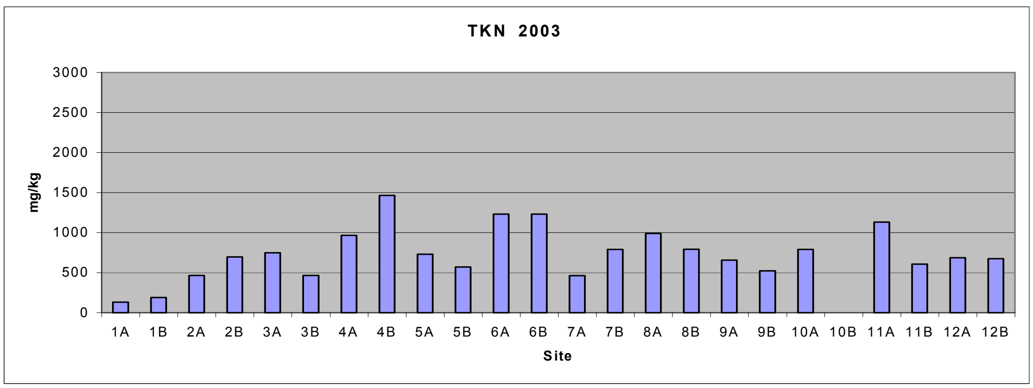


Figure 4. Sediment ammoniacal N concentrations at Rabbit/Rough Island monitoring sites (2003).



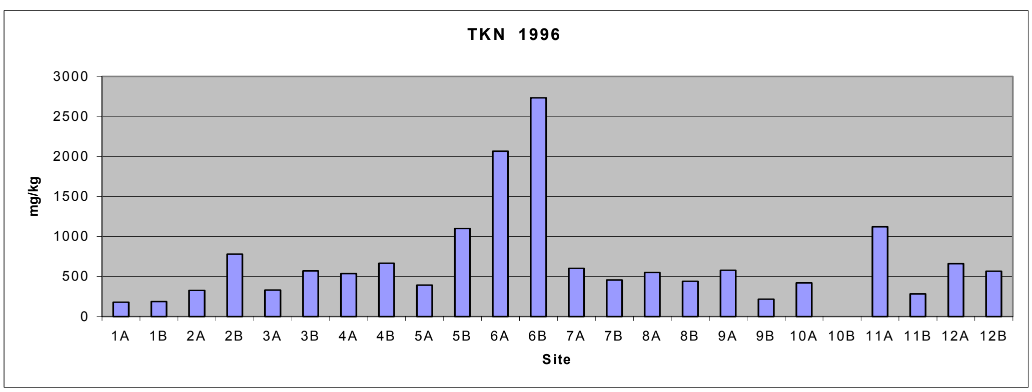


Figure 5. Variation in sediment TKN concentrations at Rabbit/Rough Island monitoring sites (1996 vs. 2003).

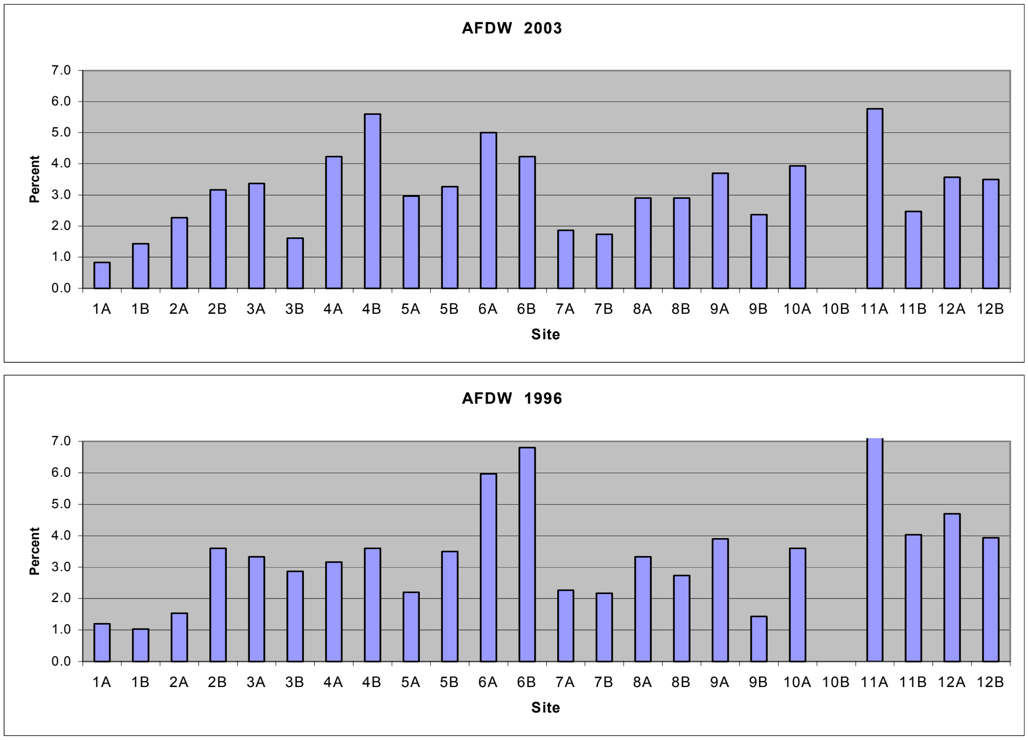


Figure 6. Variation in sediment organic matter concentrations at Rabbit/Rough Island monitoring sites (1996 vs. 2003).

3.4 Trace metals

Sediment

With the exceptions of chromium and nickel, all of the trace elements tested (Table 3) were below the ANZECC (2000) recommended threshold levels for biological effects to occur (ANZECC ISQG-Low, see Technical Box 1). They were also within ranges observed at other non-impacted sites in Waimea Inlet and other estuaries throughout New Zealand (Robertson *et al*. 2002).

Sediment chromium levels exceeded ANZECC ISQG-Low guideline at six of 12 sites, however they were all within a range considered to be "normal" for unimpacted Waimea Inlet sediments (Robertson *et al*. 2002). Nickel levels were elevated at all sites including Rough Island control sites (Sites 10-12) and, to a lesser extent, control Site 1. These results were not unexpected, as chromium and nickel concentrations of Waimea Inlet sediments are naturally elevated due to contributions from the Dunn Mountain mineral belt that is situated partly within the estuary catchment (Robertson 2002). With the exception of one site (Site 4), nickel concentrations were also within the "normal" range for unimpacted Waimea Inlet sediments. The nickel concentration observed at Site 4 (230 mg/kg) was more than twice the maximum level reported for other Waimea Inlet sites, while that observed at Site 10 (120 mg/kg) was slightly above the normal range (Robertson *et al*. 2002).

The observed sediment trace metal concentrations are consistent with the relatively low concentrations of the biosolids as indicated by the NRSBU biosolids monitoring results (Table 4). This comparison, however, can only be approximate because the latter are expressed on a weight per volume rather than a dry weight basis. Nevertheless biosolids trace metal concentrations appeared, in all cases, to be lower than ANZECC guideline levels for sediments. We recommend that, in future, biosolids monitoring results be expressed on a dry weight basis to provide a direct comparison with soil, sediment and guideline concentrations. This information is available from NRSBU if a more precise comparison is required.

Table 3. Sediment trace metal concentrations (mg/kg dry weight) at Rabbit/Rough Island sites (April 2003) compared to central Waimea Inlet sites (WI, Robertson *et al*. 2002), Bells Island sites (BI, Gillespie *et al.* 2001) and recommended guideline values (ANZECC 2000).

Transect or Site	Trace metals (mg/kg)							
	Hg	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Ni**	**Zn**
1	<0.01	<10	<0.2	22	3.5	5.7	31	20
2	0.03	<10	0.2	60	10	11	68	46
3	0.04	<10	<0.2	65	11	9.8	70	46
4	0.05	<10	0.3	61	19	14	230	67
5	0.03	<10	0.2	87	10	9.7	76	43
6	0.05	<10	0.3	99	16	13	93	66
7	0.04	<10	0.3	95	12	11	84	53
8	0.05	<10	0.2	61	10	9.5	68	40
9	0.04	<10	<0.2	60	9.1	9.4	70	41
10	0.07	<10	0.3	110	15	10	120	53
11	0.06	<10	0.3	98	15	9.3	99	54
12	0.05	<10	0.3	91	13	9.4	94	48
WI- A			0.1	69	10	4.2	65	44
WI-B			0.1	45	9	6.3	72	38
WI-C			0.4	61	7	7.7	58	34
WI-D			0.5	95	12	11.3	94	50
BI-1	0.07	<10	0.5	120	14	11		60
BI-6	0.03	<10	0.3	61	7.5	7		
BI-7	0.03	<10	0.3	50	6.1	5.3		40
BI-9	0.01	<10	<0.2	29	4.2	3.8		35
BI-10	0.02	<10	0.3	60	8.8	7.5		26
ANZECC ISQG-Low	0.15	20	1.5	80	65	50	21	200
ANZECC ISQG-High	1	70	10	370	270	220	52	410

Note: Blue shading refers to other Waimea Inlet sites (Robertson *et al.* 2002; Gillespie *et al.* 2001), brown shading refers to recommended guideline levels (ANZECC 2000), and grey shading highlights monitoring results exceeding comparative sites and guidelines.

Technical Box 1: Sediment Quality Guidelines

Sediment quality guidelines aim to predict 'acceptable' levels of contaminants in sediment, above which adverse ecological effects are possible. New Zealand has recently published national guidelines for sediment quality (ANZECC 2000) based on international guidelines (*e.g.* PSDDA & U.S. Army Corps of Engineers 1989, Long & Morgan 1991). The criteria are listed as Interim Sediment Quality Guideline- Low (ISQG-Low) and Interim Sediment Quality Guideline-High (ISQG-High) and have two distinct threshold levels under which biological effects are predicted. The criteria use statistical models to determine the levels at which effects can be predicted with a degree of certainty. The lower threshold (ISQG-Low) indicates a possible biological effect while the upper threshold (ISQG-High) indicates a probable biological effect. It should be noted however, that the guidelines are limited to certain individual analytes and do not take into account the synergistic effects of combined contaminants within the sediment. Guidelines are used as part of the risk assessment, and if exceeded, additional testing may be required.

Table 4. Trace metal concentrations of biosolids. Data are provided by NRSBU (January 2004).

	g/m^3 *							
Date	**Arsenic**	**Cadmium**	**Chromium**	**Copper**	**Lead**	**Nickel**	**Zinc**	**Mercury**
1-May-96	0.24	0.06	1.5	8.8	1.6	1	20	0.02
1-Aug-96	0.04	0.02	0.57	2.9	0.06	0.31	6.3	0.04
1-Nov-96	0.14	0.04	1	8.4	1.5	0.63	2.9	0.02
1-May-97	0.18	0.05	1.4	7.3	1.3	0.5	15	0.004
1-Aug-97	0.16	0.05	0.54	2.7	0.58	0.28	6.1	0.007
1-Nov-97	0.14	0.03	1.1	5.1	0.82	0.5	11	0.011
1-Feb-98	0.14	0.2	1	5.8	0.81	0.73	12	0.02
1-May-98	0.15	0.06	1.2	5.8	1.3	0.63	12	0.008
1-Aug-98	0.3	0.04	2.3	8.3	4.5	1.8	20	0.001
1-Nov-98	0.21	0.06	2.4	8.7	1.6	0.72	15	0.03
1-Feb-99	0.67	0.06	2.1	8.5	1.2	1	19	0.03
1-May-99	0.2	0.08	4.6	10	1.3	0.8	21	0.05
1-Aug-99	0.35	0.07	2.8	10	0.9	0.8	20	0.02
1-Nov-99	0.2	0.06	2.3	8.5	1	0.7	18	0.02
1-Feb-00	0.2	0.06	2.2	8.7	0.9	0.9	19	0.05
1-May-00	0.3	0.05	1.4	6.5	0.5	0.9	13	0.05
1-Aug-00	0.2	0.06	1.8	6.9	0.7	0.8	41	0.026
1-Nov-00	0.3	0.1	2.7	8.9	0.8	0.5	16	0.05
1-Feb-01	0.54	0.08	3.1	14	2.2	0.9	28	0.09
1-May-01	0.3	<0.02	2.8	2.2	<0.5	1.2	26	<0.05
1-Aug-01	0.4	0.16	4.5	15	2.4	1.4	31	<0.05
1-Feb-02	0.23	0.060	1.85	10.2	1.19	0.82	22	<0.05
1-May-02	<1.0	0.126	3.08	18.6	2.12	1.35	41	<0.05
1-Aug-02	0.411	0.1	2.91	17	1.72	1.2	33	0.05
1-Nov-02	0.50	0.13	3.9	21.0	2.5	2.1	45	0.20
1-Feb-03	0.31	0.11	2.5	15.0	1.5	1.3	31.0	0.05
21-Aug-03	0.53	0.12	3.19	16	1.8	1.4	35	0.07

*These results are not directly comparable to those presented in Table 3 as they are expressed as weight per volume rather than weight per weight.

Shellfish

Shellfish quality is generally assessed according to suitability for human consumption by comparing the concentrations of various contaminants in the tissues with relevant guideline criteria. The criteria used here are defined in Technical Box 2.

Arsenic concentrations in cockle flesh ranged from 1.7 to 2.8 mg/kg at the monitoring sites (Table 5). These concentrations exceeded the NZFR guideline for safe human consumption (NZFR 1984) for seven of the 12 sites and the more conservative MIS guideline (Russman 2000) for all 12 sites. In spite of this, there is no convincing evidence that these exceedences are related to the biosolids applications as no pattern was evident through comparison of control vs. potential impact sites. We note that arsenic concentrations of shellfish reported for other unimpacted sites in Waimea Inlet also occasionally exceed both guideline levels (Gillespie *et al*. 2001).

Nickel concentrations in cockle flesh exceeded guideline levels at all but one site (Site 9). Once again, however, potential impact and control sites were equally elevated. We can probably assume that shellfish nickel concentrations in Waimea Inlet are affected by the naturally elevated sediment nickel concentrations (see sediment subsection).

Table 5. Shellfish trace metal concentrations at Rabbit/Rough Island monitoring sites (April 2003). Grey shaded values exceed either (or both) the MIS or NZFR guidelines for safe human consumption.

	mg/kg (dry weight)							
Transect	**Hg**	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Ni**	**Zn**
1	0.03	2.0	0.016	0.43	0.71	<0.02	2.0	8.4
2	0.04	2.8	0.024	0.77	0.72	0.05	2.3	7.7
3	0.04	2.5	0.016	0.68	0.53	<0.02	2.4	6.4
4	0.05	1.7	0.008	0.48	0.61	<0.02	3.6	10.0
5	0.05	1.8	0.011	1.00	0.92	<0.02	3.4	10.0
6	0.04	2.2	0.032	0.73	0.81	0.08	2.5	8.5
7	0.05	2.7	0.016	0.6	0.79	0.03	2.4	6.7
8	0.04	2.6	0.021	0.64	0.71	0.03	2.4	6.5
9	0.05	1.9	0.016	0.60	0.48	0.02	1.5	4.4
10	0.04	1.7	0.013	0.81	0.79	0.03	3.3	7.9
11	0.04	1.7	0.014	0.50	0.65	<0.02	2.5	6.4
12	0.04	2.4	0.017	0.61	0.56	0.03	2.6	6.0
MIS	0.5	1.4	1	1	20	2	2*	70
NZFR	0.5	2.0			30		2	40

MIS: Mean International Standards for Trace Elements in shellfish (Russman 2000). Based on: Nauen, C.E., Compilation of Legal Limits for Hazardous Substances Fish and Fishery Products. Food and Agriculture Organization of the United nations, 1983.
NZFR: New Zealand Food Regulations. Permissible proportions of elements in foods.
*Developed for Australia

3.5 Faecal indicator bacteria

Concentrations of faecal indicator bacteria amongst the 12 monitoring sites were extremely variable (Table 6). These results were not unexpected as similar (and higher) concentrations have been reported for a variety of sites in Waimea Inlet outside the influence of the Bell Island wastewater outfall or the biosolids application areas (Gillespie & Asher 1999). Concentrations of faecal coliforms at three sites (Sites 2, 4 and 10) exceeded the lower MOH (1995) guideline value of 230

MPN/100 g (marginal for human consumption) and two sites (Sites 2 and 10) exceeded the higher guideline value of 330 MPN/100 g (unacceptable for human consumption). The highest faecal coliform concentration was observed at a Rough Island control site suggesting that the elevated bacterial numbers were not related to the biosolids applications. Moderately high values for all three indicators suggest that other sources (*e.g*. waterfowl) may have contributed.

Table 6. Shellfish faecal indicator bacteria concentrations at Rabbit/Rough Island sites (April 2003)

Transect or Site	MPN per 100 g		
	Enterococci	Faecal Coliforms	Presumptive Coliforms
1	330	130	230
2	1100	330	330
3	170	50	130
4	460	260	700
5	20	130	230
6	200	<300*	2300
7	1300	40	330
8	1300	50	230
9	230	20	230
10	800	900	2300
11	230	40	1300
12	230	<20	80

* Insufficient sample size to achieve a lower detection limit.

Technical Box 2: Shellfish Quality Guidelines

The guideline values used for comparison with shellfish monitoring results are as follows:

- **MOH Microbiological Reference Criteria for Food (1995)**: New Zealand Ministry of Health (MOH) microbiological guideline for food consumption. Used in this assessment for comparison of bivalve faecal coliform levels. The guideline specifies that shellfish faecal coliform levels above 230 MPN/100g are marginally acceptable and that levels above 330 MPN/100g are unacceptable.

- **Median International Standards for Trace Elements in Shellfish (Russman 2000):** Human health limit for metals and metalloids in edible shellfish. Used in this assessment for comparison of shellfish metals levels. The guideline is based on: Nauen, C.E., Compilation of Legal Limits for Hazardous Substances Fish and Fishery Products. Food and Agriculture Organization of the United Nations, 1983

- **New Zealand Food Regulations (1984):** Human health guideline that lists the permissable proportions of elements (metals) in food. Used in this assessment in conjunction with MIS guidelines for comparison of shellfish metals levels.

4. SUMMARY

A biosolids land disposal programme was initiated by the Nelson Regional Sewerage Authority (NRSA), now the Nelson Regional Sewerage Business Unit (NRSBU), in February 1996. Since that time, treated sewage sludge from the Bell Island wastewater treatment plant has been applied on a semi-regular basis to designated disposal areas on Rabbit Island. A monitoring programme designed to identify any significant environmental effects to the adjacent intertidal habitat of the Island consisted of:

(1) a pre-disposal baseline survey carried out February 1996,
(2) follow-up visual inspections of 12 intertidal monitoring transects carried out at approximately 6-monthly intervals after commencement of biosolids applications, and
(3) a detailed monitoring survey carried out April 2003.

The results of the three components are summarised in the following sections:

4.1 1996 Baseline survey

Eight potential impact and four non-impact transects, through the Rabbit/Rough Island intertidal zone, were identified and surveyed as a basis for assessing any impacts of the biosolids application programme. Although the majority of the selected monitoring locations were relatively well flushed by tidal flows, two (Transects 6 and 7) were identified as being potentially sensitive to enrichment effects due to restricted tidal flushing (Gillespie & Asher 1997).

4.2 Six-monthly assessments

During the period 1996-2001, changes observed at monitoring sites along the southeast intertidal margins of Rabbit and Rough Islands (Waimea Inlet) appeared to be largely unrelated to the biosolids application to Rabbit Island. Although chronological changes recorded during the 6-monthly visual assessments indicate temporary habitat disturbance and nutrient enrichment along two transects (Transects 5 and 6), these appeared to be related to physical disturbances due to logging activities in the vicinity (*e.g.* vehicle tracks, intertidal ponding and accumulations of pine debris). The associated enrichment effects, however, may have been periodically exacerbated by surface runoff from the disturbed areas. The affected habitats subsequently recovered after a series of spring tides smoothed the area. Improved flushing after opening of the culvert at the western end of the Traverse resulted in a further return to a more natural estuarine condition (particularly within the previously highly enriched channel). Minor changes in macroalgal and microalgal coverage at other monitoring locations were thought to be primarily attributable to normal seasonal fluctuations.

4.3 2003 monitoring survey

Field observations

Although a variety of changes in habitat characteristics were identified at a number of monitoring sites, these appeared to be largely attributable to normal variation or factors unrelated to biosolids applications. No symptoms of over-enrichment (*e.g.* excessive algal growth, sediment anoxia, H_2S odours, *etc*.) were observed.

Inorganic nutrients

Results of the 2003 monitoring survey indicated enrichment of intertidal sediments with dissolved inorganic nitrogen, in the form of nitrate, at 10 of 16 potential impact sites and three of seven control sites. Although not measured in 1996, sediment ammoniacal-N concentrations in 2003 were found to exceed the ranges reported for other unimpacted intertidal sediments in the Nelson region for 10 of 16 potential impact sites and one of seven control sites. These results provide strong evidence that some enrichment of intertidal sediments with inorganic nutrients has occurred at the Rabbit/Rough Island monitoring sites. Although the fact that some of the “control” sites were also enriched makes it difficult to establish a definite cause and effect relationship, it is very likely that leachates from the biosolids application areas were a contributing factor. Unfortunately, because the comparison includes only two points in time it is not clear whether the inorganic enrichment represents a long term build-up or a shorter term fluctuation in concentrations.

Organic nutrients

Sediment organic nitrogen (TKN) and organic matter (AFDW) concentrations observed during the 2003 monitoring survey were within ranges observed for other unimpacted intertidal habitats in the Nelson region. Comparing sediment TKN and AFDW concentrations from 2003 with 1996 data indicated slight organic enrichment at a number of sites, however a reduction in organic matter was observed at other potential impact sites suggesting that physical flushing characteristics were sufficient to prevent the development of symptoms of over-enrichment. This conclusion is consistent with field observations and 6-monthly visual surveys that found no evidence of adverse enrichment effects.

Sediment trace metals

Sediment trace metal (and the metalloid arsenic) concentrations observed in 2003 were, in nearly all instances, within ranges considered to be normal for Waimea Inlet sediments. Exceptions to this were nickel concentrations at one potential impact site (Transect 4) and one control site (Transect 10), however there is no evidence that these were biosolids-related. These concentrations were 4x and 2x greater (respectively) than the recommended ANZECC ISQG-High threshold level. Because of the fact that nickel concentrations are naturally elevated in Waimea Inlet sediments, further sampling and analyses would be required in order to determine the significance of these two unusually high results.

Shellfish quality

Arsenic concentrations in cockles collected from the vicinities of all monitoring transects were in excess of recommended MIS and, in some cases, NZFR guideline limits for human consumption. Nickel concentrations at all but one monitoring location (Transect 9) were also in excess of MIS and NZFR guideline limits. There is no convincing evidence, in either case, however, that the elevated concentrations are biosolids related. Since potential impact and control sites were more or less equally affected, it is more likely that these concentrations were due to other factors. We know, for example, that nickel concentrations are naturally high in Waimea Inlet sediments and that arsenic shellfish concentrations reported for other sites in Waimea Inlet occasionally exceed guideline limits. Nevertheless some bio-accumulation is possible, particularly in the case of arsenic. Further comparisons of arsenic, chromium and nickel concentrations in shellfish from the study sites and other regions within Waimea Inlet would ensure that any potential cumulative effects of continued biosolids applications are detected.

Faecal coliform and enterococci concentrations in cockles from the monitoring locations were highly variable with a number of sites (both potential impact and control) achieving values either marginal or unacceptable for human consumption according to MOH guidelines. Again, these results are not thought to be biosolids-related as similar and higher concentrations have been reported for a variety of other sites in Waimea Inlet.

5. CONCLUSIONS

- Overall monitoring results indicate that, during the period April 1996-April 2003, land applications of biosolids from the Bell Island wastewater treatment plant have not resulted in significant adverse effects to the enrichment status or contaminant levels of Rabbit Island intertidal habitats.
- No evidence of adverse environmental effects attributable to biosolids applications were identified through a series of visual surveys carried out at approximately 6-monthly intervals from 1996-2001. Temporary enrichment effects resulting from logging disturbances of upper intertidal and shore habitats in the region of the Traverse may have been exacerbated by surface runoff or groundwater seepage from adjacent biosolids application areas.
- During the 2003 monitoring survey:
  - No symptoms of over-enrichment (*e.g*. excessive algal growth, sediment anoxia, H_2S odours, *etc*.) were observed.
  - The biosolids application programme was identified as a probable contributor to elevated dissolved inorganic nitrogen concentrations in intertidal sediments at a number of monitoring locations.
  - Although slight organic enrichment was observed at some potential impact sites, the reverse was true at others suggesting that physical flushing characteristics were sufficient to prevent the development of symptoms of over-enrichment.
  - There were no indications that biosolids applications had resulted in elevated sediment trace metal concentrations.
  - Shellfish arsenic and nickel (and to a lesser extent chromium) concentrations were elevated at both impact and control sites.

6. RECOMMENDATIONS

Although monitoring results indicate that biosolids applications have thus far not resulted in significant adverse effects to the enrichment status or contaminant levels of adjacent intertidal habitats, there are indications that some minor enrichment has occurred. Likewise observations of naturally high concentrations of arsenic, nickel and chromium in the receiving environment suggest that particular care should be taken with regard to potential long term effects. Because we have carried out only one detailed monitoring survey to date, we have no data describing short term temporal variation in intertidal condition that can be interpreted in conjunction with biosolids, groundwater and soils monitoring results. The procedures adopted by NRSBU for the removal of biosolids from the Bell Island wastewater treatment plant and its subsequent use for application to pine forest growing areas are relatively new to New Zealand. The considerable monitoring information collected by NRSBU in association with the land application of biosolids on Rabbit Island provides an opportunity to further evaluate the approach for possible use in other parts of the country. In view of the minor enrichment effects observed and the possible National benefits of knowledge acquired through a more detailed case study, we recommend that the receiving environment monitoring requirements be reviewed. Consideration could be given to more frequent (*e.g*. annual or rainfall event-based) reassessment of benthic effects and comparison with a more comprehensive interpretation of existing and ongoing biosolids, soils and groundwater monitoring data. Particular intertidal indicators that would be useful for ongoing estuarine monitoring include sediment nitrogen concentration, polychaete worm species and abundance, and sediment and shellfish arsenic, nickel and chromium concentrations.

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Appendix A

Field observations for Rabbit/Rough Island monitoring locations (April 2003)

Appendix A. Field observations for Rabbit/Rough Island monitoring locations (April 2003)

TRANSECT 1: Control site on south eastern shore line. Peg at 0m(HWS). GPS location 2525551E 5991114N	
0 - 7m	Loose, soft, mobile sand. High shore area
7 - 14m	Fine sand with some shell, soft surface ~5cm and firm below. Rows of drift vegetative Debris (mostly *Ulva,* eelgrass and pine needles) on the surface parallel to the shore (each ~0.5m wide with clear sand between).
14 – 19m	Fine sand with some shell, soft surface 2-4cm and firm below. Usually patches of drift vegetative debris (mostly *Ulva* and terrestrial leaves). Drift vegetation absent, however the exact location of drift accumulation varies with tide and weather conditions.
19 – 28m	Fine sand with increasing shell, soft surface 2-4cm and firm below. Some shingle.
28 – 42m	As above with less shell extending to the channel at ~ 42m.

Site 1A. @ 17m: Fine sand with some shell, soft surface 2-4cm and firm below. Clear of drift debris on this occasion.	Ave. per $0.1m^2$ (1996 / 2003)
Austrovenus stuchburyi (cockle)	0.4 / 0
Vegetative debris (% cover)	40 / 0

Site 1B. @ 27m: Fine sand with shell, soft surface 2-4cm and firm below. Near seepage area.	Ave. per $0.1m^2$ (1996 / 2003)
Austrovenus stuchburyi (cockle)	9.4 / 1.4
Cominella glandiformis (whelk)	0.2 / 0
Drift *Ulva* (% cover)	3 / 2
Barnacle	0 / 2

Sediment Cores

Site 1A

No surface vegetation

0 - 18cm: Fine sand, medium brown / grey with some scattered shell.

Site 1B

0-18cm: Firm, fine sand, brown / grey mottled with orange.

Some shell on surface

Summary of Transect 1changes April 2003.

The relatively minor changes observed at Transect 1 over the last 7 years are the likely result of physical disturbance caused by tide and water flows.

There was slight erosion of the finer surface sediments (only mm) from mid to lower shore, exposing more old shell, small amounts of shingle and areas of a clay under-layer on the lower beach.

Drift vegetation accumulated in rows parallel to the shore. The exact position and composition of the drift lines varies with tides and seasons.

Cockle numbers were lower at both sites; probably attributable to the erosion of the fine surface sediments, however cockles were still common in the general area.

TRANSECT 2: On south eastern shore line. Peg at 0m (HWS). GPS location 2524569E 5991754N. Notes: No significant macro algae but occasional small pieces of drift *Ulva* and small *Gracilaria* plants near channel.	
0 - 7m	Loose, mobile, fine sand. High shore area with pine tree stumps and debris spilling over onto beach.
7 - ~15m	Firm fine sand with soft surface layer.
15 - 100m	Firm fine sand grading to increasing mud. Wide sand / mud flats. Crab holes abundant throughout down to main channel.
100 - 123m	Mud / sand, soft on surface 5-10cm and firmer below. Gradual slope down to wide secondary drainage channel (channel base ~117-123m).
123 - 136m	Mud / sand, soft on surface 5-10cm and firmer below. Far bank of secondary drainage channel. Pacific oysters in patches especially on top of the bank.
136 - ~160m	Firm sand / mud with some shell debris. Gradual slope down to main channel (~160m depending on tidal height). Pacific oysters in patches.

Site 2A. @ 63m: Firm fine sand with some mud. Thin patches of micro algae (*Euglena* sp.)	Ave. per 0.1m² (1996 / 2003)
Crab holes	12 / 10
Amphibola crenata (mud snail)	0 / 0.4

Site 2B. @116m: Soft mud/sand surface firmer mud/sand below. On gently sloping bank of secondary channel.	Ave. per 0.1m² (1996 / 2003)
Anemone	Abundant
Austrovenus stutchburyi (cockle)	31 / 14
Cominella glandiformis (whelk)	Occasional
Diloma subrostrata (top shells)	0.4 / 0.4
Zeacumantus sp. (spire shell)	2.6 / 0
Crab holes	11 / 26
Elminius modestus (barnacles)	0 / 2

Sediment Cores

Site 2A

0 - 1cm Fine sand with some mud on the surface, brown mottled light grey.

1 - 18cm Firm fine sand, brown.

Site 2B

0 - 3cm Fine soft mud/sand and occasional shells, medium grey mottled light grey and orange brown.

3 - 19cm Fine sand/mud and occasional shells, dark-grey mottled medium and light grey with some orange brown.

Summary of Transect 2 changes April 2003.

The cockle numbers were lower on average at Site 4, but replaced by higher crab densities. In the main channel *Crassostrea gigas* (Pacific oyster) numbers increased with mounds of oysters increasing in size. No other noticeable change occurred along the transect over 7 years of monitoring.

TRANSECT 3: On south eastern shore line.(directly opposite Bell Island oxidation ponds and ~50m east of the boulder beach area). GPS location 2524019E 5991821N	
0 - 13m	Fine, soft, mobile sand. Steep bank eroded ~4m back. Pine tree stumps and roots exposed.
13 - 19m	Firm packed mud. Top of slope down to main channel. Crab holes (A)
19 - 26m	Increasingly softer mud down slope to main channel. Occasional clumps of Pacific oysters on lower slope with large beds either side of the transect at the channels edge. Continuous band of oysters along channel edge. Crab holes (A).

Site 3A. @ 17m: Firm packed mud and sand	Ave. per 0.1m² (1996 / 2003)
Crab holes	25 / 33

Site 3B. @ 24m (Counts of fauna in 0.1m²). Soft mud; near channel edge.	Ave. per 0.1m² (1996 / 2003)
Austrovenus stutchburyi (cockle) (smaller)	5 / 25
Crab holes	17 / 17
Occasional *Cominella glandiformis* (whelk) and *Crassostrea gigas* (Pacific oyster). Pacific oyster abundant with a continuous 4-10m wide swath along channel shore.	

Sediment Cores

Site 3A

0 - 5cm: Firm packed mud and sand, mottled brown / light to medium grey with streaks of orange lining crab holes.

5 – 18cm: Firm mud and sand, brown mottled with streaks of orange. Too hard-packed at ~13cm for core tube penetration. No shingle present.

Site 3B

0 - 2cm: Soft mud, brown.

2-8cm: Soft mud / sand, mottled light - medium grey.

8-9cm: Layer of shell (*Dosinia subrosea* and *Paphies australis*)

9 - 18cm: Fine sand, light grey / brown.

Summary of Transect 3 changes, April 2003.

Two major changes on this transect. The first physical, with ~4m erosion of the steep bank leaving pine tree roots exposed and either suspended or collapsed on the beach. The main erosion period was late1997 and 1998 with further lesser erosion in 2001.

The second major change is biological with the expansion of the *Crassostrea gigas* (Pacific oyster) reef along the channel shore and also as mounds within the channel. This is not unique to this transect, but common to a number of regions in Waimea Inlet.

Cockle numbers increased at Site 3B. Their small size suggests recent recruitment into the area and is probably a normal population fluctuation.

TRANSECT 4: On southern shore line west of boat ramp. Situated approx 200m upstream of the confluence of the channel originating from the Traverse and the Waimea River channel. Peg at 0m (HWS). GPS location 2522476E 5991630N	
0 - 4m	Loose shingle. High shore area with ice plant extending down 2m and small plants of Sea blite (*Suaeda*) and Glasswort (*Sarcocornia*)
4 - 8.5m	Firm packed shingle with mud coating. A band of Glasswort (*Sarcocornia*), *Selliera radicans,* and shore pimpernel (*Samolus repens*) cover this zone.
8.5 – 11m	Firm packed shingle with mud coating. Only occasional patches of the above plants.
10 - 18m	Firm mud. Gentle slope, increasingly softer towards channel. Very little evidence of *Spartina* left. *Amphibola* and crab holes abundant.
18 - 24m	Soft mud slope down to channel edge at ~22m. Patches of Pacific Oyster growing along channel edge (5x3m patch to left and small patches to right)

Site 4A. @ 14m: Semi firm mud with soft surface. *Spartina* roots and *Enteromorpha* no longer present.	Ave. per 0.1m² (1996 / 2003)
Amphibola crenata	10 / 11
Potamopyrgus (small snail)	Abundant / 0
Crab holes	21 / 26

Site 4B. @ 21m: Deep soft mud on slope near channel.	Ave. per 0.1m² (1996 / 2003)
Amphibola crenata	5 / 11
Austrovenus stutchburyi	0.8 / 0.8
Potamopyrgus (small snail)	Abundant / 0
Crab holes	15 / 14

Sediment Cores

Site 4A

0-1cm Mud, brown surface mottled brown / medium grey with orange steaks down crab holes. Occasional shell.

1-10cm Mud, dark grey mottled medium grey with brown around burrows. Some fine, dead *Spartina* roots still present.

12 - 14cm Sand / mud, medium grey.

@ 10cm Hard shingle layer.

Site 4B

0 - 1cm Soft mud, brown surface mottled medium grey.

1 - 30cm Deep soft mud, dark grey mottled medium grey.

Summary of Transect 4 changes, April 2003

The main change at transect 4 is a result of the old *Spartina* roots finally rotting away after 10-15 years since eradication of live plants. The result is a releasing of sediment, which once formed a flat topped bank, but has now slumped down into the channel leaving a gentle slope and an extra ~10cm soft mud layer along the channel edge. The small snail (*Potamopyrgus* sp.), which fed amongst the *Spartina* stumps and *Enteromorpha,* has gone. Meanwhile the larger mud snail (*Amphibola crenata)* has increased at Site 4B where its preferred habitat has increased.

There has been a gradual increase in *Crassostrea gigas* (Pacific oyster) numbers, since 2000, in the channel, which, as mentioned, has also occurred in other parts of the estuary.

TRANSECT 5: On northern shore line of the Traverse. Peg at 0m(HWS). GPS location 2521573E 5992121N	
	This Transect lies in an indent in the shore line along the impounded lagoon and has restricted circulation. The surrounding vegetation consists of grasses and clover, Glasswort (*Sarcocornia)* ,*Selliera, Samolus*, and patches of *Juncus*
0 - 8m	Firm mud. Glasswort (*Sarcocornia)* covers ~50%, along with shore pimpernel (*Samolus repens*).
8 – 33m	Firm mud with soft sticky surface. Crab holes (C-A) No *Spartina* since 1998.
33 - 40m	Increasingly softer mud. *Amphibola* (C) crab holes (A). Patches of glasswort (*Sarcocornia)* 5-10m from either side of the transect.
~50m	No visible *Enteromorpha*, water clear. Small *Gracilaria* plants along shoreline.

Site 5A. @ 12m: Firm mud with soft sticky surface.	Ave. per 0.1m² (1996 / 2003)
Amphibola crenata (mud snail)	0.2 / 4.8
Crab holes	19 / 41

Site 5B. @ 40m: Soft mud.	Ave. per 0.1m² (1996 / 2003)
Amphibola crenata	8 / 7
Potamopyrgus (small snail)	Abundant / 0
Austrovenus stutchburyi (cockle)	0 / 1
Crab holes	24 /32

Sediment Cores

Site 5A

0 - 4cm Mud with some sand, medium - light grey with lines of brown lining burrows.

4 - 17cm Mud with some sand, brown mottled with orange and light grey.

Site 5B

0 – 20cm Soft mud, mottled light to medium grey. Even texture

Summary of Transect 5 changes, April 2003

Activities outside this transect line, as well as Transect 6, have largely altered the surrounding area. Firstly, around 1998 the causeway at the western end of the Traverse was removed allowing improved water flow. Over the next 2 years the amount of *Enteromorpha* along the Traverse declined and the water clarity improved.

Secondly, during 1999, forestry operations cleared pine trees away from the edge of the Traverse, especially surrounding the upper drainage channels of Transect 5 and 6. The ground was extensively dug into hollows and mounds with large amounts of pine debris. Gradually over the next year, the site was cleaned up by some smoothing of the soil and removal of debris. With the causeway removed, the two low lying embayments surrounding the Transects have been more vigorously flushed by the tides resulting in further smoothing and a gradual change to a more natural estuarine appearance.

During this time, neither transects 5 or 6 were physically disturbed. However there appeared to have been a succession of nutrient releases (probably due, primarily, to the logging activities). These resulted in increased algal growth (as seen on some occasions). These nutrient releases may have been exacerbated by seepage, or surface runoff, from adjacent sludge application areas.

Compared with the baseline study in 1996, the actual transects were cleaner in appearance, with no remnant *Spartina* debris, and less *Enteromorpha* clogging of channels. There was also an increase in crab and mud snail populations and an introduction of cockles nearer the channel.

TRANSECT 6: On northern shore line of the Traverse. Peg at 0m (HWS). GPS location 2520861E 5992587N. This Transect follows a small, natural, drainage channel bed into the main impounded lagoon of the Traverse. The surrounding area is similar to Transect 5.	
0 – 4m	Firm mud, with 80-90% cover of glasswort (*Sarcocornia quinqueflora*). Crab holes (C), some patches of drift *Ulva*.
4 - 7.5m	Firm mud, with patches of glasswort . Crab holes no longer present.
8m	NB. 0.5m diameter clump of Spartina in 96 Cleared since 1998
4 – 25m	Firm mud. Old dead Spartina roots and stalks no longer present. A small channel runs approx 1.5m left of, and parallel t, the Transect at this point. Crab holes and mud snail abundant.
25 – 27m	Soft mud hollow as Transect crosses the small channel.
27 – 34m	As for 4 – 25m but with channel on right of transect
34 – 36m	Soft mud. Transect follows down middle of small channel.
36 – 51m	Firm mud. Old dead *Spartina* roots and occasional stalks no longer present. Semi firm mud with soft sticky surface No *Spartina*
51 - 57m	Deep soft mud in channel base with low banks (old dead Spartina roots no longer present)
57m+	Main impounded channel, deep soft mud (floating mat of *Enteromorpha* along edge decreasing since 1999 and clear since 2001).

Note: small steam channel has shifted position over time.

Site 6A. @ 22m: Soft mud in slight hollow of channel. No visible micro algae.	Ave. per 0.1m² (1996 / 2003)
Amphibola crenata (mud snail)	0 / 11
Crab holes	2 / 23

Site 6B. @ 57m: Soft mud especially in the channel. Smooth mud flats. No visible micro algae or remnant *Spartina* debris.	Ave. per 0.1m² (1996 / 2003)
Amphibola crenata (mud snail)	0 / 22
Austrovenus stutchburyi (cockle, small)	0 / 3
Crab holes	16 / 8

Sediment Cores

Site 6A

1mm Light brown surface
0 – 8cm Soft mud, dark grey to black.
8 – 18 cm Mud (clay like), mottled light / medium / dark grey.

Site 6B

3mm Light brown surface.
0 – 2cm Soft mud, dark grey.
2 – 19cm Firmer mud, mottled, light to mid grey with streaks of dark grey.
14 - 16cm Occasional shell fragments.

Summary of Transect 6 changes, April 2003

See notes for Transect 5

TRANSECT 7: On southern shore line 3-400m west of the traverse causeway. Pegs at 0m(HWS) & 25m. GPS location 2519913E 5993263N	
0 - 6.5m	Firm, shingle / cobbles / mud. Glasswort (*Sarcocornia)* up to 90% cover with *Selliera, Samolus*, and patches of Sea blite (*Suaeda)* and sedges in the high shore zone.
6.5 - 8m	Firm, shingle and mud. No vegetation
8 - 14m	Mud mixed with shingle, soft surface and firm below. Crab holes (A)
14 - 17m	Soft mud with firm shingle base. Occasional small *Gracilaria* plants (<1%)
17 - 28m	Soft black mud up to 12cm deep with firm shingle base. Covered with patchy *Gracilaria* (20-50% cover) and small fragments of Ulva (<1%)
28 - 30m	A soft surface of mud mixed with shingle and a hard base of shingle and cobbles. *Gracilaria* <5% cover. Channel edge at 30m

Site 7A. @ 15m (counts of fauna in 0.1m²) Soft mud.	Ave. per 0.1m² (1996 / 2003)
Amphibola crenata (mud snail)	0.6 / 5.2
Austrovenus stutchburyi (cockle)	10 / 9
Diloma subrostrata (top shell)	0.8 / 0.2
Diloma zelandica (top shell)	0.6 / 6.4
Cominella glandiformis (whelk)	0.2 / 0
Notoacmea helmsi (limpet)	0.2 / 3.6
Zeacumantus sp. (spire shell)	0 / 1.2
Crab Holes	21 / 6
Gracilaria (% cover)	2 / 3

Site 7B. @ 25m (counts of fauna in 0.1m²) Soft mud 5-10cm, with hard shingle base.	Ave. per 0.1m² (1996 / 2003)
Crassostrea gigas (Pacific oyster)	0.2 / 4.4
Austrovenus stutchburyi (cockle)	3 / 16
Diloma subrostrata (top shell)	2.6 / 1
Diloma zelandica (top shell)	2 / 16
Zeacumantus sp. (spire shell)	2 / 0.8
Turbo smaragdus (cats eye shell)	0 / 0.4
Notoacmea helmsi (limpet)	0 / 5
Amphibola crenata (mud snail)	0 / 0.8
Xenostrobus pulex (black mussel)	0 / 0.4
Crab Holes	13 / 2
Gracilaria (% cover)	53 / 37

Sediment Cores

Site 7A

0 - 1cm	Soft mud surface, grey / brown with some shell.
1 - 14cm	Soft mud, medium grey mottled light grey, and dark grey
14cm	Hard shingle layer.

Site 7B

0-5mm	Layer of *Gracilaria.*

0 - 3mm	Very soft mud surface, brown.
3 – 50mm	Soft mud, medium grey.
50mm	Hard shingle and cobbles.

Summary of Transect 7 changes, April 2003.

There has been small fluctuations in *Gracilaria* cover over the years, which also affects presence and densities of invertebrates, notably cockles, mud snail, top shells and crabs. Pacific oysters are slowly increasing in numbers in the area.

TRANSECT 8: On south western shore line. Diagonally opposite Hunter Brown Reserve on Rough Island. Peg at 0m (HWS). GPS location 2519584E 5993400N	
0 - 6m	Firm, shingle / cobbles. High shore zone covered with thick layer of pine debris.
6 - 14m	Firm, sloping. Cobbles / shingle and mud.
14 - 18m	Soft mud with scattered shingle, cobbles and pine debris. Flat area
18 - 24m	Continuation of cobble slope with more soft mud in patches.
24 - 28m	Soft mud and scattered shingle and shell. Edge of channel ~28m
NB Seepage spring in channel 5m to right of transect. Small tufts of both *Gellidium*, on lower cobble bank, and *Gracilaria*, on cobbles & pebbles in the mud (total <5% cover).	

Site 8A. @ 16m: Soft mud with scattered shingle, cobbles and pine debris. Level area half way down cobble slope.	Ave. per 0.1m² (1996 / 2003)
Austrovenus stutchburyi (cockle)	10 / 14
Diloma zelandica (top shell)	0.4 / 0.8
Zeacumantus sp. (spire shell)	0 / 2.2
Amphibola crenata (mud snail)	0 / 2
Crab holes	15 / 6

Site 8B. @ 28m: Soft mud with scattered shingle and shell.	Ave. per 0.1m² (1996 / 2003)
Austrovenus stutchburyi (cockle)	31 / 17
Diloma zelandica (top shell)	2.2 / 1.6
Diloma subrostrata (top shell)	0 / 1
Crab holes	8 / 6
Gracilaria (% cover)	1 / 1

Sediment Cores

Site 8A

0 - 1cm. Soft mud, brown surface.
1 – 12cm. Soft mud with scattered shingle, medium grey.
12cm Hard cobble / shingle

Site 8B

0 - 3cm Soft mud, brown mottled medium grey.
3 - 21cm Soft mud with scattered patches of sand and occasional shell, medium grey.

Summary of Transect 8 changes, April 2003.

No significant changes.

TRANSECT 9: On western shore line opposite Mapua. Peg at 0m (HWS). GPS location 2518903E 5994392N	
0 - 5m	Soft sand, high shore zone.
5 - 12m	Firm, sand with increasing firm mud. Crab holes (C).
12 – 21m	Firm mud and sand, sticky on surface when closer to small, secondary drainage channel, which crosses transect at 19m
21 – 27m	Firm mud bank. Crab holes (A).
27 – 34m	Soft mud & cockle shell with a bank of *Crassostrea gigas* (Pacific oysters).
34 - 60	Firm with semi soft surface, shingle / sand / mud / shell. Wide flat secondary channel almost empty at low tide. Scattered *Ulva* <5% and occasional *Gracilaria* <1% cover.

Site 9A. @ 20m: Semi soft mud in hollow with winding small drainage channel.	Ave. per 0.1m² (1996 / 2003)
Austrovenus stutchburyi (cockle)	10 / 0.4
Xenostrobus pulex (black mussel)	2 / 0
Crab holes	45 / 33

Site 9B. @ 38-40m: Soft mud with scattered shingle and shell.	Ave. per 0.1m² (1996 / 2003)
Anemone (variable, occasional to abundant)	No change
Austrovenus stutchburyi (cockle)	3 / 3
Diloma zelandica (top shell)	6 / 4
Diloma subrostrata (top shell)	0.6 / 0.8
Micrelenchus tenebrosus (small snail)	2.8 / 1.2
Lepsiella scobina (oyster borer)	0.2 / 0
Notoacmea helmsi (limpet)	16 / 3
Chiton glaucus (green chitin)	1.2 / 0.4
Serpulidae tube worm	1.6 / 0
Zeacumantus sp. (spire shell)	0 / 0.8
Crab holes	8 / 0
*Ulva or *Gracilaria* (% cover)	7 / 6

Sediment Cores

Site 9A

0 - 18cm Firm mud with some sand, mottled brown, light and medium grey and orange.

Site 9B

0 - 18cm Loose and wet shingle, sand and shell, grey / brown.

Summary of Transect 9 changes, April 2003.

No significant changes. There was normal seasonal variation of *Ulva* and *Gracilaria* cover within the channel.

TRANSECT 10: Control site On southern shore line of Rough Island. Situated along straight road parallel to shore, past Borlace Rd and ~100m before Kingsland Rd. Peg at site 19. GPS location 2520627E 5991927N	
0 - 3m	From grass covered clay bank. Cobble and shingle high shore area. Patches of. glasswort (*Sarcocornia*), *Selliera radicans,* and shore pimpernel (*Samolus repens)* and occasional sea blite (*Suaeda)* and plantain plus pine debris.
3 - 6m	Firm, shingle / mud and cobbles. Covered in open growth of glasswort (*Sarcocornia*), *Selliera radicans,* and shore pimpernel (*Samolus repens)*. Crab holes (C).
6 - 8m	As above and covered by a band of dense *Selliera radicans,* with shore pimpernel (*Samolus repens* and glasswort (*Sarcocornia*).
8 - 11m	Band of cobbles with increasing mud between. Covered with glasswort (*Sarcocornia*) and *Selliera radicans*
11 - 13m	Mud with exposed cobbles and shingle.
13 - 23m	Soft mud over firm shingle below 5-10cm.
23-24m	Secondary channel edge. Patches of *Crassostrea gigas* (Pacific oyster) and pine debris.

Site 10A. @ ~15 m: Soft mud (5-10 cm) over firm shingle:	Ave. per 0.1m² (1996 / 2003)
Austrovenus stutchburyi (cockle)	1 / 2.2
Amphibola crenata (mud snail)	10 / 9
Crab holes	5 / 14

Site 10B. No site 10B due to short length of transect.	

Sediment Cores
Site 10A

0 - 1cm	Soft mud, mottled brown, light and medium grey
0 - 10cm	Soft grey mud
5 – 10cm	Mottled medium and dark grey, variable depth
10cm	Hard packed shingle / cobble.

Summary of Transect 10 changes, April 2003.
No significant changes.

TRANSECT 11: On mid southern shore line of Rough Island. Pegs at 0m(HWS) & 50m GPS location 2519646E 5992240N	
-7 - 0m	From road edge to peg. Mixed tangled vegetation, grasses, ice plant, wire bush, Glasswort (*Sarcocornia)* and Sea blite (*Suaeda)*
0 - 1m	Band of Juncus. (Peg located just behind)
1 - 10m	Hard cobbles / shingle and mud, with Glasswort (*Sarcocornia)* at variable densities
10 - 26m	Hard cobbles / shingle and mud between. Scattered pacific oysters below 18m
26 - 37m	Deep soft mud with variable patches of mud / sand and scattered drift wood & vegetative debris. A deposition area. Scattered pacific oyster, shell only.
37 - ~70m	Flatter area of coarse sand & shingle base with a layer of fine soft mud & silt. Scattered pacific oyster (shell only) and small pieces of vegetative debris. Spread out delta of small drainage channels.

Site 11A. @ 34m (counts of fauna in 0.1m²). Depositional area of deep soft mud with variable patches of mud / sand and scattered drift wood & vegetative debris.	Ave. per 0.1m² (1996 / 2003)
Austrovenus stutchburyi (cockle)	5 / 2
Diloma zelandica (top shell)	1 / 16
Diloma subrostrata (top shell)	1.6 / 0.4
Cominella glandiformis (whelk)	0.2 / 0.4
Notoacmea helmsi (limpet)	0.8 / 0
Xenostrobus pulex (black mussel)	0.2 / 0
Zeacumantus sp. (spire shell)	0 / 0.2
Crassostrea gigas (Pacific oyster)	0 / 0.2
Crab holes	6 / 6

Site 11B. @ 60m. Delta area of coarse sand & shingle base with a layer of fine soft mud & silt.	Ave. per 0.1m² (1996 / 2003)
Austrovenus stutchburyi (cockle)	0 / 0.6
Diloma zelandica (top shell)	0 / 7
Crab holes	5 / 18

Sediment Cores

Site 11A

0 - 1cm	Soft mud, grey brown.
1 - 5cm	Soft mud and fibrous vegetative debris, black.
5 - 20cm	Soft mud, black to dark grey. Occasional scattered shell.

Site 11B

0 - 1cm	Surface fine silt, grey / brown.
1 - 10cm	Coarse sand and shingle, medium grey.

Summary of Transect 11 changes, April 2003.

No significant changes. Variable amounts of drift seaweed from time to time

TRANSECT 12: Control site on southern shore line at the western end of Rough Island within the Hunter Brown Reserve.. Peg at 0m (HWS) & 60m. The transect actually runs to the 60m peg and then at right angles for 40m, parallel to the shore, towards the main channel. Small tufts of *Gracilaria* and *Ulva* (<5% cover) exist in a 20 -30m band parallel and next to the main channel. GPS location of 0 m peg 2519146E 5993009N	
0 - 50m	Firm cobble / shingle / sand, in a gentle slope. Mud gradually increases on the surface with Periwinkles abundant 20 to 30m, Barnacles abundant 32 to 50m and scattered Pacific oysters 40 to 50m.
50 - 60m	Deep soft mud flats with narrow drainage channels. Abundant crab holes and cockles.
60m to site 24	At right angles to 60m peg towards main channel and following small drainage channel. Soft mud with increasing sand and shell.
10m to channel	Firm sand / shell / shingle / mud along the shore line of the main channel.

Site 12A. @ 60m from land and 10m into mud flats from edge of cobbles. Deep soft mud on banks of a winding, small drainage channel.	Ave. per $0.1m^2$ (1996 / 2003)
Anemones (variable occasional to abundant)	Occasional
Austrovenus stutchburyi (cockle)	13 / 13
Diloma zelandica (top shell)	0.8 / 0.8
Cominella glandiformis (whelk)	0.4 / 0.6
Crab holes	23 / 8

Site 12B. @ At right angles 40m from site 23 (counts of fauna in $0.1m^2$). Soft mud / sand and shell.	Ave. per $0.1m^2$ (1996 / 2003)
Anemone (variable occasional to abundant)	Occasional
Austrovenus stutchburyi (cockle)	31 / 4
Diloma zelandica (top shell)	3.2 / 1.2
Diloma subrostrata (top shell)	0.4 / 0.2
Micrelenchus tenebrosus (small snail)	0.2 / 0.4
Notoacmea helmsi (limpet)	5 / 0
Cominella glandiformis (whelk)	0 / 0.6
Zeacumantus sp. (spire shell)	0 / 0.2
Crab holes	4 / 6
Gracilaria (% cover)	8 / 3

Sediment Cores

Site 12A

0 - 2cm Soft mud, brown / grey.

2 – 18cm Soft mud (gradually firming (12 – 15cm) and occasional shell, medium grey to dark grey.

Site 12B

0 - 2cm Sand / mud and shell, medium to dark grey.

2 - 15cm Mud / sand and shell, dark grey.

Summary of Transect 12 changes, April 2003.

No significant changes. Cockle numbers dropped at Site 24, but they were still common to abundant in the immediate area.