Delaware Inlet Fine-Scale Benthic Baseline 2009

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EXECUTIVE SUMMARY

Background

Cawthron Institute was commissioned by the Nelson City Council, through Envirolink NLCC19, to establish a baseline of benthic fine-scale characteristics for Delaware Inlet in order to contribute to a coordinated coastal State of Environment monitoring strategy for the Nelson Bays. To this end, a suite of benthic intertidal indicators of estuary condition/health was assessed at three reference locations according to a standardised methodology (the estuary monitoring protocol or EMP) that has been used throughout New Zealand including a number of estuaries in the Nelson Bays region. The fine-scale baseline is intended to provide one component of the EMP to facilitate incorporation of Delaware Inlet into the greater Nelson Bays estuary surveillance network.

Based on a comparison of the EMP suite of fine-scale environmental indicators with other New Zealand and overseas estuaries, the three Delaware Inlet study locations were found to be in a relatively pristine functional condition. Comparison of nutrient results for the study locations with historical data for a range of sites in the same estuary suggested that their enrichment status had not increased over a 28-year period. The dataset provided in this report can be used as a benchmark for comparison with future repeat assessments to form a component of an integrated Nelson Bays estuary monitoring programme. The results are reported here with brief interpretation to provide a point-in-time (January 2009) description of habitat condition that can be used as a baseline for monitoring change over time.

Fine-scale baseline results

Key findings of the baseline assessment are as follows:

- No obvious signs of pollution (*e.g.* odours, visible scums from fats/oils or unnatural debris), were noted.
- Core profiles showed no signs of excessive oxygen depletion (*e.g.* black anoxic zones or sulphide odours), and were typical of other productive estuarine sites that are in a relatively healthy condition.
- No nuisance-level microalgal mat development or excessive macroalgal coverage was observed at the time of the survey.
- Nutrient and organic contents of the sediments were not unusually elevated although TP concentrations were near the high end of the range, suggesting that super phosphate fertilisers may have been previously applied to parts of the catchment. Low TN:TP atomic ratios suggest that nitrogen was the more limiting plant nutrient. Thus symptoms of over-enrichment would not be expected to result from elevated phosphorous levels alone, although future nitrogen inflows could carry an added eutrophication risk.
- Sediment cadmium, chromium, copper, lead, nickel and zinc concentrations were all well below various guideline levels that are often used to indicate potential biological effects. Nickel and chromium concentrations however were slightly elevated compared to some other estuaries, probably due to natural catchment sources.
- Animal communities were fairly typical of those observed at sites of similar sediment particle size distribution in a variety of other New Zealand estuaries, however, both infauna and epifauna

communities at the predominantly sandy Site B (eastern arm) had relatively low diversity and abundance. Animal communities at Site B were assumed to have been naturally limited by the exposure of the site to wave and tide disturbances.

Recommendations

Fine-scale physical, chemical and biological assessment of benthic intertidal habitats is one of two EMP components required to adequately evaluate the condition of estuary seabed habitats. We recommend that Council also consider inclusion of GIS-based, broad-scale mapping of intertidal and peripheral shoreline habitats of Delaware Inlet as a second component. Broad-scale mapping with detailed ground-truthing would provide spatial context for fine-scale monitoring results and enable a more encompassing evaluation of change over time. Of particular importance with regard to Delaware Inlet, would be determination of the area coverage and rate of expansion of the invasive Pacific oyster that represents a threat to the natural character and function of the estuary environment.

Through a separate Envirolink grant (NLCC 27), Nelson City Council has contracted Landcare Research Ltd (Garth Harmsworth, Palmerston North) and Tiakina Te Taiao Ltd (Dean Walker, Nelson) to develop and trial a suite of iwi estuarine indicators designed to improve articulation of Maori cultural values and foster increased iwi participation in the environmental management of coastal habitats. Delaware Inlet was chosen as one of several locations for trialling iwi monitoring based on these indicators and special effort was made to coordinate sites with those chosen for the present analyses of baseline scientific indicators. This was considered to increase the spatial coverage of estuary surveillance and enhance the interpretive value of ongoing monitoring of the parallel programmes in a synergistic manner. We recommend that this integrative approach be fostered as a model for improved management of coastal habitats in New Zealand.

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1. INTRODUCTION

1.1. Background

Through a Ministry for the Environment Sustainable Management Fund (SMF) grant, with support from 11 councils throughout New Zealand, Cawthron developed a standardised protocol for the assessment and monitoring of New Zealand estuaries (Robertson *et al*. 2002). The initial development of the estuary monitoring protocol (EMP) included baseline surveys of fine-scale benthic characteristics for representative sites in nine estuaries ranging from Northland to Southland. This provided a comparative database that councils could use to facilitate interpretation of State of Environment (SOE) and consent-related estuarine monitoring data. During the past seven years, a number of additional estuaries have been surveyed using the protocol and some have been (or are scheduled to be) resurveyed in order to monitor any changes in condition. This has significantly expanded the database and enhanced its value for evaluating estuary condition in a national context. To date, fine-scale characteristics have been assessed in two estuaries in Golden Bay; Ruataniwha and Motupipi, (Robertson *et al*. 2002; Robertson & Stevens 2008) and two estuaries in Tasman Bay; Moutere (Gillespie & Clark 2006) and Waimea, (Robertson *et al*. 2002; Gillespie *et al*. 2007) using the EMP.

Gillespie (2009a) provides a compilation of background and historical information required for preliminary assessment of the environmental status of Delaware Inlet. Evaluation of this information using a decision matrix scoring index indicated an estuarine environment of sufficiently high value to warrant implementation of ongoing environmental monitoring as a management tool. Cawthron Institute was commissioned by the Nelson City Council, through Envirolink NLCC19, to establish a baseline of benthic fine-scale characteristics for Delaware Inlet in order to progress a combined coastal SOE monitoring strategy for the Nelson Bays. To this end, a suite of indicators of estuary condition/health was assessed at three reference sites in accordance with the EMP methods. The results are provided here with brief interpretation as a basis for ongoing monitoring.

1.2. Study area

Delaware (or Wakapuaka) Inlet is a relatively small (336 ha) bar-built, fluvial erosion estuary situated on the eastern side of Tasman Bay approximately 19 km northeast of the city of Nelson (Figure 1). The estuary consists of a complex salt marsh at the mouth of the main tributary, the Wakapuaka River (average flow 1.5 m^3/s) and extensive intertidal flats over two major arms; a western arm on the Cable Bay side of Pepin Island and an eastern arm on the Delaware Bay side. Based on historical information, the preliminary assessment report (Gillespie 2009a) describes the Inlet as a ‘relatively pristine’, high-value estuary containing complex intertidal habitats of high biodiversity. Although the estuary and its catchment have been subjected to a variety of anthropogenic (human-induced) modifications during the past 160 years, these have not included industrial or municipal wastewater discharges or excessively high-nutrient catchment runoff. Thus the relatively natural functional qualities of the estuary, as described by Gillespie & MacKenzie (1981), are thought to have been largely preserved (Gillespie 2009a).

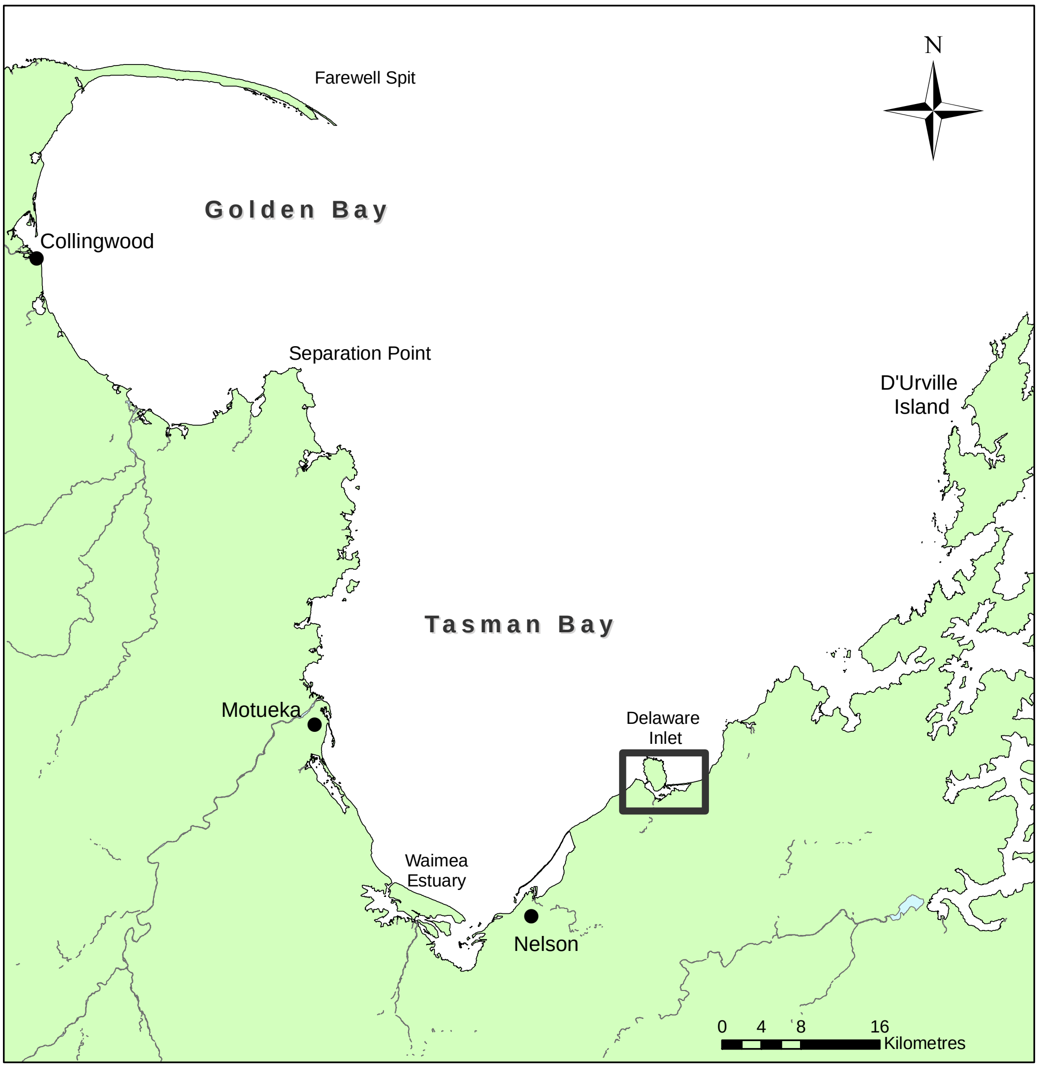

Figure 1. Delaware Inlet location in relation to Golden and Tasman Bays.

2. METHODS

2.1. Field sampling procedures

Three Delaware Inlet study locations (Figure 2) were selected from open, largely unvegetated tidal flats at approximate neap mid-low to low tide elevations. Site A was a centrally located (mudflat) habitat closest to freshwater (riverine) influences. This site was chosen to be representative of the depositional zones closer to terrestrial inputs, and because of the considerable historical information describing its condition (Gillespie 2009a and references therein). Site B was a sandflat habitat closest to the tidal outlet and therefore strongly influenced by tidal flushing. Site C was a sandflat habitat within the semi-enclosed western arm of the Inlet and therefore less subject to strong tidal flushing. Sites B and C were chosen to be representative of the dominant substrate type found in the Inlet overall (Stanton *et al.* 1977) and particularly in central regions of both arms.

Fine-scale sampling was carried out on 8 and 9 January 2009 according to procedures modified slightly from those of the estuary monitoring protocol described by Robertson *et al*. (2002). At each location, a 30 x 60 m area containing twelve 150 m^2 (10 x 15 m) grids was marked out to achieve 10 replicates per location (Figure 2).

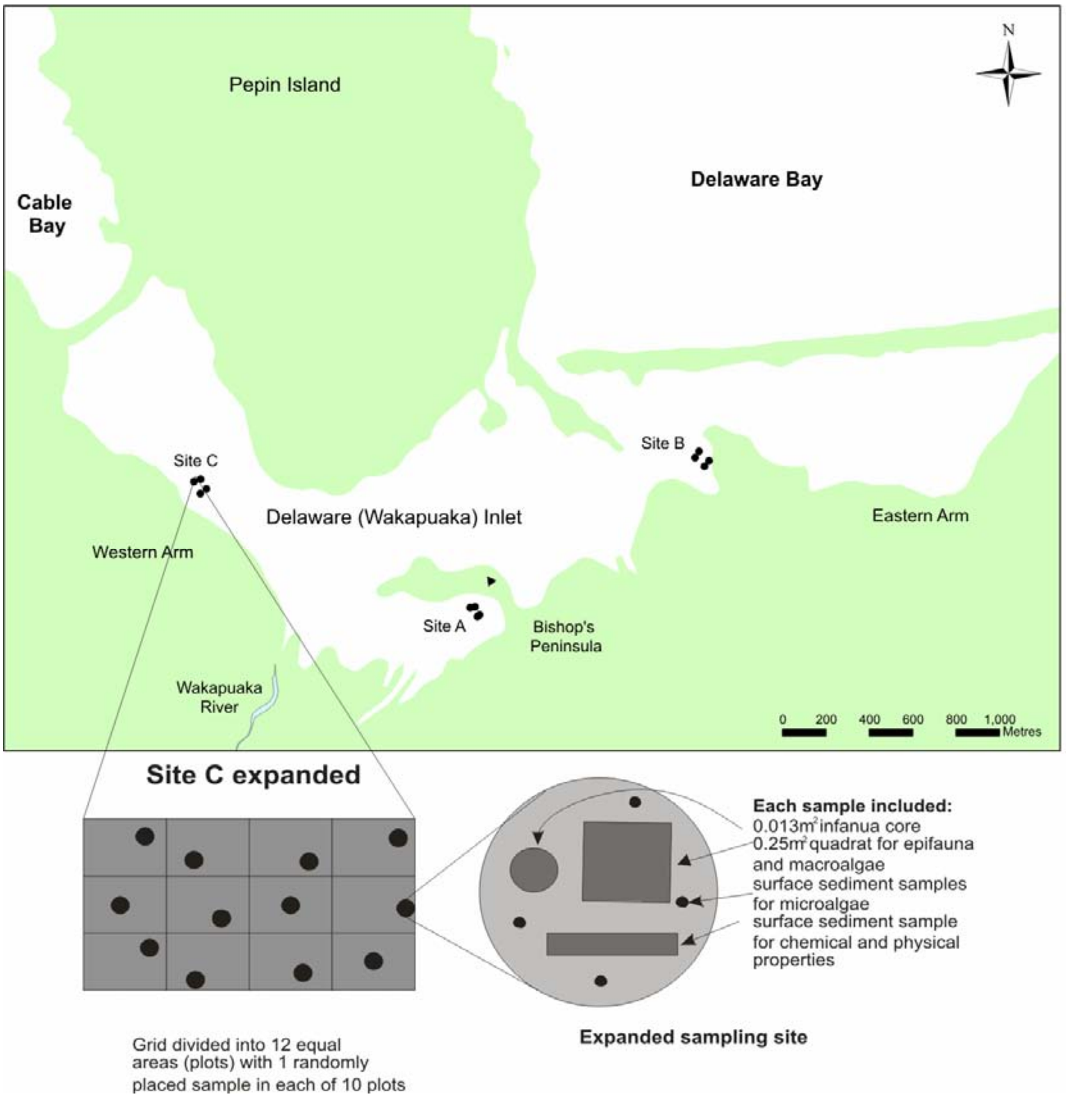

Figure 2. Map of Delaware Inlet showing locations of the study sites and the sampling strategy (modified from Robertson *et al*. 2002). GPS coordinates of corner points are listed in Appendix 1.

A 0.25 m^2 quadrat was placed randomly within each of 10 grid rectangles. The quadrats were photographed to provide a visual record and any obvious signs of pollution in the site location were noted. All remaining samples, except those for chlorophyll *a* (chl *a*), were collected adjacent to the quadrats (Figure 3).

Figure 3. The field team collecting fine-scale samples adjacent to epifauna quadrat within a site grid.

Cores for sediment profile descriptions were collected with 62 mm diameter Perspex tubes pushed to a depth of at least 150 mm into the seabed. These cores were extruded onto a white viewing tray along-side a ruler and photographed. Sediment colour profiles were described and the depth of any apparent redox discontinuity layer (RDL) was recorded.

Samples for physical and chemical analyses (Table 1) were scraped from the top 25 mm of sediment, returned to the laboratory and stored at either 4ºC or -20ºC until analysed. Three composite samples were prepared for analyses by mixing replicates 1-3, 4-6 and 7-9. The individual replicates were retained for later analyses in the event that high variability amongst composites was encountered.

Samples for chl *a* analyses were collected as a proxy for microalgal biomass in order to determine the potential for development of nuisance blooms. The top 5 mm of sediment was sliced from a 15 mm diameter syringe barrel core collected from three randomly selected positions within the site. Since microalgal densities are known to be inherently extremely variable, core positions were intentionally selected to sample regions of visible yellow/green colouration in order to estimate maximum chl *a* concentrations.

Any visible epibiota (plants and animals on the sediment surface) within the 0.25 m^2 quadrats were identified and counted. Also included in the epibiota descriptions were crab and polychaete burrows and any obvious microalgal mat development.

Animals buried within the sediment matrix (infauna) were collected by inserting a 130 mm diameter core to a depth of ~100 mm into the sediment. The core contents were gently washed through a 0.5 mm mesh sieve attached to one end of the core and the residual was preserved with 50% ethanol (in seawater) for later sorting, identification and counting. Five replicates (replicates 1, 3, 5, 7 and 9) were analysed initially while the remaining samples were retained for later analysis in the event that high within-site variability was encountered.

2.2. Sediment analyses

Sediments were analysed for a range of physical, chemical and biological indicators of estuary condition. Table 1 summarises the analytical methods used and their corresponding detection limits.

Table 1. Analytical methods and detection limits for sediment physical and chemical indicators.

Parameter	Method	Detection Limit
Grain Size	Wet sieving and calculation of dry weight percentage fractions	-
Ash Free Dry Weight	Dry sediment weight loss after combustion at 550°C (APHA 21st Edn, modified 2540D + E).	-
Total Nitrogen	APHA 21st Edn 4500N C	100 mg m $^{-3}$
Total Phosphorus	ICP-MS Aqua Regia Digest	20 mg kg $^{-1}$
Chlorophyll *a*	Limnology & Oceanography 1967 No 12	-
Metals:	Perchloric/nitric acid digestion and flame atomic absoption spectrometry	
Cadmium	US EPA 2002 mod/APHA metals by ICP_OES	0.1 mg kg $^{-1}$
Chromium	US EPA 2002 mod/APHA metals by ICP_OES	1.0 mg kg $^{-1}$
Copper	US EPA 2002 mod/APHA metals by ICP_OES	0.5 mg kg $^{-1}$
Nickel	US EPA 2002 mod/APHA metals by ICP_OES	2.0 mg kg $^{-1}$
Lead	US EPA 2002 mod/APHA metals by ICP_OES	0.5 mg kg $^{-1}$
Zinc	US EPA 2002 mod/APHA metals by ICP_OES	0.2 mg kg $^{-1}$

When results were below or equal to the analytical detection limit, site averages were calculated using ½ the detection limit, providing a conservative measure of potential sediment contamination. Standard deviations were only calculated where all data were above the analytical detection limit.

The ANZECC (2000) Sediment Quality Guidelines have been used to assess and interpret the contaminant status of the observed metals concentrations. These guidelines present Interim Sediment Quality Guideline-Low (ISQG-Low) and High (ISQG-High) as two threshold levels under which biological effects are predicted (ANZECC 2000). The lower threshold indicates a *possible* biological effect while the upper threshold (ISQG-High) indicates a *probable* biological effect. These trigger values are essentially conservative criteria for sediment quality that, if complied with, will ensure that specified environmental values are protected. Note, however, that the converse is not necessarily true (*i.e.* exceeding of trigger values does not necessarily suggest environmental damage) hence the intent of these values is to act as a trigger for more intensive assessment if they are not met.

2.3. Benthic biological community structure

Epibiota data were used only as a general descriptor of habitat type, while the more comprehensive infauna data were evaluated according to a variety of statistical descriptors of community structure (Table 2). The number of infauna taxa, their density, evenness and diversity were calculated for each site. The maximum value for the diversity index (H') is dependent on the number of categories or species sampled for a given data set. Values typically range between 0 (indicating low community complexity) and 4 (indicating high complexity). The evenness value (E) ranges from 0 (highly irregular distribution) to 1 (regular distribution).

Table 2. Descriptors of macro-invertebrate community characteristics.

Descriptor	Equation	Description
No. species (S)	Count (taxa)	Total number of species in a sample.
Density (N)	Sum (n)	Total number of individual organisms in a particular sample area.
Evenness (J')	$J' = H'/Log_e(S)$	Pielou's evenness. A measure of equitability, or how evenly the individuals are distributed among the different species. Values can theoretically range from 0.00 to 1.00, where a high value indicates an even distribution and a low value indicates an uneven distribution or dominance by a few taxa.
Diversity (H' log_e)	$H' = -SUM(Pi*log_e(Pi))$	Shannon-Wiener diversity index (log_e base). A diversity index that describes, in a single number, the different types and amounts of animals present in a collection. Varies with both the number of species and the relative distribution of individual organisms among the species. The index ranges from 0 for communities containing a single species to high values (4.6) for communities containing many species and each with a small number of individuals.

3. RESULTS AND DISCUSSION

3.1. General signs of pollution

General visual characteristics of the sediment habitats are shown in Appendix 2. No obvious signs of pollution *e.g.* odours, visible scums from fats/oils or unnatural debris, were noted at the study locations.

3.2. Sediment characteristics

The physical and chemical properties of the three Delaware Inlet sites (Appendix 3) are summarised and compared with previously reported values for Delaware Inlet and other New Zealand estuarine sites in Table 3. Salinity values of sediment interstitial waters at Sites A, B and C were 33.3, 38.6 and 31.2 respectively, indicating little freshwater influence and/or some evaporation effect.

3.2.1. Particle grain size

Particle grain size analyses (Table 3) confirm that sediments from Site A were dominated by mud (73% silt/clay, 26% sand). Sites B and C were sand-dominated (96% and 80% sand, respectively).

3.2.2. Core profiles

No black anoxic zones or hydrogen sulphide (H_2S) odours were noted within the cores at any of the sites, however a gradation of colouration from light grey at the surface to darker grey, often referred to as a redox discontinuity layer (RDL), was observed at Sites A and C (Figure 4 and Appendix 4). These darker zones represent discrete 4-6 cm reduced oxygen layers with lighter colouration, indicating higher oxygen concentrations, above and below. Such reduced oxygen layers were visible within Sites A and C between about 1.5-5 cm and 2-8 cm below the sediment surface, respectively. These observations indicate slight to moderate enrichment that would be typical for relatively productive estuaries in the Nelson region. Under highly enriched conditions, a black anoxic layer would be expected to occur at or very near the surface of the sediment and the objectionable “rotten egg” odour of hydrogen sulphide would be evident. In the case of Site B, no gradation of colouration was observed, probably because the higher sand content enabled more efficient tidal flushing and oxygenation of the core sediment profile.

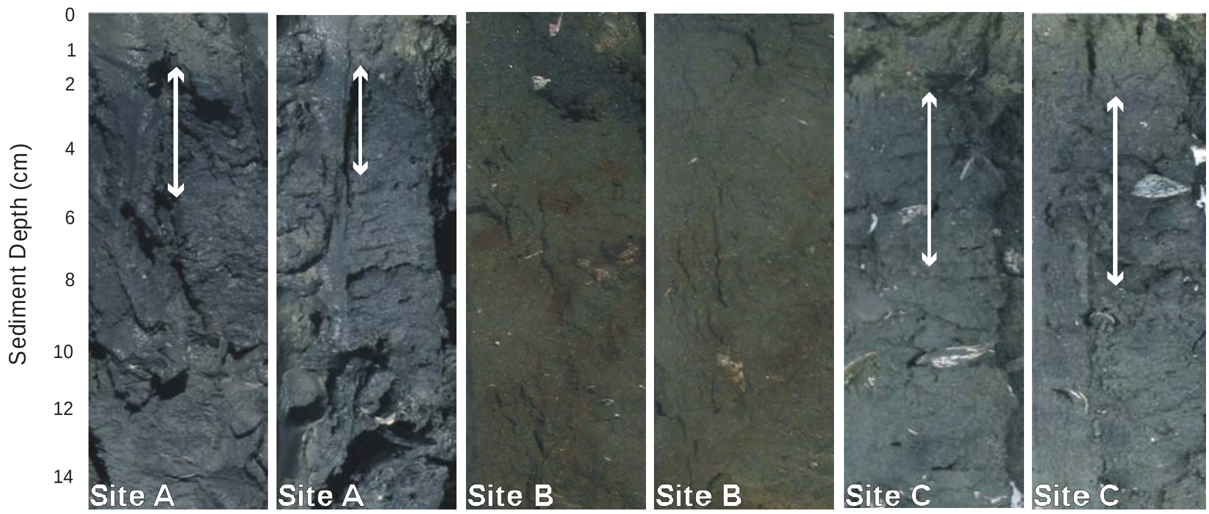

Figure 4. Representative core profiles demonstrating the gradation between zones of oxygenated (*i.e.* light grey and brown mottled) and lower oxygen (*i.e.* darker grey) sediments as indicated by the arrows.

3.2.3. Nutrient and organic composition

Sediment total nitrogen (TN), total phosphorus (TP) and organic content (AFDW) are indicators of organic nutrient enrichment that are often closely linked with sediment grain size characteristics. In general terms, higher nutrient and organic concentrations are usually associated with muddier substrata. Thus the higher AFDW and TN contents observed at Site A were not unexpected, however it is somewhat unusual that TP concentrations were not also higher at Site A, compared to the sand-dominated sites (Table 3). Sediment TP concentrations were, in fact, similar and slightly elevated at all three sites resulting in unusually low TN:TP molar ratios, particularly at the sandy sites of the eastern and western arms. Such ratios indicate that nitrogen was relatively more limiting for plant (macro- and micro-algal) production than phosphorus. These results may be due to a history of aerial top dressing of surrounding agricultural lands (Gillespie 2009a and references therein). They suggest that the estuary may be particularly sensitive to any future high-nitrogen runoff (*e.g*. from applications of nitrogen fertilisers or a conversion of catchment land use leading to nitrogen-rich wastewater discharge).

A comparison of the observed sediment nutrient concentrations with previously reported values for Delaware Inlet sites of similar textures sampled in 1981 (Table 3) suggests that the enrichment status had not increased over this 28-year interval. Further comparisons with sites in other New Zealand estuaries (including slight to moderately enriched sites and one highly enriched site) indicate that the three Delaware study sites were within a range typical for relatively undisturbed to slightly enriched or productive estuarine conditions.

Table 3. Comparison of average particle size and nutrient characteristics of sediments sampled during the present survey with previously reported values for the same estuary and some other New Zealand estuaries. Mud-dominated sites are shaded.

Location	Sand	Mud	TN	TP	TN:TP	AFDW	Condition/Health
	%	%	mg kg^{-1}	mg kg^{-1}	Molar	%	
Delaware Inlet (present study)							
Site A	26.1	73.3	823.3	587	3.1	3.4	-
Site B	96.0	3.9	250.0	543	1.0	2.1	-
Site C	80.3	18.9	313.3	573	1.2	2.3	-
Delaware Inlet (sampled 1981)							
Sand dominated sites[a]		7.4	304	539	1.2	2.3	-
Mud-dominated sites[b]		73	1260	716	3.9	5.9	-
Other NZ estuaries							
Moutere (sites A, B)[c]	88	12	339	530	1.4	1.6	slight to moderately enriched
Orowaiti (sites A, B)[d]	42	53	529	938	1.9	3.2	slight to moderately enriched
Kaipara (Otamatea Arm sites A, B)[e]	27.2	67.7	1850	503	8.1	6.3	moderately enriched
Ohiwa (sites B, D)[f]	87	11	524	248	4.7	1.7	slight to moderately enriched
Ruataniwha (sites A,B,C)[f]	86	9	263	458	1.3	1.2	slightly enriched
Waimea (sites B,C)[f]	87	13	304	377	1.8	1.0	slight to moderately enriched
Havelock (sites A,B)[f]	77	19	422	330	2.8	1.6	slight to moderately enriched
Avon-Heathcote (sites A, B, C)[f]	94	5	301	327	2.0	1.8	moderately enriched
Waimea (highly enriched site)[g]		82.5	4340	1063	8.9	9.1	highly enriched

a Mean of five sand-dominated sites sampled 1981 (Gillespie & MacKenzie 1990).
b Mean of five mud-dominated sites sampled 1981 (Gillespie & MacKenzie 1990).
c Slightly modified estuary near Motueka, affected by food processing industry wastes and urban runoff (Gillespie & Clark 2006).
d Slightly modified estuary near Westport (Gillespie & Clark 2007).
e Subset of mud-dominated sites from an inter-estuary comparison, 2001 (Robertson *et al*. 2002).
f Subset of sand-dominated sites from an inter-estuary comparison, 2001 (Robertson *et al*. 2002).
g Mudflat affected by a freezing works effluent, 1981 (Gillespie & MacKenzie 1990).

3.2.4. Microalgae

Microalgae, which colonise the entire benthic surface area of a tidal inlet, are the major primary producers over large areas of sand and mud flats (Gillespie 1983). They consist primarily of diatoms but in some instances may include a variety of other microalgal groups. Microalgal production rates per square metre in the Inlet, although reported to be generally low (Gillespie & MacKenzie 1981), were considered to provide a significant beneficial contribution to the coastal food web due to the large area that they occupy. Under conditions of excessive enrichment however prominent green to olive coloured mats may develop to a level that can result in a degradation of estuarine health/condition.

No potentially problematic microalgal growths were noted during the baseline field assessment. Although a patchy, olive-green film was visible on the sediment surface at Site B, this was assumed to be indicative of a naturally productive sandflat habitat rather than nutrient runoff from the surrounding agricultural land use. Average chl *a* concentrations (a proxy for microalgal biomass) at Sites A, B and C (3.6±1.2, 5.3±3.4 and 2.5±0.3 µg g^{-1}, respectively) were consistent with those reported for productive sand and mudflat habitats in other New Zealand estuaries (Robertson *et al*. 2002). The sediments of Site A were colonised by a diverse mixture of mainly diatom species that are typical of the mudflat habitat. These included species of the genera *Amphiprora, Navicula, Nitzschia, Paralia, Pleurosigma and Thalassiosira* and an unidentified diatom. Site B was colonised by a characteristic association, shown in Figure 5, of highly motile euglenoids and the filamentous cyanobacter (*Oscillatoria* sp.), along with the more typical diatoms and another cyanobacter (*Merismopedia* sp.) that was less frequently seen. Site C contained fewer species of diatoms along with dinoflagellates of the genus *Gymnodinium*. All three sites contained small (<5 µm) unidentified unicells.

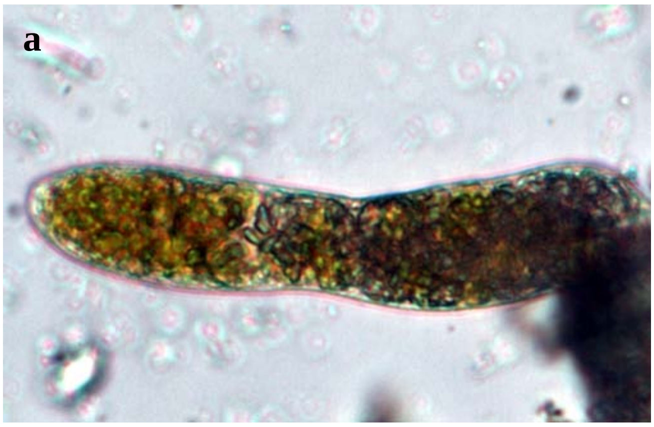

Figure 5. Photo-micrographs taken at 400x magnification of (a) a motile euglenoid (length ~75 µm) and (b) a filamentous cyanobacter (width ~7.5 µm) from Site B sediments.

3.2.5. Metals

All three Delaware Inlet sites showed acceptably low levels of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn), compared to ANZECC (2000) ISQG trigger values and other New Zealand estuaries and overseas estuaries that had been contaminated to varying degrees (Table 4). However Ni and Cr concentrations were slightly elevated compared to some of the sites included in the table. Elevated sediment Ni and Cr concentrations have been reported for other coastal and estuarine locations in the Nelson/Marlborough region (*i.e.* Waimea Inlet, Havelock Estuary, Moutere Inlet and Nelson Haven) and linked to natural catchment geological characteristics (Robertson *et al.* 2002; Gillespie & Asher 2004; Gillespie & Clark 2006; Gillespie 2009b). The slightly elevated Ni and Cr levels found in Delaware sediments indicate that the upper Wakapuaka catchment does not receive significant erosion input from the mineral belt formations that contribute to elevated metals concentrations of nearby estuaries.

Table 4. Concentrations of heavy metals in sediments from Delaware Inlet and a selection of New Zealand and overseas estuaries that have been contaminated to varying degrees. Some values drawn from other studies are approximate as they were estimated from figures.

		Cd $mg\ kg^{-1}$	**Cr** $mg\ kg^{-1}$	**Cu** $mg\ kg^{-1}$	**Pb** $mg\ kg^{-1}$	**Ni** $mg\ kg^{-1}$	**Zn** $mg\ kg^{-1}$
	ANZECC (2000) ISQG-Low	*1.5*	*80*	*65*	*50*	*21*	*200*
	ANZECC (2000) ISQG-High	*10*	*370*	*270*	*220*	*52*	*410*
Delaware Inlet 2009	**Site A**	0.05	45.3	14.3	5.3	20.0	41.0
	Site B	0.05	40.0	8.9	2.6	15.0	38.3
	Site C	0.05	43.3	9.7	3.4	16.3	56.7
EMP study [a]	Otamatea Arm	0.4	20.5	13.8	11.4	9.4	54.5
	Ohiwa	0.1	7.4	4.0	3.4	3.9	27.7
	Ruataniwha	0.1	24.0	7.1	4.7	13.7	37.5
	Waimea	0.3	67.6	9.6	7.4	72.5	41.8
	Havelock	0.3	48.8	10.7	5.6	26.5	43.0
	Avon-Heathcote	0.1	15.6	3.2	6.3	6.6	38.3
	Kaikorai	0.1	48.4	16.8	45.3	15.6	184.2
	New River	0.1	11.1	3.8	0.7	5	17.1
Other NZ sites	Tamaki A (E1) [b]		14.5	27.8	132.1	56.9	136.1
	Tamaki B (E2) [b]		20.6	26.1	72.9	6.6	167
	Tamaki C (E3) [b]		17.3	29.4	69.7	9.3	173
	Tamaki D (E4) [b]		35.9	38.5	145.2	12.8	233
	Manukau (rural catch) [c]	0.03		20	9	15	114
	Manukau (industrial catch) [c]	0.25		90	58	14	285
	Waitemata Harbour [d]	<0.5	52	60	65	28	161
	Lampton Harbour, Wellington [e]		91	68	183	21	249
	Poriora Harbour, Wellington [e]		20	48	93	20	259
	Aparima Estuary [f]	0.067	15	12	11	10	49
	Mataura Estuary [f]	0.024	7.1	6.6	6.2	6	27
Overseas sites	Delaware Bay, USA [h]	0.24	27.8	8.3	15		49.7
	Lower Chesapeake Bay, USA [h]	0.38	58.5	11.3	15.7		66.2
	San Diego Harbour, USA [h]	0.99	178	218.7	51		327.7
	Salem Harbour, USA [h]	5.87	2296.7	95.1	186.3		238
	Rio Tinto Estuary, Spain [g]	4.1		1400	1600		3100
	Restronguet Estuary, UK [g]	12	1060	4500	1620		3000
	Nervión Estuary, Spain [i]	0.2-15	50-300	50-350	50-400	20-100	200-2000
	Sorfjord, Norway [h]	850		12000	30500		118000

Sources: a Robertson *et al.* (2002), b Thompson (1987), c Roper *et al.* (1988), d Glasby *et* al. (1988), e Stoffers *et al.* (1986), f Glasby *et al.* (1990), g Robertson (1995), h Kennish (1997),i Jezus Belzunce *et al.* (2001).

3.3. Benthic plant and animal communities

3.3.1. *Epibiota*

A total of six epifaunal taxa were present amongst the three sites (Table 5). The surface living animals were dominated by a variety of gastropods (snails, *e.g*. Figure 6) as well as tube worms (polychaetes) and burrowing crabs. The predominately sand site (Site B) had a much lower abundance of epifauna (similar to infauna results) while the other sites had a variety of species that reflects a pattern commonly found in sand and mud habitats of other New Zealand estuaries (Robertson *et al*. 2002). The relative impoverishment of the animal community at Site B was thought to be a natural condition due to exposure to strong tidal flows. This was evidenced by the rippled mobile sand habitat as seen in the quadrat photographs (Appendix 2). Such habitats can be dominated by photosynthetic production rather than animal production. Through tidal harvesting and translocation of the rapidly growing epibenthic microalgae, they function as sources of nourishment for animals living in peripheral mudflat and salt marsh habitats (Gillespie & MacKenzie 1981).

Table 5. Epifaunal species and average abundance per quadrat (0.25 m^2) in Delaware Inlet sites. Quadrat photographs are shown in Appendix 2.

Taxon	Common Name	Feeding Type	*SiteA*	*SiteB*	*SiteC*
POLYCHAETA	Worm tubes	Surface deposit feeder	0	0	40.4
DECAPODA	Mud crab holes	Deposit feeder & scavenger	24.7	1.2	0.4
GASTROPODA					
Amphibola crenata	Mud snail	Microalgal grazer	5.5	0	0
Zeacumantus subcarinata	Small spire shell	Microalgal & detrital grazer	0.2	0	2.8
Diloma surostrata	Mudflat topshell	Microalgal & detrital grazer	0.3	0.1	0.7
Cominella glandiformis	Mudflat whelk	Carnivore and scavenger	2.4	0.1	0.2
		Total	30.9	1.4	44.5

Figure 6. An example of the gastropod *Zeacumantus subcarinata*, one of the more abundant epifauna species found at Delaware Inlet sites.

Macroalgae were rare at the sites surveyed. Two species, *Gracilaria* sp. and *Ulva* sp. were observed in very small amounts. However, macroalgal production and coverage can vary considerably both spatially and temporally. The species observed and some others occurring within the Inlet, notably *Enteromorpha* spp., (recently reclassified under the genus *Ulva*) may have the potential to reach nuisance proportions. This nuisance potential could not adequately be assessed through the one point-in-time survey reported here.

3.3.2. Infauna

The composition of animals living within the sediment matrix of the Delaware Inlet sites (Table 6) was fairly typical of comparable relatively unmodified habitats in other New Zealand estuaries. They were characterised by polychaetes and bivalves (Robertson *et al*. 2002 and Figure 7). Also common were gastropods (snails), amphipods (small crustaceans) and oligochaetes (segmented worms).

Table 6. Summary of the top 15 most abundant infaunal species from the three sampling sites in Delaware Inlet. Data are presented as average abundance per core (0.0133 m^2).

Taxon	Common Name	Feeding Type	Abundance		
			SiteA	*SiteB*	*SiteC*
POLYCHAETA:					
Paraonidae		Infaunal deposit feeder	1.2	0	40.8
Prionospio sp.		Surface deposit feeder	6	0	15.2
Maldanidae	Bamboo Worms	Infaunal deposit feeder		0	4.2
Polydora sp.		Surface deposit & filter feeder	2	0	0
Nereidae	Rag worms	Omnivore	0.8	0	1
OLIGOCHAETA	Oligochaete worms	Infaunal deposit feeder	9.2	0	0
BIVALVIA					
Austrovenus stutchburyi (0-5mm)	Cockle (0-5mm)	Infaunal suspension feeder	0	1	1.4
A. stutchburyi (06-10mm)	Cockle (6-10mm)	"	1.4	0	4.6
A. stutchburyi (11-20mm)	Cockle (11-20mm)	"	1.6	0	1
Macomona liliana	Wedge shell (Hanikura)	Infaunal suspension feeder	0.2	0	4
Arthritica bifurca	Small bivalve	Infaunal suspension feeder	3.2	0	0.2
Paphies australis	Pipi	Infaunal suspension feeder	0.2	1.8	0.2
AMPHIPODA					
Amphipoda A	Amphipods	Epifaunal scavenger	0.8	0	0.4
Amphipoda B	Amphipods	Epifaunal scavenger	0.4	1	2.6
GASTROPODA					
Cominella glandiformis	Mud Flat Whelk	Carnivore & scavenger	0.2	0	0.6

Figure 7. Two of the more abundant infauna species found at Delaware Inlet sites (a) polychaete - *Prionospio* sp. and (b) bivalve - *Austrovenus stutchburyi*.

Thirty-seven different animal taxa, including both infauna and epifauna, were recorded amongst the three Delaware Inlet sites. This represents a relatively rich community in total and is similar to those estuaries studied by Robertson *et al.* (2002), which ranged from 13 to 53 taxa (average 37) per site. Although some species of opportunistic polychaetes were present that can indicate enriched conditions (*e.g. Prionospio* sp.,Figure 7), their abundance was not unusually high. A full list of the taxa observed in the Delaware samples is provided in Appendix 5.

Species richness and density indices were high at two of the three sites (Figure 8) however the general lack of infauna present within Site B, was unexpected. This was most likely due to the high mobility of the fine-textured sands when exposed to strong tidal flows (see Section 3.3.1). There is no indication that the relatively impoverished community at Site B was due to other than natural factors. Despite these differences, species Evenness values were reasonably high at all sites (range ~0.7-0.9), indicating that the no single species dominated a particular habitat. The Shannon-Weiner diversity scores of Sites A and C were 1.7 and 2.1, respectively, indicating a moderate spread of individuals amongst the different taxa found. Site B had a lower diversity index (0.9) which is consistent with the harsh conditions of the mobile sand environment which can restrict infauna colonisation.

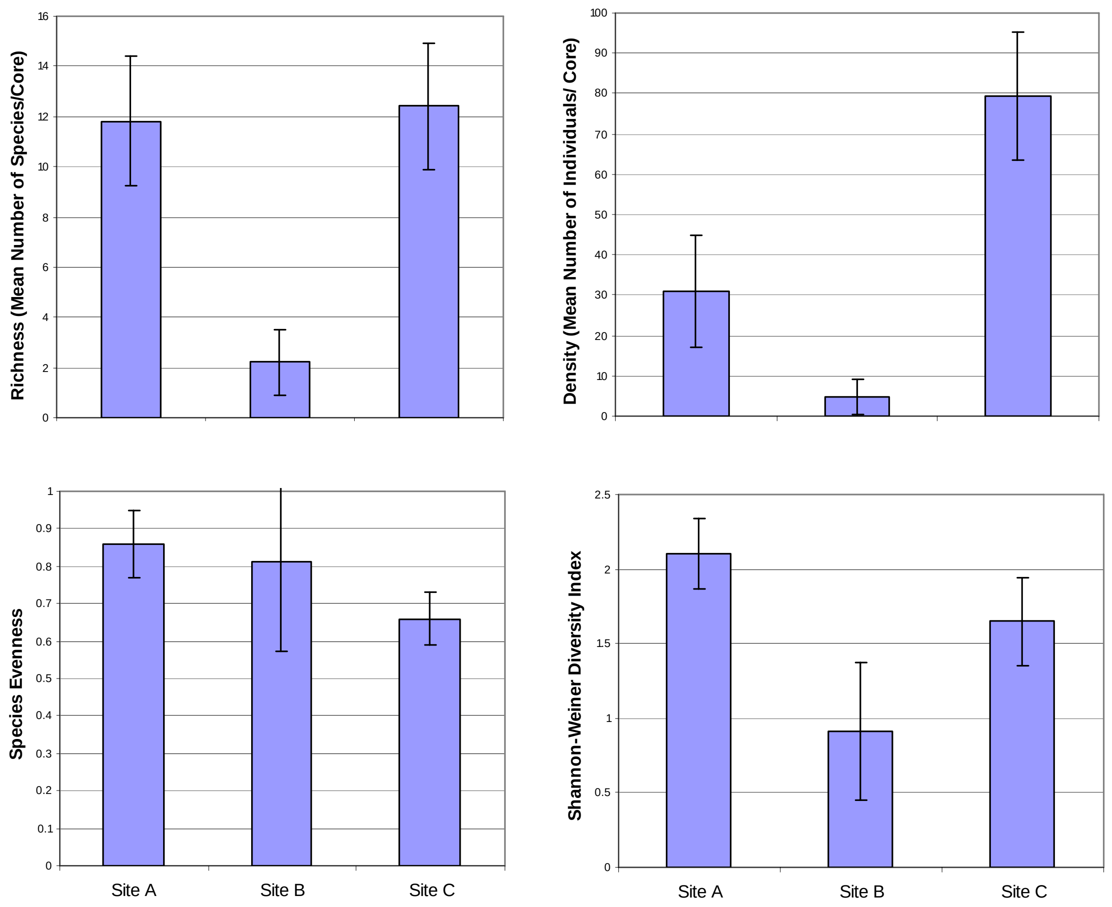

Figure 8 The average infauna species richness, density, evenness and diversity at each site in Delaware Inlet. Data are mean values ± standard deviation.

Further analyses of the macroinvertebrate community structure (*e.g.* univariate and multivariate assessments of community characteristics) were not undertaken but can be addressed in conjunction with subsequent monitoring surveys as a means of detecting change.

4. SUMMARY

Based on a comparison of the EMP suite of fine-scale environmental indicators with other New Zealand and overseas estuaries, the three Delaware Inlet study locations were found to be in relatively pristine functional condition. Comparison of nutrient results for the study locations with historical data for a range of sites in the same estuary suggested that their enrichment status had not increased over a 28-year period. The dataset provided in this report can be used as a benchmark for comparison with future repeat assessments to form a component of an integrated Nelson Bays estuary monitoring programme. The results are reported here with brief interpretation to provide a point-in-time (January 2009) description of habitat condition that can be used as a baseline for monitoring change over time.

Key findings of the baseline assessment are as follows:

- No obvious signs of pollution *e.g.* odours, visible scums from fats/oils or unnatural debris, were noted.
- Core profiles showed no signs of excessive oxygen depletion (*e.g*. black anoxic zones or sulphide odours), and were typical of other productive estuarine sites that are in a relatively healthy condition.
- No nuisance-level microalgal mat development or excessive macroalgal coverage was observed at the time of the survey.
- Nutrient and organic contents of the sediments were not unusually elevated although TP concentrations were near the high end of the range, suggesting that super phosphate fertilisers may have been previously applied to parts of the catchment. Low TN:TP atomic ratios suggest that nitrogen was the more limiting plant nutrient. Thus symptoms of over-enrichment would not be expected to result from elevated phosphorous levels, alone, although future nitrogen inflows could carry an added eutrophication risk.
- Sediment cadmium, chromium, copper, lead, nickel and zinc concentrations were all well below various guideline levels that are often used to indicate potential biological effects. Nickel and chromium concentrations however were slightly elevated compared to some other estuaries, probably due to natural catchment sources.
- Animal communities were fairly typical of those observed at sites of similar sediment particle size distribution in a variety of other New Zealand estuaries, however, both infauna and epifauna communities at the predominantly sandy Site B (eastern arm) had relatively low diversity and abundance. Animal communities at Site B were assumed to have been naturally limited by the exposure of the site to wave and tide disturbances.

5. RECOMMENDATIONS

Fine-scale physical, chemical and biological assessment of benthic intertidal habitats is one of two EMP components required to adequately evaluate the functional condition of an estuary (Robertson *et al*. 2002). We would suggest that Council also consider inclusion of GIS-based, broad-scale mapping of intertidal and peripheral shoreline habitats of Delaware Inlet as a second component. Broad-scale mapping with detailed ground-truthing would provide spatial context for fine-scale monitoring results and enable a more encompassing evaluation of change over time. Of particular importance with regard to Delaware Inlet, would be determination of the area coverage and rate of expansion of the invasive Pacific oyster that represents a threat to the natural character and function of the estuary environment (Gillespie 2009a).

We recognise that one limitation of the EMP, as employed here, is the often prohibitive cost of assessing more than a few representative sites within any one estuary. Because of this, localised areas of environmental degradation can remain undetected and, if environmental deterioration is detected, it can be difficult to develop cause and effect relationships. We therefore also recognise the potential two-way benefit (and additional insight) that could be gained by coordinating the EMP with community and/or iwi monitoring initiatives wherever possible. Through a separate Envirolink grant (NLCC 27), Nelson City Council is presently facilitating development and implementation of a suite of iwi estuarine indicators designed to improve articulation of Maori cultural values and foster increased iwi participation in the environmental management of coastal habitats. Delaware Inlet was chosen as one of several case study regions for trialling iwi monitoring. Integration of sites and cross-referencing of the results of parallel scientific and cultural monitoring programmes within Delaware Inlet (and elsewhere) would increase the spatial coverage in a synergistic manner increasing the interpretive value of both. We therefore recommend that this integrative approach be further developed and implemented as a model for improved management of coastal habitats in New Zealand.

6. ACKNOWLEDGEMENTS

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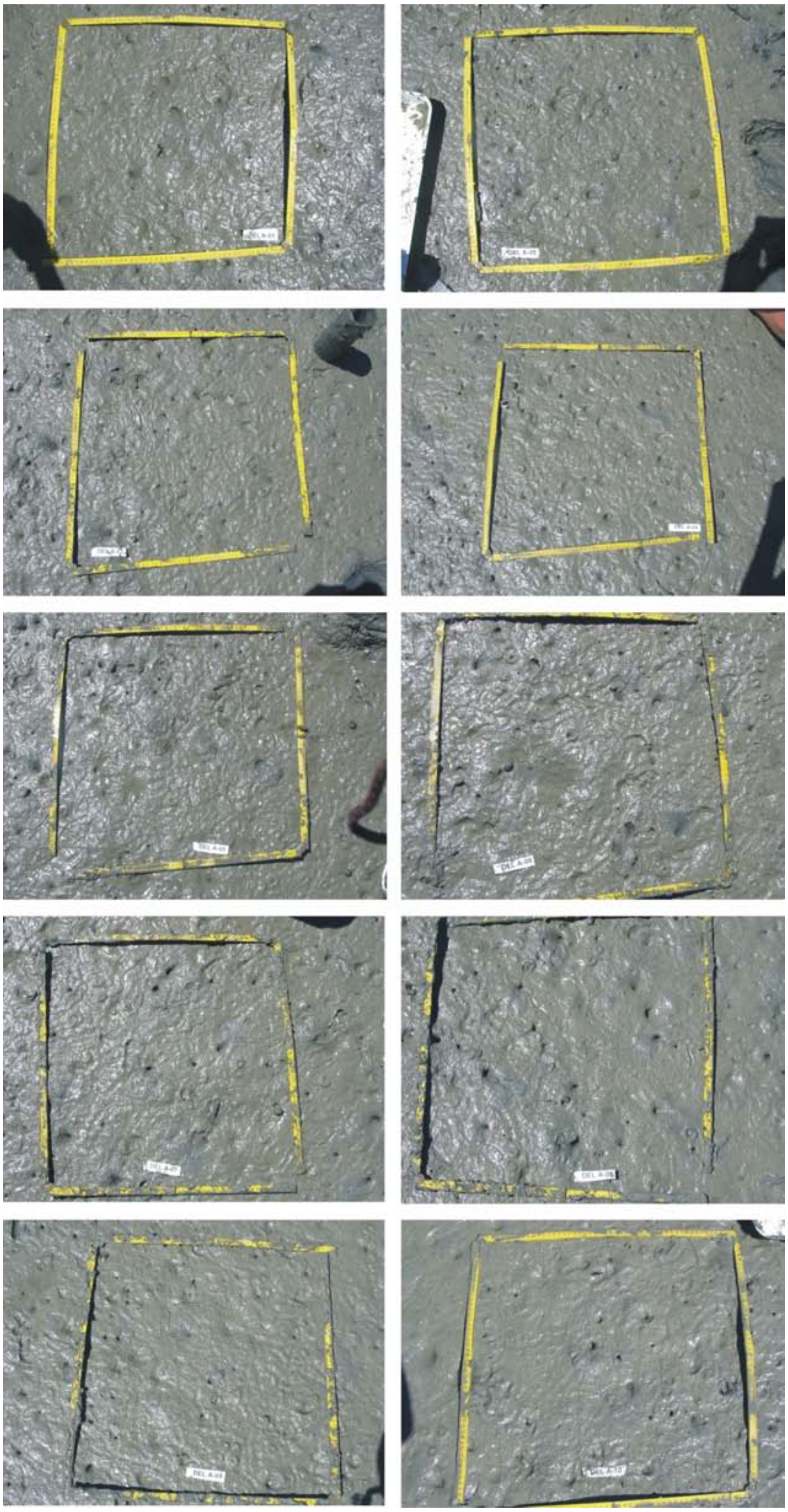
8. APPENDICES

Appendix 1. Coordinates (New Zealand Map Grid) of the four corners of Delaware Inlet sampling locations

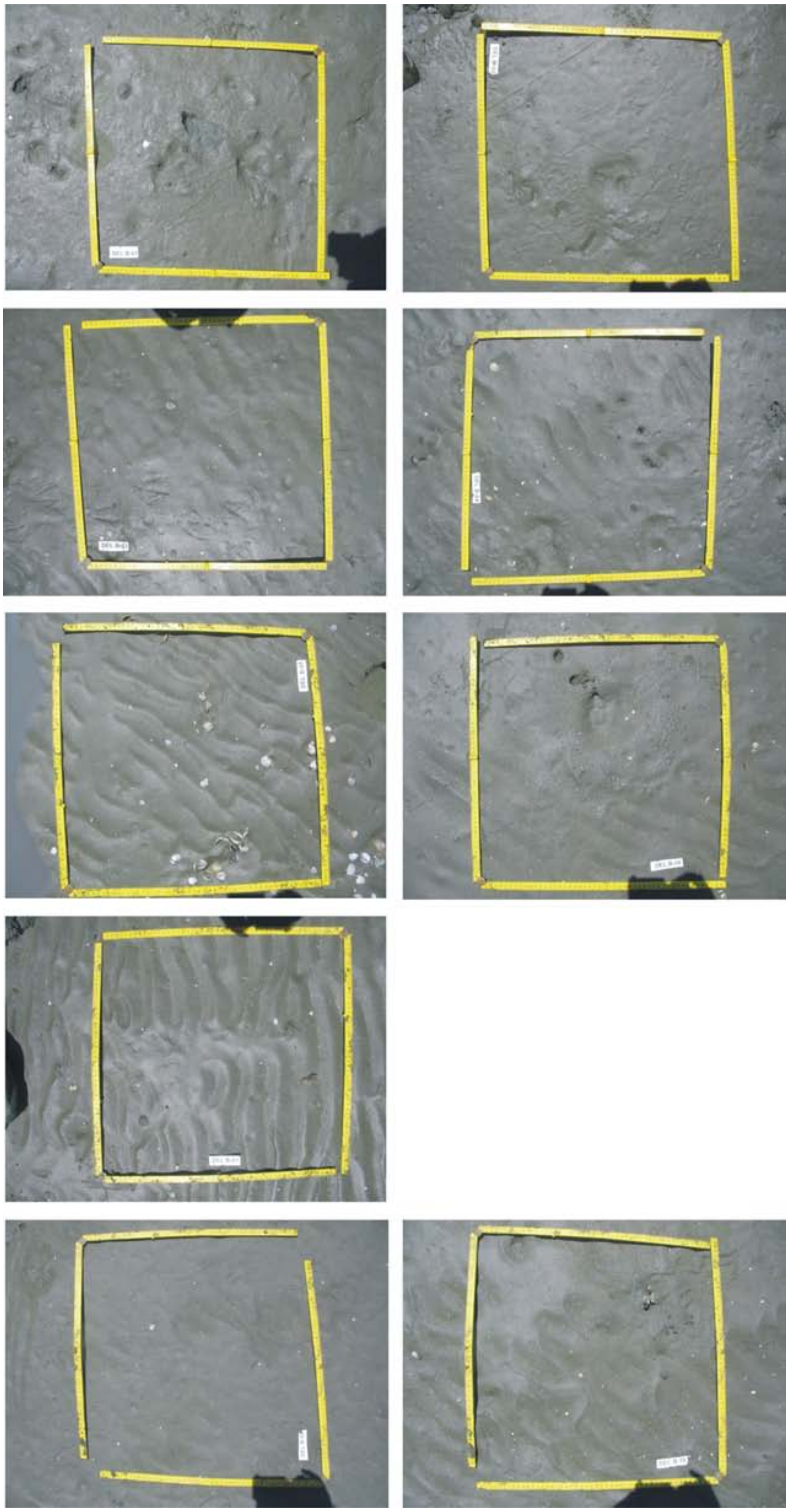
LOCATION	NZMG-E (m)	NZMG-N (m)
A	2546648.410	6003803.640
	2546627.618	6003840.760
	2546604.294	6003837.792
	2546639.056	6003797.517
B	2547707.960	6004517.011
	2547661.561	6004560.436
	2547642.770	6004532.770
	2547686.854	6004492.442
C	2545387.893	6004386.671
	2545360.144	6004433.075
	2545329.781	6004420.883
	2545359.817	6004365.213

Appendix 2. Quadrat photographs for Delaware Inlet Site A (near Bishop's Peninsula)

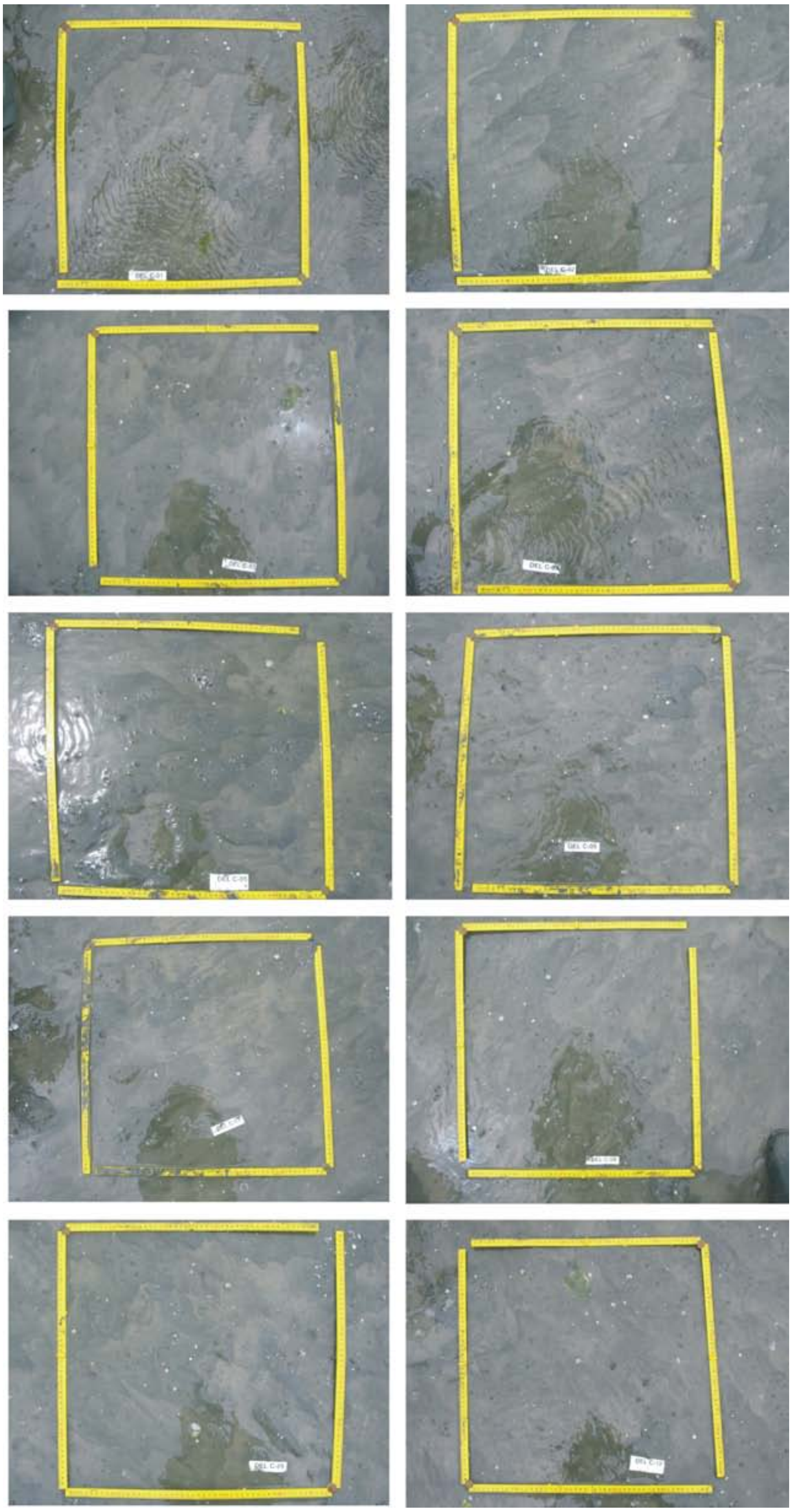


Appendix 2 (cont.). Quadrat photographs for Delaware Inlet Site B (eastern arm)

Note that the photograph of quadrat #8 was fuzzy and thus not included.



Appendix 2 (cont.). Quadrat photographs for Delaware Inlet Site C (western, Cable Bay, arm)



Appendix 3. Physical and chemical properties of sediments from Delaware Inlet

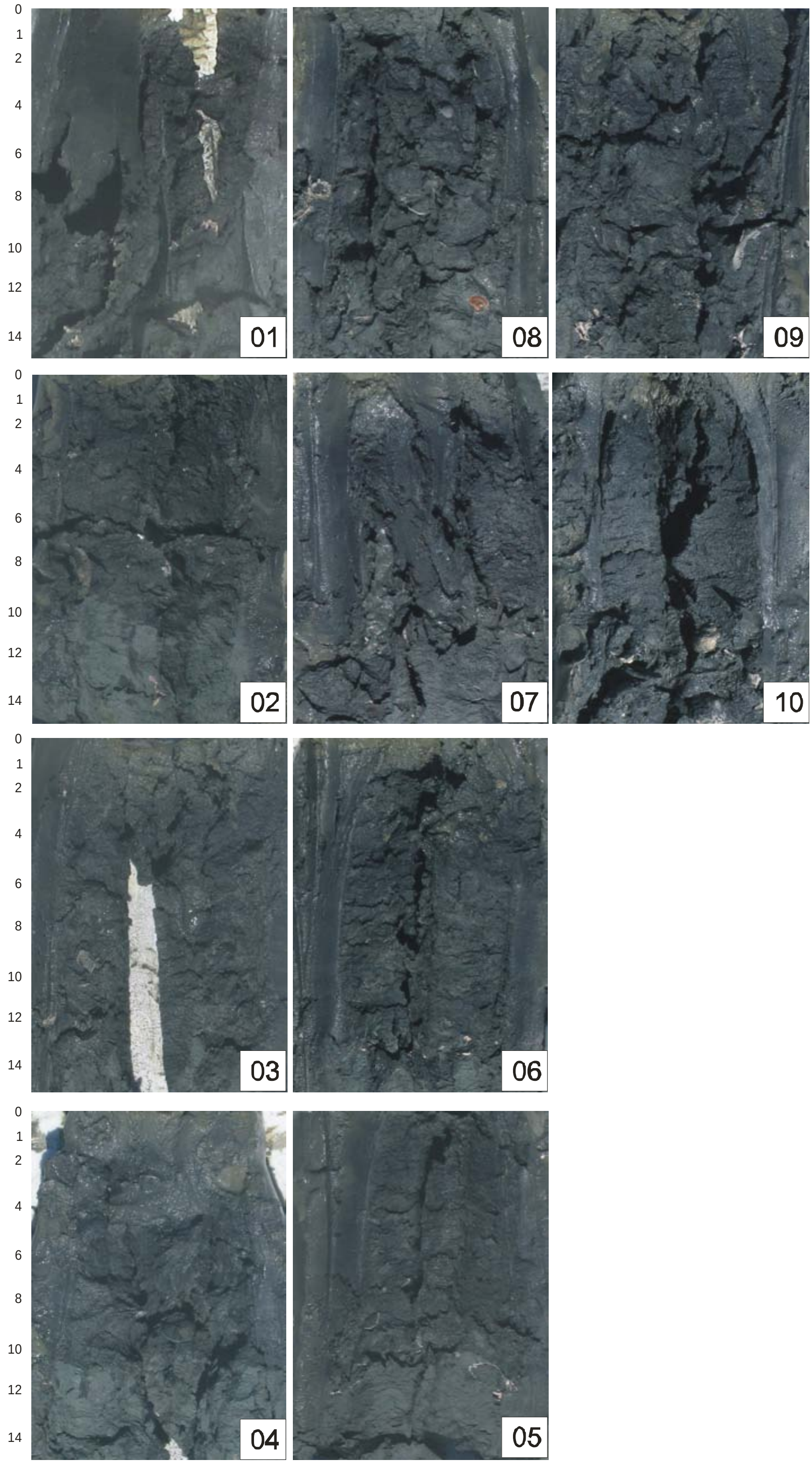
Site-replicate	Gravel	Sands	Silt&Clay	AFDW	Chl a	TN	TP	Cd	Cr	Cu	Ni	Pb	Zn
	(>2mm)	(<2mm & >63µm)	(<63µm)	% w/w	ug/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
A-01	0.2	28.6	71.1	2.6	2300	790	600	<0.1	47	14	21	5.5	42
A-02	1.1	25.8	73.1	4.3	4600	850	630	<0.1	46	15	20	5.5	39
A-03	0.4	23.8	75.7	3.4	4000	830	530	<0.1	43	14	19	4.9	42
Average	0.6	26.1	73.3	3.4	3633.3	823.3	586.7	0.05	45.3	14.3	20.0	5.3	41.0
SD	0.5	2.4	2.3	0.9	1193.0	30.6	51.3	0.0	2.1	0.6	1.0	0.3	1.7
Min	0.2	23.8	71.1	2.6	2300	790	530	0	43	14	19	4.9	39
Max	1.1	28.6	75.7	4.3	4600	850	630	<0.1	47	15	21	5.5	42

Site-replicate	Gravel	Sands	Silt&Clay	AFDW	Chl a	TN	TP	Cd	Cr	Cu	Ni	Pb	Zn
	(>2mm)	(<2mm & >63µm)	(<63µm)	% w/w	ug/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
B-01	0.1	94	6	1.9	2300	270	540	<0.1	40	8.9	15	2.6	41
B-02	0.1	97.5	2.4	2.2	9000	230	550	<0.1	40	8.8	15	2.6	39
B-03	0.1	96.5	3.4	2.3	4600	250	540	<0.1	40	9	15	2.7	35
Average	0.1	96.0	3.9	2.1	5300.0	250.0	543.3	0.05	40.0	8.9	15.0	2.6	38.3
SD	0.0	1.8	1.9	0.2	3404.4	20.0	5.8	0.0	0.0	0.1	0.0	0.1	3.1
Min	0.1	94	2.4	1.9	2300	230	540	0	40	8.8	15	2.6	35
Max	0.1	97.5	6	2.3	9000	270	550	<0.1	40	9	15	2.7	41

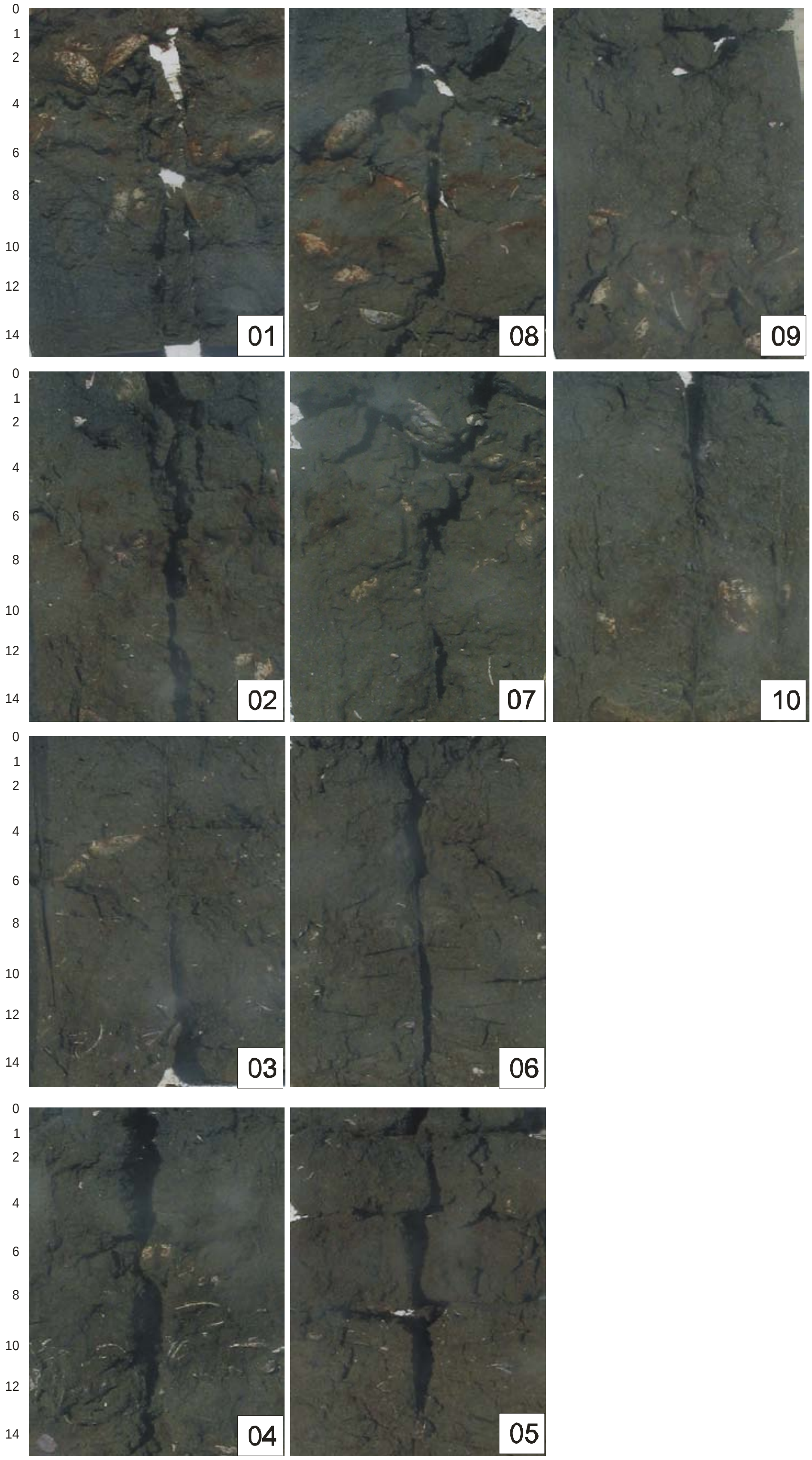
Site-replicate	Gravel	Sands	Silt&Clay	AFDW	Chl a	TN	TP	Cd	Cr	Cu	Ni	Pb	Zn
	(>2mm)	(<2mm & >63µm)	(<63µm)	% w/w	ug/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
C-01	1.6	79.4	19	2.3	2800	320	570	<0.1	43	9.6	16	3.4	39
C-02	0.8	81.2	18	2.2	2400	310	580	<0.1	44	9.8	17	3.6	53
C-03	0.2	80.2	19.6	2.3	2300	310	570	<0.1	43	9.8	16	3.3	78
Average	0.9	80.3	18.9	2.3	2500.0	313.3	573.3	0.05	43.3	9.7	16.3	3.4	56.7
SD	0.7	0.9	0.8	0.1	264.6	5.8	5.8	0.0	0.6	0.1	0.6	0.2	19.8
Min	0.2	79.4	18	2.2	2300	310	570	0	43	9.6	16	3.3	39
Max	1.6	81.2	19.6	2.3	2800	320	580	<0.1	44	9.8	17	3.6	78

Appendix 4. Sediment cores from Delaware Inlet Site A laid out according to their spatial location on the sampling grid.

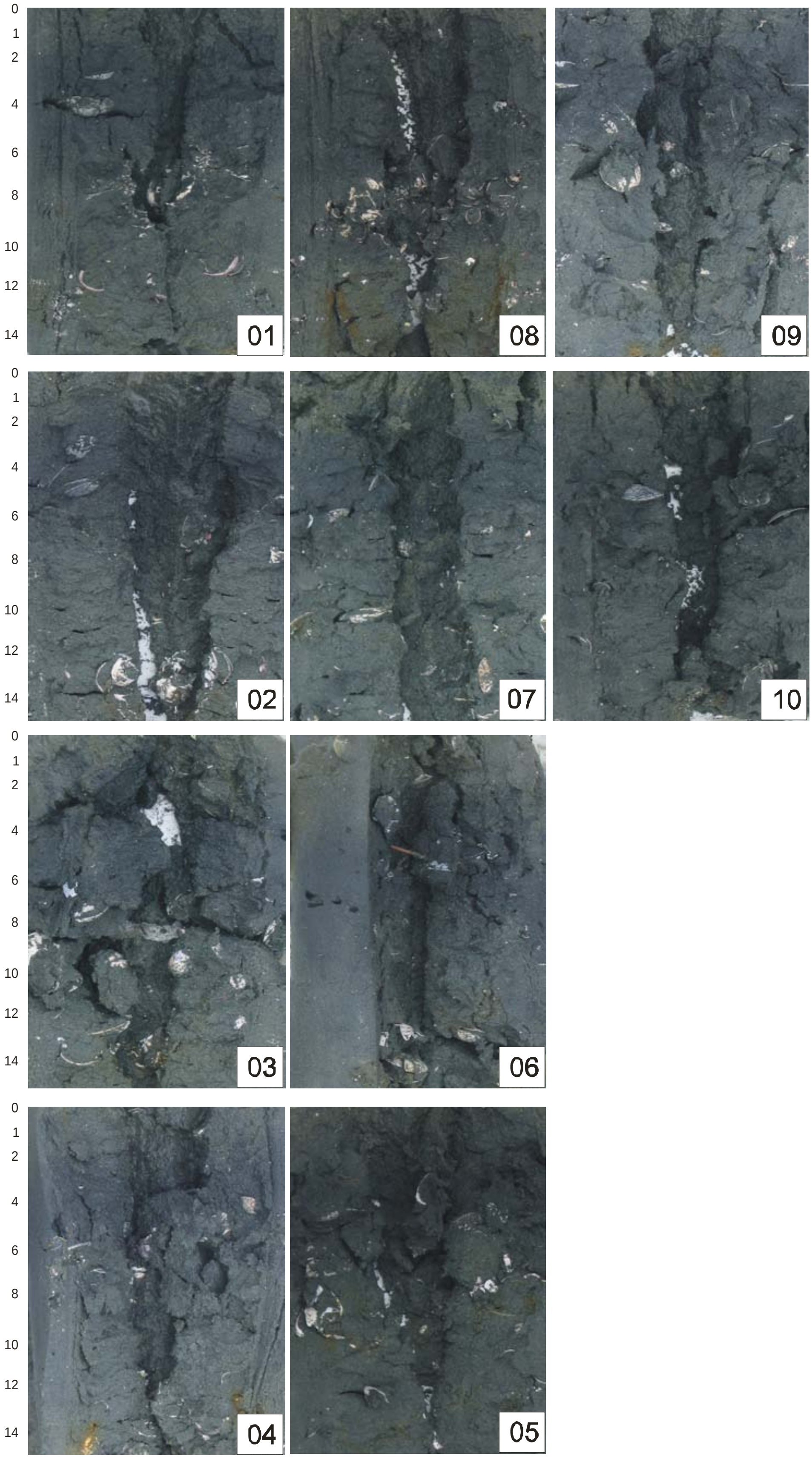
The ruler on the left is in centimetres with 0 cm representing the surface.



Appendix 4 (cont.). Sediment cores from Delaware Inlet Site B laid out according to their spatial location on the sampling grid. The ruler on the left is in centimetres with 0 cm representing the surface.



Appendix 4 (cont.). Sediment cores from Delaware Inlet Site B laid out according to their spatial location on the sampling grid. The ruler on the left is in centimetres with 0 cm representing the surface.



Appendix 5. Infauna species and abundance within Delaware Inlet replicate cores.

Taxon	Common Name	Feeding Type	A-01	A-03	A-05	A-07	A-09	B-01	B-03	B-05	B-07	B-09	C-01	C-03	C-05	C-07	C-09
AMPHIPODA																	
Amphipoda A	Amphipods	Epifaunal scavenger		1	2		1										2
Amphipoda B	Amphipods	Epifaunal scavenger	1		1			1		1		3	1	2	2	2	6
Amphipoda C	Amphipods	Epifaunal scavenger												1			
Edwardsia sp.	Burrowing anemone			1								1				1	
BIVALVIA																	
Arthritica bifurca	Small bivalve	Infaunal deposit feeder	2	2	7	2	3							1			
Austrovenus stutchburyi (0-5mm)	Cockle	Infaunal deposit feeder										5	2		2		3
A. stutchburyi (06-10mm)	Cockle	Infaunal deposit feeder	2	1	4								2	9	4	5	3
A. stutchburyi (11-20mm)	Cockle	Infaunal deposit feeder	2	2	1	2	1							1	1		3
A. stutchburyi (21-30mm)	Cockle	Infaunal deposit feeder						1	1								
Macomona liliana	Wedge shell (Hanikura)	Infaunal suspension feeder			1								4	3	4	4	5
Paphies australis	Pipi	Filter feeder					1			7		2	1				
DECAPODA																	
larvae unid.	Unidentified Crab Larvae												1				
Halicarcinus cookii	Pill-box Crab	Omnivore												1	1		
Halicarcinus whitei	Pill-box Crab	Omnivore	1		1												
Helice crassa	Tunnelling Mud Crab	Deposit feeder & scavenger						1									
Hemigrapsus crenulatus	Hairy-handed Crab - Mud Crab	Deposit feeder & scavenger													1		
Macrophthalmus hirtipes	Stalk-eyed Mud Crab	Deposit feeder & scavenger	1	1	1	1											
GASTROPODA																	
Amphibola crenata	Mud Snail	Surface grazer			1		1										
Cominella glandiformis	Mud Flat Whelk	Carnivore & scavenger					1						1	1		1	

Taxon	Common Name	Feeding Type	A-01	A-03	A-05	A-07	A-09	B-01	B-03	B-05	B-07	B-09	C-01	C-03	C-05	C-07	C-09
Diloma subrostrata		Surface grazer					2										1
Zeacumantus lutulentus	Spireshell	Surface grazer													1		1
NEMATODA	Roundworm												1				
NEMERTEA	Proboscis worms				1												1
OLIGOCHAETA	Oligochaete worms	Infaunal deposit feeder	3	7	23	11	2										
POLYCHAETA:																	
Capitella capitata	Capitellid worm	Infaunal deposit feeder			1	1											
Heteromastus filiformis	Capitellid worm	Infaunal deposit feeder				1											1
Maldanidae	Bamboo Worms	Infaunal deposit feeder											4	2	7	4	4
Nereidae	Rag worms	Omnivore	1	2	1								1		2	1	1
Nicon aestuariensis		Omnivore				1	1										
Perinereis vallata		Omnivore		1													
Scoloplos cylindrifer	Polychaete worm	Infaunal deposit feeder											1				1
Paraonidae		Infaunal deposit feeder	3			2	1						28	54	39	52	31
Pectinaria australis		Infaunal deposit feeder			1												
Sigalionidae		Infaunal carnivore									1						
Polydora sp.		Surface deposit & filter feeder	3	2	3		2										
Prionospio sp.		Surface deposit feeder	4	6	6	9	5						8	16	17	24	11
Sphaerosyllis sp.		Omnivore												1			
Species Richness (total no. of species)			**11**	**11**	**16**	**9**	**12**	**3**	**1**	**2**	**1**	**4**	**13**	**12**	**12**	**9**	**15**
Abundance (total no. of individuals)			**23**	**26**	**55**	**30**	**21**	**3**	**1**	**8**	**1**	**11**	**55**	**92**	**81**	**94**	**74**