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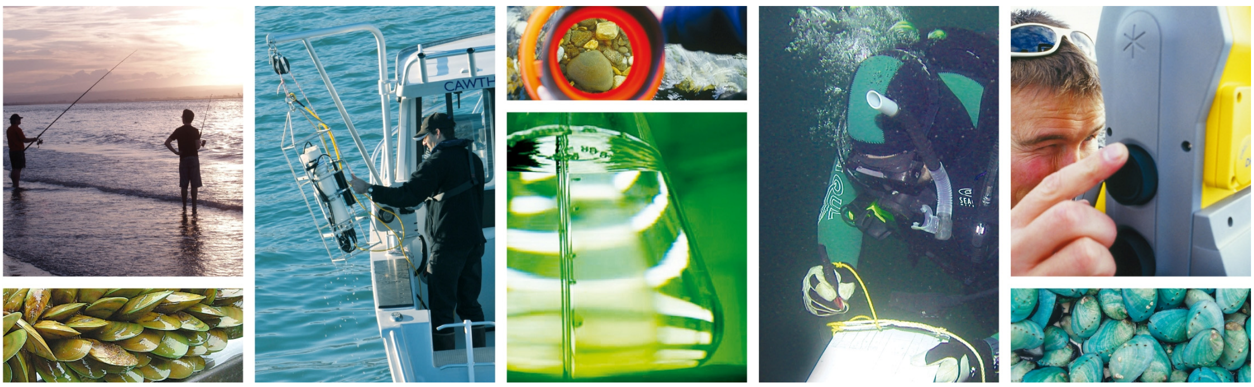
State of the Environment Monitoring of Delaware Inlet: Broad-Scale Habitat Mapping January 2009



RESEARCH BASED SOLUTIONS

State of the Environment Monitoring of Delaware Inlet: Broad-Scale Habitat Mapping January 2009

Paul Gillespie

Deanna Clement

Rod Asher

Prepared for

Nelson City Council

Cawthron Institute
98 Halifax Street East, Private Bag 2
Nelson, New Zealand
Ph. +64 3 548 2319
Fax. + 64 3 546 9464
www.cawthron.org.nz

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EXECUTIVE SUMMARY

Overview

Cawthron Institute (Cawthron) was commissioned by the Nelson City Council, through Envirolink NLCC48, to prepare a baseline vegetation and structural class habitat map for Delaware Inlet in order to progress a combined coastal State of Environment (SOE) monitoring strategy for the Nelson Bays. This work follows a preliminary assessment of the environmental status of Delaware Inlet (Envirolink NLCC18) providing a compilation of background and historical information and a fine-scale benthic assessment of the dominant mud/sand habitat (Envirolink NLCC19).

The present report describes the Estuary Monitoring Protocol (EMP) mapping methodology used, the 2009 mapping results and observations of habitat changes that have occurred since the only previous detailed mapping survey of Delaware Inlet almost 30-years prior. Implications for overall estuary ecological health are discussed and recommendations are made regarding possible management responses and ongoing Delaware Inlet SOE monitoring.

Mapping results

Unvegetated substrata covered 264 ha, which represents approximately 75% of the total Delaware intertidal area. This was comprised largely of firm sand (29.7%) and firm mud (15.5%) with lesser but significant areas of firm shell/sand (11.1%), soft mud (8.8%) and gravel/cobble fields (7.8%). The remaining 2% of unvegetated habitats were comprised of a mixture of rock fields, various shell banks and man-made structures (wharves, rock walls *etc.).*

Vegetated substrata covered a total area of 68 ha, which represents approximately 19% of the total intertidal area. The most common vegetated class was macroalgal beds (9.5%), dominated by *Ulva* sp. and/or *Enteromorpha* sp. and *Gracilaria chilensis*, which was scattered across central regions of the intertidal zone. Rushland, comprised largely of *Juncus kraussii* (searush) and *Leptocarpus similis* (jointed wirerush), covered 4.5% of habitats closer to the estuary margin while herbfields and eelgrass meadows covered 1.8% and 1.3%, respectively. Subtidal areas accounted for the remaining 6% of the estuary's mapped habitats.

Habitat changes - 1983 versus 2009

Changes in the spatial coverage of some habitats were identified by comparing the 2009 broad-scale mapping results with previous habitat mapping undertaken by Cawthron in 1983. Notable differences between surveys include:

- The total estuary area mapped in 2009 was ~353 hectares, which is slightly greater than the 336 hectares often cited for Delaware Inlet.
- The extent of mud habitats appears to have varied over time with some possibility of expansion as compared to historical generalised estimates. However mapping results provide no confirmation of a significant increase in mud coverage.
- The coverage of macroalgal habitats was lower at the time of the 2009 survey than the 1983 survey. However, because of the high natural variability of macroalgal coverage this was not considered as ecologically significant.

- The coverage of eelgrass habitat was slightly (~2.6 ha) less in 2009 as opposed to 1983, even when both dominant and subdominant areas are considered. The demotion of some eelgrass areas from a dominant (1983) to a subdominant (2009) ranking may be a warning of ecological stress within this habitat.
- A general reduction of 25-35% in the extent of rushlands and herbfields was found, although their general locations appear to have remained the same since 1983.
- Small expansions of the areas of tussockland, terrestrial scrub/forest, introduced weeds, grassland and estuarine shrubs were also documented, with little to no change in the extent of reed and sedgelands.
- Pacific oyster (*Crassostrea gigas*) beds currently cover ~1 hectare of intertidal habitat, however, sparsely scattered shells were also observed over much of the central and mud-dominated peripheral intertidal regions. These areas represent ecologically significant new habitat colonised by an exotic species.

Estuary condition

In comparison to other estuaries in the Nelson Bays and Marlborough region, Delaware reflects a high general diversity with some indications of a healthy and functioning estuarine system (*e.g.* relatively high seagrass presence and low percentage coverage of muddy habitats). Nevertheless, apparent changes in intertidal habitat coverage could potentially translate to an increased risk of ongoing deterioration of Delaware Inlet's ecosystem services/values.

Warning signals suggesting a possible divergence from the pre-existing unmodified estuary ecosystem are:

- A modest reduction in some vegetated habitats including eelgrass meadows along tidal channels and rushland and herbfield habitats around the estuary margin. These changes could be partially attributed to natural fluctuation and differences in survey methods, but they may also be indicative of deterioration.
- The developing Pacific oyster habitat represents a significant departure from the natural character of the tidal flats and this invading bivalve is likely to compete with other suspension-feeding organisms (*e.g.* cockles). This point-in-time baseline mapping will help to more accurately track any future expansion or reduction in oyster habitat.

Recommendations

- Continuation of Delaware Inlet SOE habitat mapping surveys, in conjunction with other components of the EMP, at approximately five-year intervals as a means of identifying long-term trends in estuary condition. This will enable an expanded inter-estuary comparison within the Nelson Bays region according to a standardised methodology. In particular, further investigations of:
  - Decreases in area coverage of key vegetative habitats, such as seagrass meadows,
  - Expansion in area coverage of mud-dominated substrata, and
  - Spread of Pacific oyster habitat.

- Continuation of habitat restoration projects to achieve a more natural land to sea succession of plant communities.
- Further development and implementation of an integrative approach that coordinates the EMP with a suite of iwi estuarine indicators. This could serve as a model for improved management of coastal habitats in New Zealand.

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1. INTRODUCTION

1.1. Background

Estuarine intertidal areas play an important role in linking terrestrial and marine environments. As such, they are conduits for a two-way land/sea exchange of materials and they function as nutrient processing zones that are critical for sustainability of coastal ecosystems. Estuary intertidal areas often encompass habitats of high ecological value and contain resources of cultural, recreational and/or commercial importance. Broad-scale mapping of these habitats can be used to assist in regional strategic planning, and in the management of specific issues associated with estuarine habitat; *e.g.* resource consents, pollution monitoring, and State of the Environment (SOE) monitoring.

Through a Ministry for the Environment Sustainable Management Fund (SMF) grant, with support from 11 councils throughout New Zealand, Cawthron Institute (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 broad-scale habitat boundaries and 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 SOE, and consent-related, estuarine monitoring data. During the past eight 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 utility for evaluating estuary condition in a national context. To date, the EMP has been fully implemented in two estuaries in Golden Bay; Ruataniwha (Robertson *et al*. 2002) and Motupipi (Robertson & Stevens 2008; Stevens & Robertson 2008), and two estuaries in Tasman Bay; Moutere (Clark *et al.* 2006; Gillespie & Clark 2006) and Waimea (Robertson *et al*. 2002; Gillespie *et al*. 2007; Clark *et al*. 2008).

Cawthron was commissioned by the Nelson City Council (NCC), through Envirolink NLCC48, to prepare a baseline vegetation and structural class habitat map for Delaware Inlet in order to progress a combined coastal SOE monitoring strategy for the Nelson Bays. This work follows a preliminary assessment of the environmental status of Delaware Inlet (Gillespie 2009) providing a compilation of background and historical information and a fine-scale benthic assessment of the dominant mud/sand habitat (Gillespie *et al.* 2009).

The present report summarises the results of a detailed point-in-time spatial survey of major habitats in the intertidal regions of Delaware Inlet completing implementation of the EMP. The following components are included:

- A methodology outline,
- Maps defining the broad-scale habitats present (*e.g.* rushland, tussockland, firm mud),
- A CD-ROM providing access to a working version of the completed habitat maps (entitled "Broad-Scale Intertidal Habitat Mapping: Delaware Inlet January 2009"),

- A summary table of major habitats and substrates within the estuary, providing the area and relative proportions of each grouping,
- A discussion of habitat changes that were detected through comparison with mapping based on a 1983 aerial survey and other historical information,
- Interpretation of mapping results with regard to estuary condition, and
- Recommendations based on mapping results.

1.2. Study area

Delaware (or Wakapuaka) Inlet is a relatively small (353 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 and 2). 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 (Figure 2).

Based on historical information, the preliminary assessment report (Gillespie 2009) 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 2009).

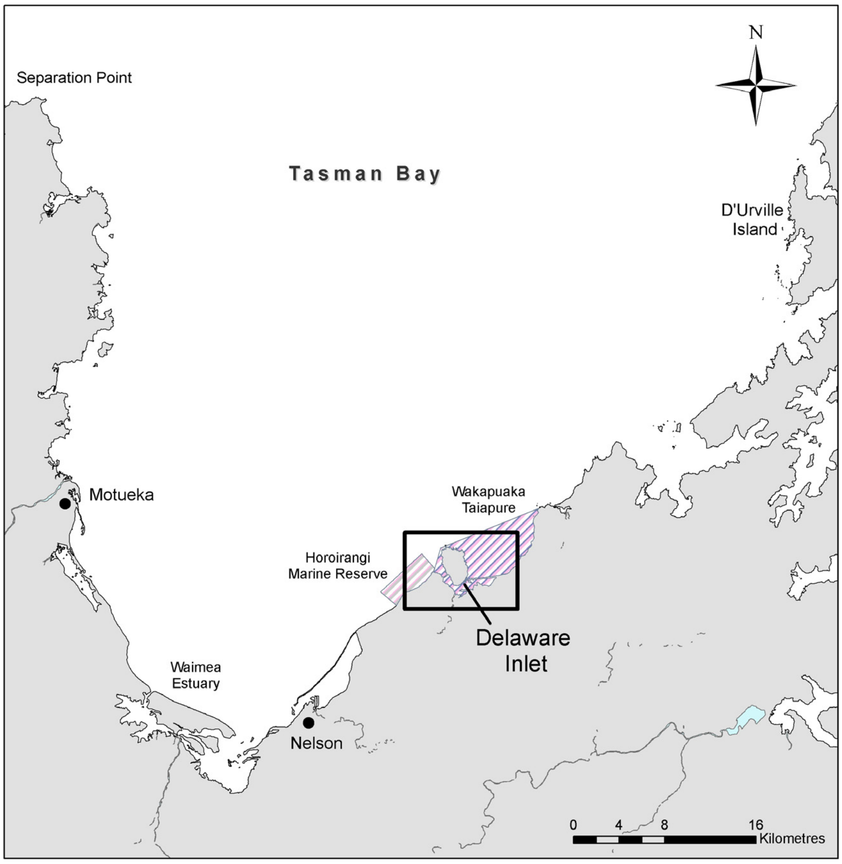

Figure 1. Delaware Inlet location in relation to Tasman Bay.

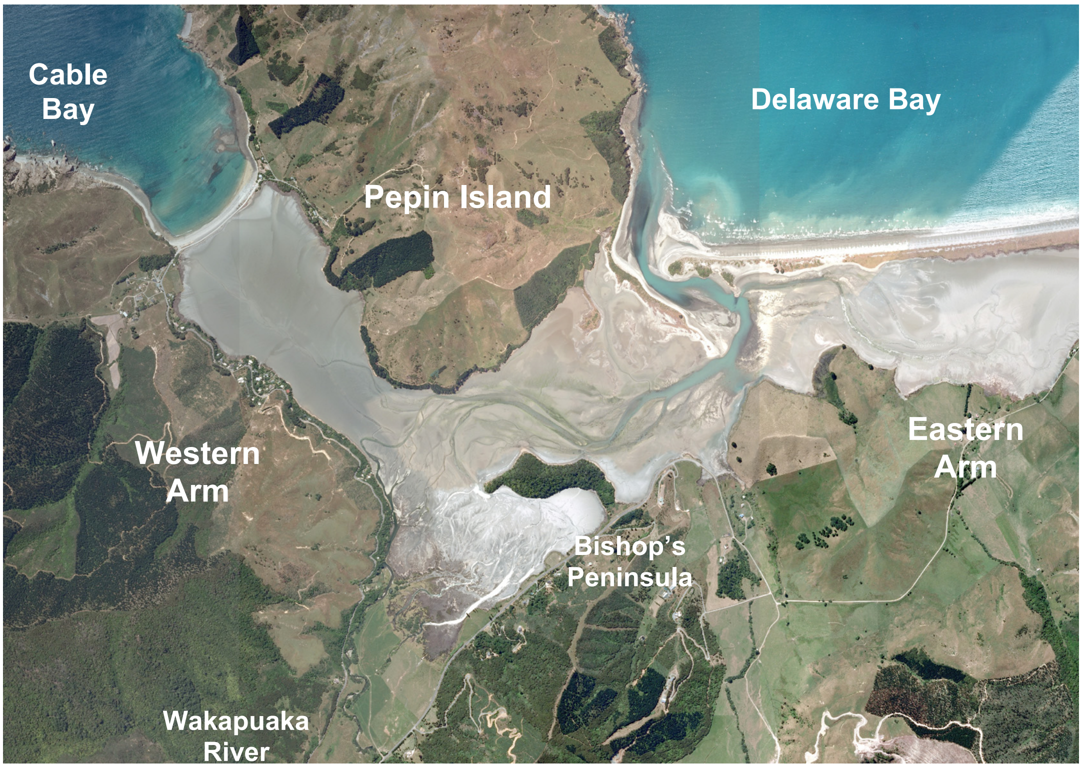

Figure 2. Expanded map of Delaware Inlet and key features.

2. METHODS

2.1. Overview

The methodology used to collect data was based on the standardised Estuary Monitoring Protocol (EMP - Robertson *et al*. 2002), which uses field-verified broad-scale mapping of habitat zones as a monitoring tool. This procedure involved the use of aerial photography together with detailed ground-truthing and digital mapping using Geographical Information System (GIS) technology. The broad-scale habitat mapping approach provides a description of the intertidal environment according to dominant habitat types based on substrate characteristics (mud, sand, cobble, rock, shellfish beds *etc*.) and the vegetation present (*e.g.* rushes, eelgrass, macroalgae *etc*.) in order to develop a baseline map of the estuary. Once a baseline map has been constructed, changes in the position and/or size of habitats (MfE Confirmed Indicators for the Marine Environment, ME6 2001) can be assessed by repeating the mapping exercise over time. This information can then be used to evaluate changes associated with natural perturbations, such as flood/climatic events, and human impacts, such as land management practices (and related river water quantity and quality), on the structure of the intertidal ecosystem.

2.2. Aerial photography

Colour aerial photographs of Delaware Inlet were taken on 23 January 2009 for NCC and provided to Cawthron as rectified "MrSid" files at a resolution of 0.5 metres.

2.3. Ground-truthing of habitat features

Aerial photographs, through different textural and tonal patterns, indicate the presence and spatial extent of different substrate and vegetation types. To identify the dominant habitats present and confirm the boundaries between substrates, field surveys were undertaken over the whole estuary at low-mid tide April 2010 and December 2010. Dominant habitat types, including various categories of bare and vegetated substrate were recorded directly onto laminated copies of the aerial photographs using the codes listed in Appendix 1 and described in detail in Appendix 2.

The upper intertidal boundary was set at the apparent MHWS (Mean High Water Spring) and the lower boundary was set at approximately MLWS (Mean Low Water Spring). A 10 m wide riparian strip above MHWS (called the supra-littoral fringe) was also assessed visually to enable general comment on the type of habitat surrounding the edge of the estuary.

2.4. Digitisation of habitat boundaries

Vegetation and substrate features were digitally mapped from the rectified photographs using ArcMap 9.3 GIS software. This procedure involved creating digital polygons of the field-verified habitat features as precisely as possible by tracing them directly from the rectified aerial photographs within the GIS software. The software was then used to produce digital maps and calculate the area cover of each habitat type.

3. CLASSIFICATION AND DEFINITION OF HABITAT TYPES

The classification of substrate and habitat features is based on the estuarine national classification system (with adaptations), which was developed under a Ministry for the Environment SMF programme (Monitoring Changes in Wetland Extent: An Environmental Performance Indicator for Wetlands) by Lincoln Environmental, Lincoln. The classification system for wetland types is based on the Atkinson System (Atkinson 1985) and covers four levels, ranging from broad- to fine-scale (Appendix 1 and Appendix 2). The broad-scale mapping focuses on Levels III (Structural Class) and IV (Dominant Cover). Substrate classification is based on surface layers only and does not consider underlying substrate (*e.g.* gravel fields covered by sand would be classed as sand).

3.1. Habitat codes and terminology

Dominant biota with a spatial coverage of >2 m in diameter was classified using an interpretation of the Atkinson (1985) system. In this report, biota and substrata are listed in order of dominance as described below:

- Individual plant species are coded using the two first letters of their Latin species and genus names; *e.g.* Pldi = *Plagianthus divaricatus* (ribbonwood), Lesi = *Leptocarpus similis* (jointed wire rush).
- Subdominant species are indicated by an underscore (_); *e.g.* Lesi_Pldi = Pldi is subdominant to Lesi. The classification is based on the subjective observation of which vegetation is the dominant or subdominant species within the patch, and not on percentage cover.
- Individual features in the GIS maps have been labelled in the same manner as that described above.

4. RESULTS

4.1. 2009 habitat and substrate characteristics

A total of 353 ha of intertidal zone and an additional 69 ha of supra-littoral fringe (estuary margin) within Delaware Inlet were mapped in 2010 based on colour aerial photographs collected in January 2009. Detailed maps show the intertidal areas covered by the dominant substrata and vegetation types (Figure 3 and 4) and their area coverage is summarised in Table 1 and Figure 5. Of the total mapped area, 6.2% (~22 ha) was subtidal (*i.e*. underwater) at the time the aerial photographs were taken and the remaining intertidal area was predominantly unvegetated (74.7%, 264 ha) with 19.1% of habitats (~68 ha) covered in some form of vegetation. We note that some small habitat areas cannot be seen at the scale of the maps, however these areas are quantified in Appendices 3 and 4, and individual GIS layers can be accessed and evaluated through the CD-ROM in Appendix 5.

4.1.1. Unvegetated habitats

The unvegetated habitats of Delaware Inlet's intertidal zone (Table 1) were dominated by sand (29.7% firm sand and 0.1% soft or mobile sand), mud (15.5% firm mud, 8.8% soft mud and 0.5% very soft mud) and shell/sand (11.1%). Although these open tidal flats are classed as "unvegetated", they harbour a surface community of benthic microalgae, primarily diatoms, which constitute an important component of the photosynthetic production of the estuary (Gillespie & MacKenzie 1981). The benthic microalgae are sometimes visible as a patchy golden or olive-green film on the surface of the sediment.

Gravel and cobble fields also covered important parts of the estuary (5.3 and 2.5% respectively), with the remaining habitats comprised of a mixture of rock fields, various shell banks and man-made structures (wharves, man-made rock walls *etc.* - for more detail see Appendix 3).

4.1.2. Pacific oyster

The extent of Pacific oyster (*Crassostrea gigas*) distribution was found to cover ~1 ha or 0.3% of the intertidal zone. Sparsely scattered dead shell and clumps of living oysters (
Figure 6) were also observed over much of the central (~10-15 ha) and peripheral (~12 ha) intertidal regions.

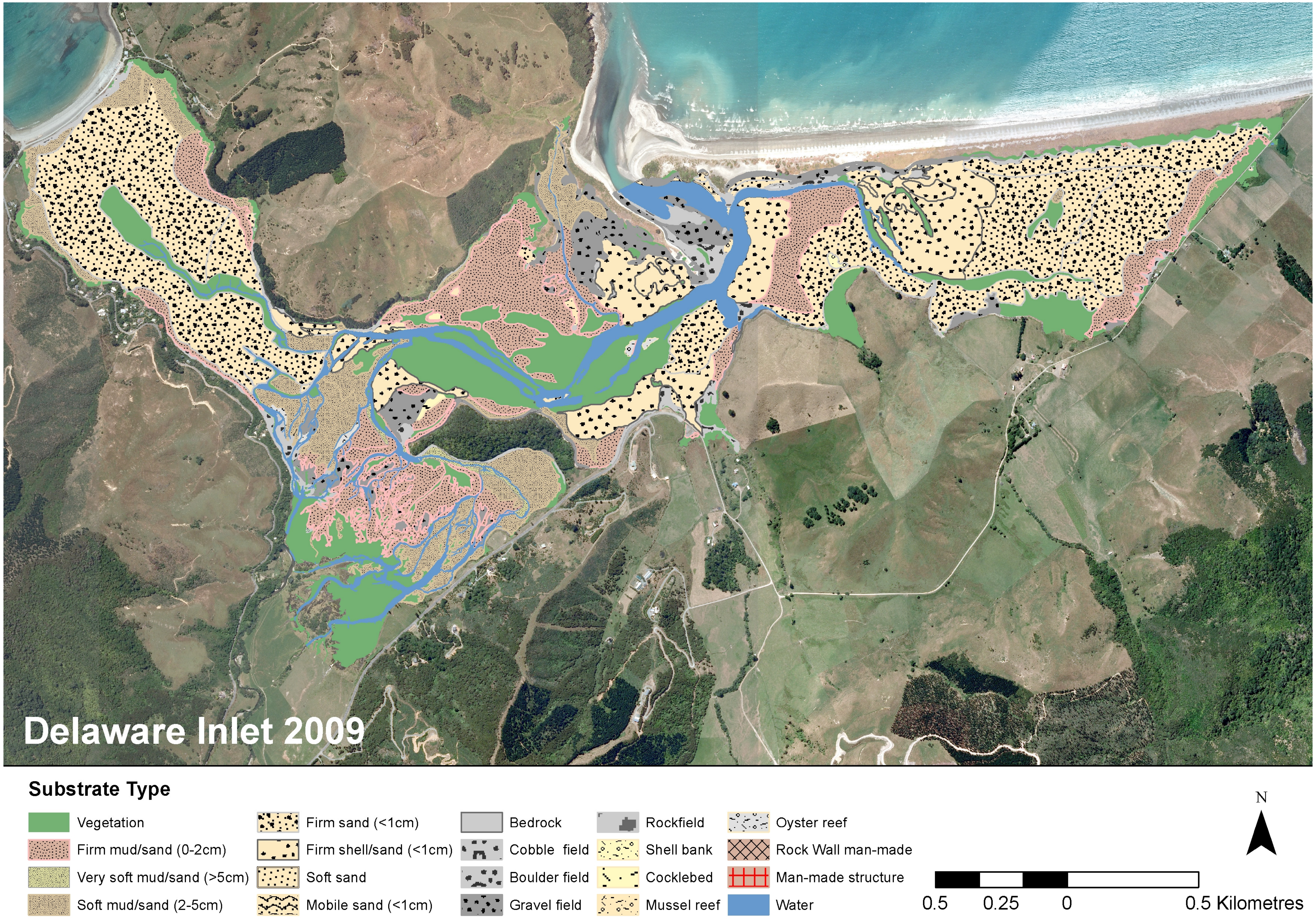

Figure 3. Aerial photograph of Delaware Inlet showing substrate characteristics in January 2009.

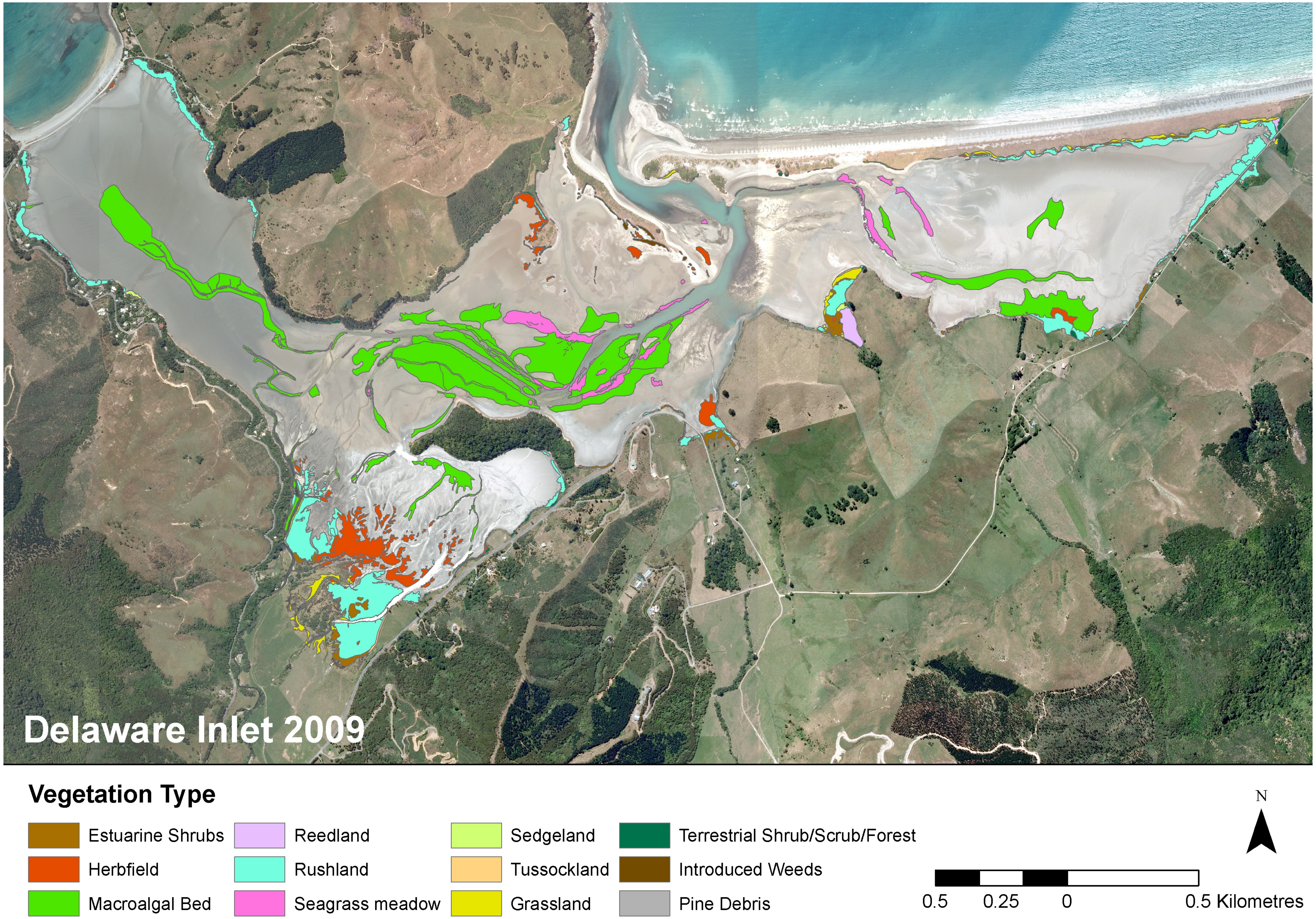

Figure 4. Aerial photograph of Delaware Inlet showing vegetation present in January 2009.

4.1.3. Vegetated habitats

Vegetated habitats within and surrounding the estuary showed considerable complexity with most classification categories present; including grassland, scrubland, tussock land, rushland, herbfield, eelgrass meadows, sedgeland, estuarine shrubs and terrestrial shrubs/trees (for more detail see Appendix 4). The most extensive class within the vegetated intertidal habitats was macroalgal bed, dominated by *Ulva* sp. and/or *Enteromorpha* sp. and *Gracilaria chilensis*, which covered large and diverse areas of the estuary at the time of the survey (~34 ha, 9.5% - Table 1). However, it must be recognised that the coverage of these species can fluctuate considerably over the short term (*i.e.* weeks to months).

Also fairly common were rushlands (~16 ha, 4.5%), dominated by *Juncus kraussii* (searush) and *Leptocarpus similis* (jointed wirerush) and herbfields (6.5 ha, 1.8%) primarily of *Sarcocornia quinqueflora* (glasswort) and *Samolus repens* (primrose) found mainly along the estuary edges. Eelgrass meadows (*Zostera* sp.), although relatively less abundant, covered an ecologically significant area of 4.5 ha or 1.3% of the vegetated intertidal substrata.

Table 1. Key broad-scale habitats mapped within Delaware Inlet in January 2009.

Habitat Groupings		Area (Ha)	% Total Area
Water		**21.81**	**6.18%**
Unvegetated habitats		**263.65**	**74.70%**
	Cobble field	8.70	2.47%
	Firm mud	54.63	15.48%
	Firm sand	104.98	29.74%
	Firm shell/sand	39.04	11.06%
	Gravel field	18.82	5.33%
	Soft mud	31.10	8.81%
Vegetated habitats		**67.48**	**19.12%**
	Herb field	6.45	1.83%
	Macroalgal Bed	33.68	9.54%
	Rush land	15.72	4.45%
	Seagrass meadow	4.49	1.27%
Total Area of Estuary		**352.95**	

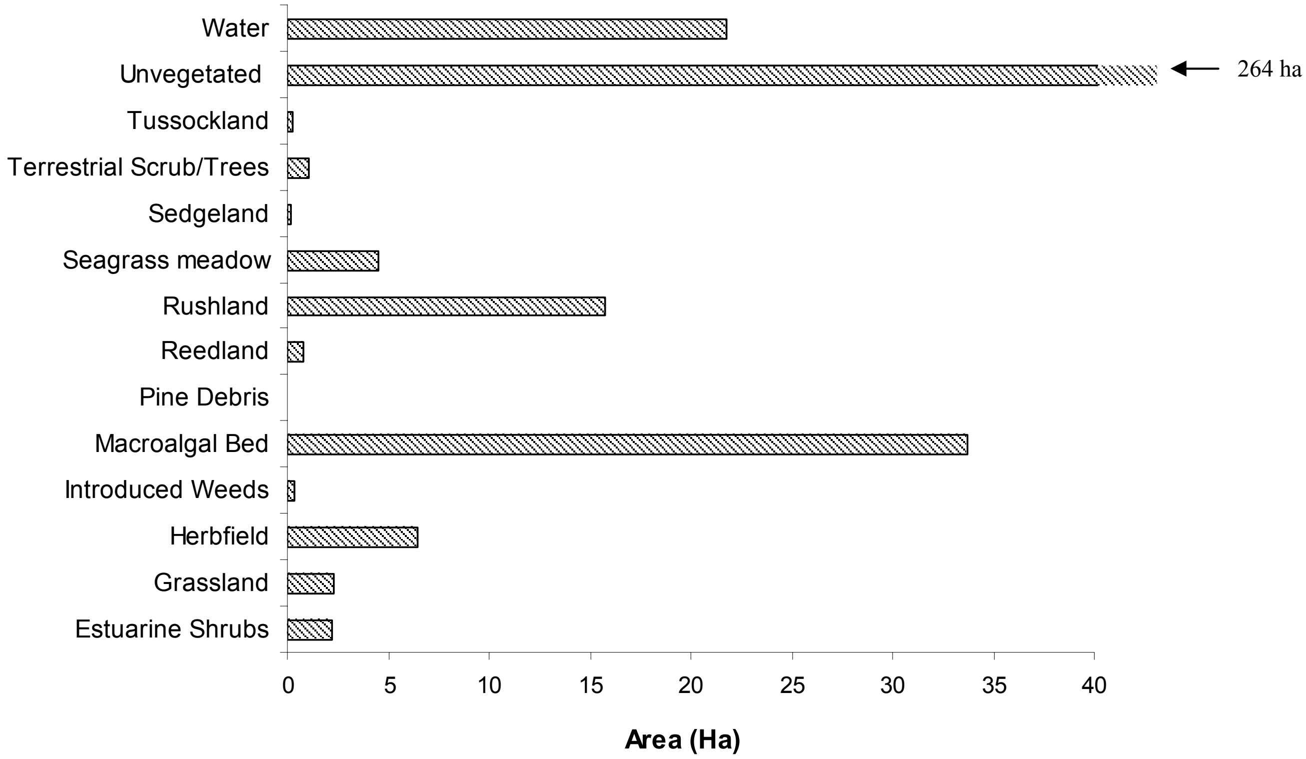

Figure 5. The overall area (ha) of mapped habitats within Delaware Inlet, January 2009.

Figure 6. Scattered living Pacific oysters and dead shell in upper tidal regions of Delaware Inlet, December 2010.

4.1.4. *Supra-littoral fringe (estuary margin habitats)*

Vegetated habitats along the estuary margin (Figure 7) consisted mainly of terrestrial shrubs/trees (~20 ha – largely native species) and grasslands (~17 ha), dominated by *Ammophila arenaria* (marram grass) and *Festuca arundinacea*. Along some shoreline regions, native vegetation has been displaced by exotic species, such as gorse (*Ulex europaeus*) and/or pine trees (*Pinus radiata*). Large areas of the estuary margin along the western and eastern arms were significantly modified; primarily due to roading, agricultural uses and residential development. These areas are not mapped in detail.

Over the last ten years, various council and iwi-led revegetation projects involving community and school groups have begun to restore estuary margin habitats in a number of regions; *i.e.* within Paremata Reserve, between the reserve and Bishop Peninsula and along sections of Pepin Island. These are identified in more detail in Appendix 5. The replanting projects have resulted in significant growth over this short time period and successfully aided in restoring a more natural land to sea plant succession.

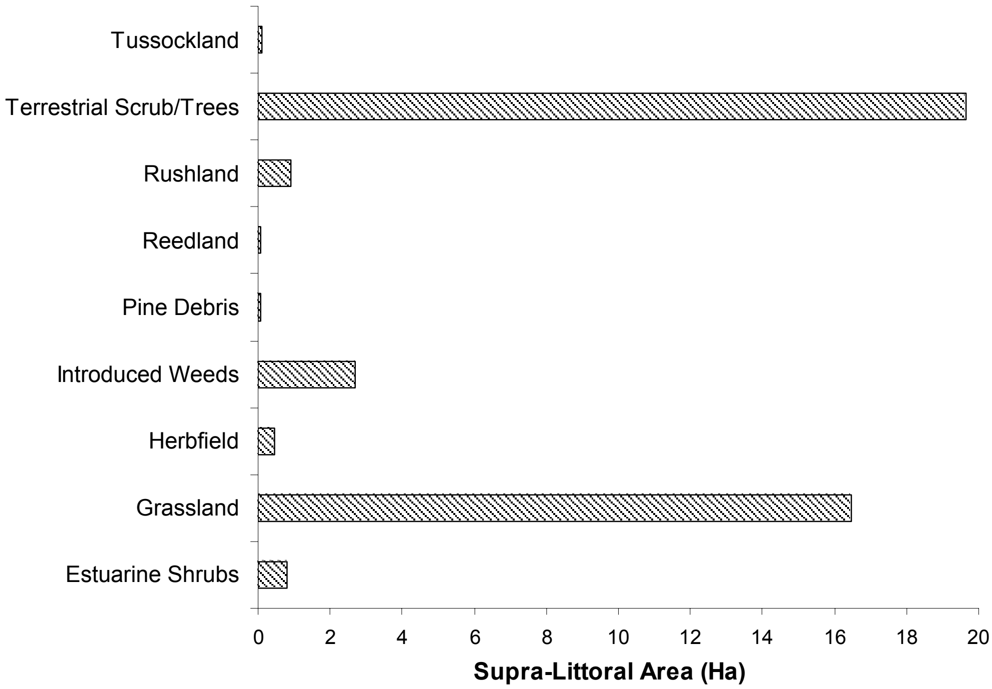

Figure 7. Additional habitats within supra-littoral regions (~68 ha) mapped around Delaware Inlet, January 2009.

5. CHANGES SINCE 1983

A habitat map of Delaware Inlet was constructed by Cawthron (Franko 1988) based on colour aerial photographs taken June 1983 and ground-truthing undertaken between May 1983 and April 1984. This map was recently updated to a digitised GIS format (Gillespie 2009). In order to facilitate comparison with the results of the 2009 mapping exercise reported here, the 2009 habitat map was clipped to the same exact boundaries as those of the earlier 1983 map.

5.1. Substrata

While the 1983 habitat mapping included intertidal substrata, there was not enough detail to make adequate comparisons to the more recent mapping in terms of differentiation between different sediment types (*e.g.* mud versus sand). Instead, more informative comparisons were made with substrata descriptions from previous literature (*e.g.* Stanton *et al*. 1977; Gillespie & Mackenzie 1981).

Considerable areas of pine forest have been harvested within the Wakapuaka catchment since the 1980s, when the last detailed investigation of intertidal habitat structure was undertaken. Although this may account for the larger percentage of muddy substrates identified in the recent mapping (~25%) compared to only 15% mud flats described previously by Stanton *et al*. (1977), this interpretation is largely conjectural due to the generalised nature of the historical estimates.

Development of agriculture, particularly adjacent to the eastern estuary arm, is likely to have had some enrichment effects on intertidal habitats. However, although not specifically investigated here, no evidence of significant over enrichment was observed in either arm of the inlet during map validation surveys. Nevertheless increased catchment nutrient runoff due to human activities has likely contributed to the relatively high productivity of the estuary (Gillespie & MacKenzie 1981) and dense growths of *Enteromorpha* sp. (now reclassified as *Ulva* sp.) along the tidal section of the lower Wakapuaka River. .

5.2. Vegetation

A noticeable difference between the two vegetation maps is due to the much larger extent of the macroalgal beds and eelgrass (*Zostera* sp.) meadows in 1983 and a small expansion in estuary margin habitats such as tussocklands and grasslands and terrestrial and estuarine scrub/shrubs/trees (Figure 8).

5.2.1. Macroalgae

Macroalgal beds tend to be dominant features of intertidal regions over summer months. Ground-truthing of the January 2009 map took place in April 2010 and the large macroalgal beds present in 1983 were not as extensive or as distinct in the aerial photographs due to their lower density. However, it is important to note that these plants; *e.g.* sea lettuce (*Ulva* sp.), agar weed (*Gracillaria* sp.) and *Gelidium* sp., can grow rapidly with considerable seasonal and inter-annual variability. Hence, interpretation of changes in macroalgal coverage would require detailed, longer-term monitoring.

5.2.2. Eelgrass

Mapping results found current eelgrass beds had been reduced to half of the former 1983 coverage (Figure 8). The EMP broad-scale mapping protocol is based on assessing the dominant feature of a habitat. Seagrass beds can be patchy (less than 20% coverage), and are often ranked subdominant to other flora or substrata. When areas classed as dominant seagrass habitat in 2009 are combined with areas of the same habitat but classed as subdominant, a much smaller reduction in overall size since 1983 is apparent (*i.e.* 8.9 ha in 1983 versus.6.3 ha in 2009 - Figure 9). The 1983 mapping also included some eelgrass beds within subtidal regions, in this case extensive water channels, and this may also account for some of the temporal differences.

Thus it may be important to also consider the more subtle reduction in the density of eelgrass coverage (*i.e.* resulting in demotion from dominant to subdominant habitat) as a warning of possible habitat deterioration. Eelgrass meadows are recognised as having significant ecological importance and biodiversity values. Although their photosynthetic contributions are relatively modest, eelgrass provides stable physical habitat and a localised food source to support a diverse community of animals. Because eelgrass meadows are sensitive to macroalgal overgrowth, sediment deposition and reduced water quality conditions, changes in area coverage or density over time can be a particularly good indicator of estuary health. In this case, it appears that, even if we include the lower density subdominant eelgrass areas, there has still been a slight, but perhaps ecologically significant, reduction in this habitat since 1983. More detailed investigation would be required, however, in order to evaluate the implications of the apparent reduction in eelgrass density as a potential sign of habitat deterioration.

5.2.3. Salt marsh

Two other productive estuarine habitats found in Delaware Inlet are rushlands and herbfields. Rushlands and associated herbfields are functionally important in that they are areas of active production and decomposition (Gillespie & MacKenzie 1981). The area of these higher intertidal habitats mapped in 2009 is less (by ~25-35%) than recorded in 1983 (Figure 8), however their general locations appear to have remained the same as those observed in 1976

(Stanton *et al*. 1977) and in 1983 (Franko 1988). Reedlands and sedgelands are recognised as important lowland freshwater wetland habitats that also generally help process catchment nutrient inflows and facilitate terrestrial exchange with the marine environment. These particular habitats do not appear to have been extensive in 1983 and currently remain at similar low levels.

5.3. Pacific oyster

Pacific oyster (*Crassostrea gigas*) was not noted during the 1983 mapping exercise although a seeding population was probably present at that time as individual specimens were observed in the main channel near the entrance to the estuary during the late 1970s (P Gillespie, pers. obs.). The 2009 mapping result therefore represents development of a small, but potentially ecologically significant new oyster reef habitat covering an area of ~1 ha. However dead shell and scattered clumps of live oysters covered a much larger area (20-27 ha) thus resulting in further divergence from the pre-existing (1983) character of the estuary.

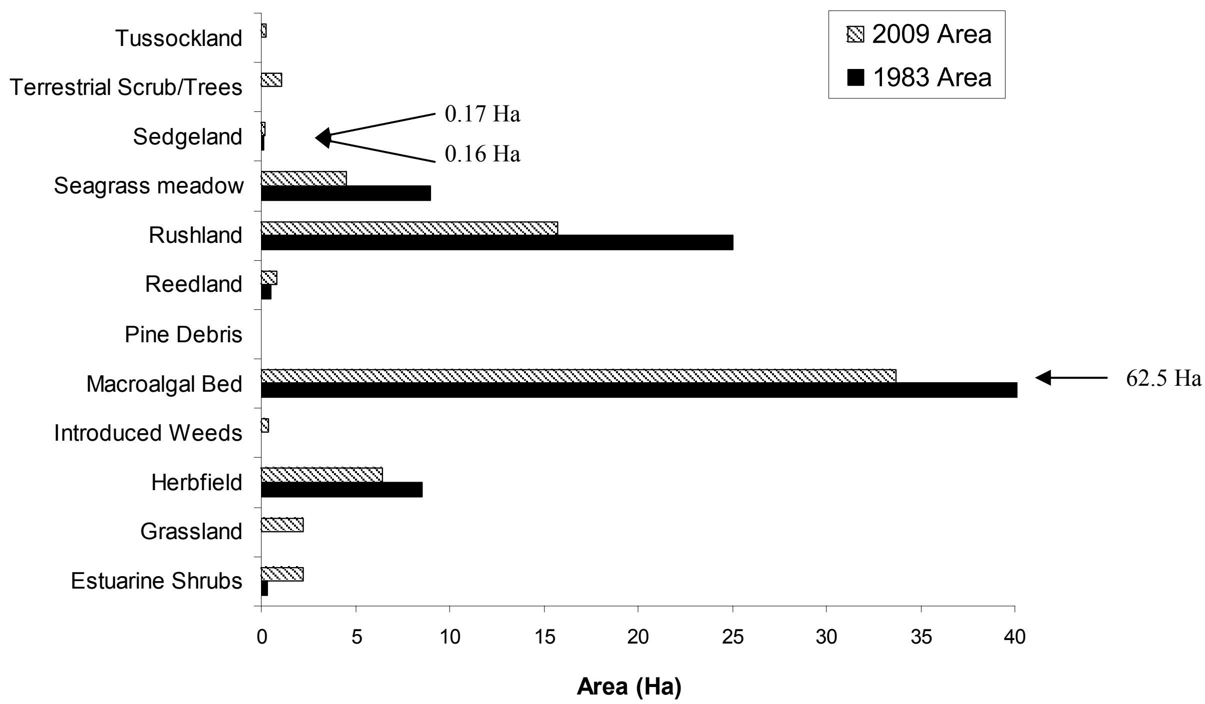

Figure 8. The area of vegetated habitats present in Delaware Inlet in 1983 and January 2009 (note – the extent of 2009 mapping has been clipped to match that of 1983 mapping and includes only dominant habitats).

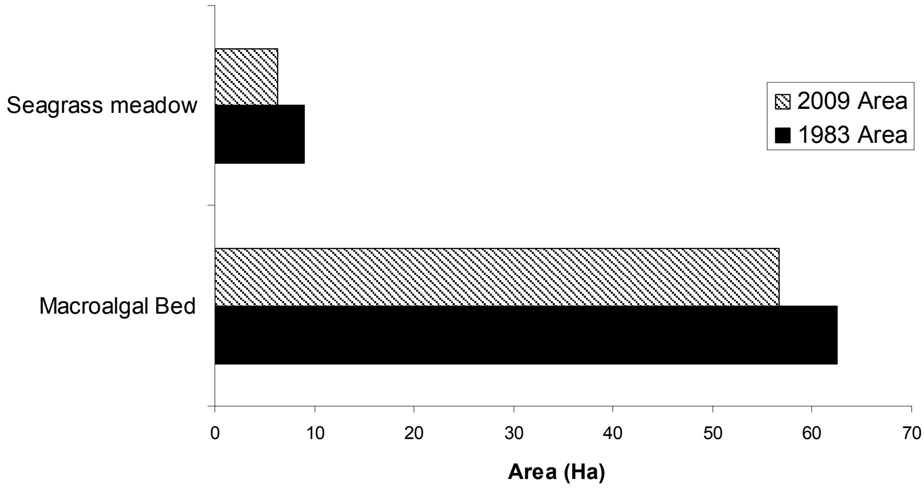

Figure 9. A comparison of seagrass meadows and macroalgal beds within Delaware Inlet between 1983 and 2009 with subdominant habitats included in 2009 area estimates.

6. INDICATORS OF ESTUARY CONDITION

The following sections evaluate the mapping results as indicators of the existing ecological condition of Delaware Inlet. The conclusions drawn should be considered in conjunction with those of the preliminary and fine-scale assessment 'companion' reports (Gillespie 2009; Gillespie *et al*. 2009) that comprise the combined EMP.

6.1. Habitat structural composition

The complex mixture of habitats documented within Delaware Inlet is representative of a functional, but slightly modified estuarine system. As such, the natural functions and values of the estuary, as described by Gillespie & MacKenzie (1981) and Gillespie (2009), are thought to have been largely preserved to date. Nevertheless some apparent changes in intertidal habitat coverage, as discussed in the following subsections, could potentially indicate an increased risk for ongoing deterioration of Delaware Inlet's ecosystem services/values.

6.1.1 Vegetative cover

Delaware Inlet has historically been known to contain a generally low proportion of vegetative cover relative to the more extensive mud and sand flats (Gillespie & MacKenzie 1981). However, it appears that there has been a modest reduction in some vegetated habitats in at least the last 30 years. Some of this decrease may be attributed to differences with the EMP classification scheme compared to earlier survey methods, or in the case of macroalgal beds, actual differences being difficult to document; given the plants short-term temporal and seasonal variability in growth. Despite these caveats, our evidence indicates that some vegetated habitats have declined, particularly around the estuary margin and former wetland areas.

The small reduction in area coverage of eelgrass meadows since 1983, in conjunction with a demotion from a dominant to a subdominant classification in some areas, raises some concern for the long-term sustainability of this habitat. We also note that, during the 2010 field verification survey, physical damage to existing meadows was documented at one location within the eastern arm of the estuary (Figure 10). This was due to vehicle traffic across sand flats and into eelgrass beds during recreational boat launching and retrieval. Such disturbances, although extremely localised, can take several seasons to regenerate and repeated disturbances could potentially result in long-term displacement of meadows. However, it is important to recognise that while Delaware's seagrass habitats are small (~1.3 ha), they are regionally important considering the low percentages of seagrass habitats present in other nearby estuaries (Table 2).

Figure 10. Vehicle tracks across eelgrass and associated cockle habitat in the eastern arm of Delaware Inlet, December 2010.

6.1.1. Expansion of muddy substrata

The deposition of terrigenous sediments in estuarine intertidal zones is a natural process that occurs wherever there is substantial freshwater inflow. The rate of deposition within an estuary will depend on the sediment loading characteristics of the inflow stream(s) and the hydrodynamic characteristics of the receiving environment. In many catchments throughout New Zealand (including the Delaware Inlet (Wakapuaka) catchment) human activities have resulted in increased erosion and flushing of fine-grained terrigenous sediments into the coastal environment. The resulting acceleration of sedimentation rates and increases in habitat "muddiness" can be considered a serious threat to estuarine health (Thrush *et al*. 2004).

Unvegetated mud habitats in Delaware Inlet covered approximately 25% of the total intertidal area in 2009, of which only 8.8% represented soft mud habitats (a proxy often used to indicate sediment depositional zones). This proportion of mud habitat is well within the range of the nine estuaries (~10% to ~58%) surveyed by Robertson *et al.* (2002), with only three estuaries having lower percentages. While this extent represents a doubling of mud flat habitats compared to Stanton *et al.* (1977), it is similar to mud flat coverage (~39%) reported by Gillespie & MacKenzie (1981). We note, however, that these earlier estimates were not based on extensive field verification and were therefore subject to error. The more recent mapping results suggest that sediment depositional rates may have varied over time, but estuary function (based on Gillespie *et al.* 2009) has been largely unaffected. This may be due to the estuary's heavy reliance on mud habitats and their associated communities. Gillespie & MacKenzie (1981) and Gillespie (1982) suggest that the extensive mudflats in Delaware Inlet are important habitats for the support of benthic microalgal production and the recycling and export of nutrients. This appears to serve an important function with regard to the productivity of the estuary and surrounding coastal region (*e.g.* including Horoirangi Marine Reserve and Wakapuaka Taiapure area, (Figure 1).

6.1.2. Spread of exotic species

The colonisation of a number of coastal habitats in the Nelson region by Pacific oyster was reported during the early 1980s (Bull 1981) and this species has now become well established in a number of intertidal locations within the northern South Island including Delaware Inlet. A small sparsely colonised Pacific oyster bed was observed off the tip of Bishop Peninsula by Asher (1999), and by 2005 coverage had increased dramatically at a number of locations in the Inlet. While previous surveys have raised concerns over the spread of Pacific oysters in this estuary, visual and anecdotal evidence suggests that this species fluctuates greatly in the Nelson Bays region and is presently undergoing a reduction in Delaware Inlet (Figure 11).

This developing habitat represents a significant departure from the natural character of the tidal flats and the invading bivalve is likely to compete with other suspension-feeding organisms (*e.g.* cockles). For example, it could disadvantage cockle populations in two ways; (a) by directly competing for food, and (b) by altering the physical, chemical and biological properties of the seabed. The resulting oyster beds and shell banks develop as raised mounds that contain enriched, fine-grained sediments with altered biological community characteristics (Figure 12). This type of modified ecological structure presently only covers ~1 ha of the intertidal habitat, however, sparsely scattered dead shells and clumps of living oysters over significant areas of the Inlet (most likely a relic of earlier fluctuating populations) also represents a departure from the natural estuary condition.

Other than the Pacific oyster, no other potentially invasive intertidal pest species were identified. For example potential invaders such as the sea squirts, *Didemnum vexillum* and *Styela clava*, and the Asian kelp, *Undaria pinnatifida* were not observed in the study area.

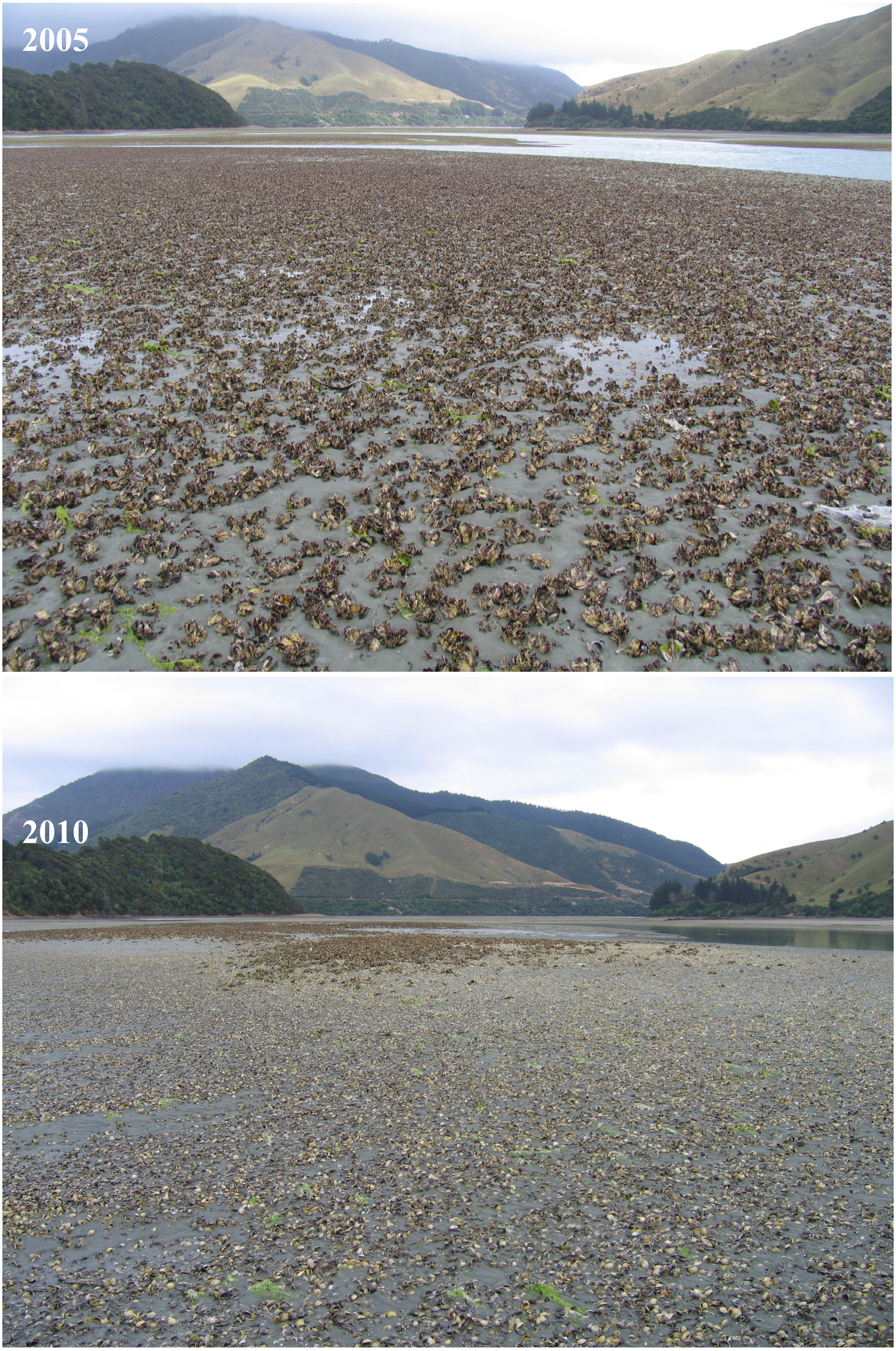

Figure 11. An example of an established Pacific oyster bed in Delaware Inlet in 2005 as compared to 2010.

Figure 12. An example of the fine-grained (note footprints) mounds that Pacific oyster beds have created in Delaware Inlet, December 2010.

6.1.3. Regional comparison

Comparing the relative 'health' of estuaries is not a straight-forward process due to differences in influencing factors, such as freshwater inflow rate, tidal flushing regime, geology and catchment characteristics. Hence, the absence or dominance of a particular habitat does not necessarily mean one estuary is 'healthier' than another. However, a general comparison between both local and regional estuaries can indicate similar trends and potentially signify problem areas that require further investigation. A comparison of the percent coverage of the key structural and vegetative habitats within Delaware Inlet with those of other estuaries in the Nelson Bays and Marlborough region (Table 2) reflects a high general diversity with some indications of a healthy and functioning estuarine system (*e.g*. relatively high seagrass presence and low percent coverage of muddy habitats). When interpreting these comparisons, however, it is important to recognise that none of the estuaries surveyed represent completely unmodified ("pristine") conditions. Historical mapping exercises carried out on some estuaries in the Nelson region (*i.e.* Waimea Inlet (Tuckey & Robertson 2003), Moutere Inlet (Clark & Gillespie 2007) and the Motueka Delta (Tuckey *et al*. 2004) identified significant losses in salt marsh vegetation (herbfield and rushland classes) between the earliest available records in the 1940s and the 1980s. In most cases these losses were due to infilling of estuary margins for roading, flood control or other developments with consequent destruction of primarily *Sarcocornia quinqueflora* and *Juncus kraussii* marsh habitats. Losses since the 1980s have been far less. Historical comparisons for Delaware Inlet do not go back far enough to assess the earlier effects of development (*e.g.* catchment clearing, roading), although it is likely that some losses of salt marsh habitats have occurred.

Table 2. A comparison of the percent coverage of dominant vegetated and unvegetated habitats in Delaware Inlet with other Nelson/Marlborough estuaries. Note specific habitat percentages (*e.g.* mud or herbfield) represent the proportion of that habitat out of the total estuary area.

Habitat Type	Delaware Inlet 2009 (%) *	Waimea Inlet 2007 (%) [1]	Ruataniwha 2002 (%) [2]	Moutere 2004 (%) [3]	Havelock 2002 (%) [2]
Water	6.2	11.8	15.9	7.5	27.9
Unvegetated	74.7	77.0	68.7	81.4	36.8
Mud Habitats	24.8	57.3	34.0	65.9	36.3
Sand Habitats	29.8	10.8	24.8	9.2	0.0
Gravel/Cobble	7.8	8.6	9.9	5.9	0.5
Vegetated	19.1	11.1	15.4	11.1	35.3
Herbfield	1.8	4.6	0.4	3.8	0.2
Reedland	0.2	0.0	0.0	<0.01	6.2
Rushland	4.5	3.1	13.4	5.6	22.9
Seagrass meadow	1.3	0.6	1.4	<0.01	0.1
Sedgeland	0.05	<0.01	0.0	<0.01	0.0
Total area of estuary (ha)	**353***	**3345**	**863.5**	**761.9**	**817**

* Delaware Inlet results were clipped to 1983 boundaries in order to remove supra-littoral fringe habitats from the current comparison.
[1] Clark *et al.* 2008
[2] Robertson *et al.* 2002
[3] Clark *et al.* 2006

6.2. Hardening of the land/sea interface

In most estuaries in New Zealand, modification or development of the surrounding land has resulted in a loss of connectivity with freshwater wetland habitats. These wetland regions process inorganic nutrients, thereby reducing the potential for macro- and microalgal blooms, and are important sources of dissolved and particulate organic materials that contribute to the coastal food web. They also provide habitat for a wide range of species, including fish that migrate across salinity gradients and a variety of birds.

There are a number of small streams bordering Delaware Inlet where this connectivity has been compromised due to roading, agricultural uses and/or residential development. Through this loss in land-sea connectivity, these modifications have likely had some impact on estuarine ecosystem processes. This form of inhibition of estuarine function is a common occurrence amongst estuaries in the Nelson/Tasman region (Clark & Gillespie 2007), and can be described in simple terms as the "hardening" of intertidal boundaries and associated reduction in area of ecologically important peripheral estuary habitats.

7. RECOMMENDATIONS

7.1. Ongoing SOE monitoring

Delaware Inlet is an integral component of the marine ecosystem of eastern Tasman Bay. Its contribution to ecosystem processes (*e.g.* maintenance of biodiversity and nourishment of the coastal food web) takes on added importance due to close proximity of the Horoirangi Marine Reserve to the west and the Wakapuaka Taiapure Management Area that includes the estuary and the receiving environment of Delaware Bay (see Figure 1). Consequently monitoring of the health of the estuary should be considered a high priority in the context of the values attached to the surrounding coastal region.

The general characteristics of Delaware Inlet and its contributing catchment provide evidence to a complex, high-value estuarine environment (Gillespie 2009). Despite suspected early historical changes to estuary margins and more recent changes in catchment land-use activities (*e.g.* forestry and agriculture), the functional and structural integrity of Delaware's estuarine environment appears to have remained relatively intact. Results of the broad-scale habitat mapping survey reported here, in conjunction with earlier preliminary and fine-scale assessments of estuary condition completes implementation of the three main components of the EMP for Delaware Inlet providing a baseline for ongoing monitoring. The EMP decision matrix, trialled for Delaware Inlet as part of the preliminary health assessment (Gillespie 2009), highlights this estuary as one of the more 'pristine' estuaries in the region. Therefore, it should be considered a high priority for inclusion in a coordinated Nelson Bays SOE monitoring programme.

We recommend that Council consider reassessment of estuary characteristics at approximately five-year intervals in accordance with the EMP. This will enable evaluation of changes in estuary condition over time and comparison with the performance of other estuaries in the Nelson Bays as an important step towards achieving integrated coastal management for the region.

7.2. Potential areas of further investigation

7.2.1. Decreases in area coverage of key vegetative habitats

Eelgrass meadows are recognised as having particular ecological importance, however the area coverage of this habitat is relatively small in most Nelson Bays estuaries. Eelgrass meadows can be sensitive to changing catchment influences and physical disturbance, such as referred to in Section 6.1.1. Since the mapping results suggest that this habitat may be under stress, efforts should be made monitor and minimise any ongoing decline or direct disturbance where possible.

The aerial coverage of peripheral salt marsh habitats (*e.g*. rushland) has declined in many Nelson Bays estuaries over the past 50 to 70 years, and, although speculative at this stage, there is some indication that a modest decline in rushland area has occurred in Delaware Inlet over the past 26 years. This potential reduction warrants further researcher into the extent and more importantly, possible causes.

7.2.2. Expansion in area coverage of mud-dominated substrata

Since exotic forestry is a major land use in the Wakapuaka catchment (*i.e*. 42% of the total catchment), and significant areas have been harvested during recent years, there is an increased risk that periodic pulses of erosional input of fine-grained sediments will result in a change in habitat structure with greater dominance of muddy substrata. Although there are a number of uncertainties concerning the apparent increase in the area of muddy substrata by way of comparison of 2009 mapping results with generalised historical estimates, this is seen as an important area for further investigation and/or future monitoring.

7.2.3. Spread of Pacific oyster habitat

The exotic Pacific oyster population has become well established in Delaware Inlet. As with any invading species, however, there are questions concerning the rate of its spread and implications to the physical structure and ecological function of the estuary. There is also potential for Delaware Inlet to act as a source location for larval delivery and settlement in adjacent coastal regions. These questions highlight the need for further investigation/monitoring of temporal changes in oyster habitat coverage and associated ecological characteristics.

7.3. Habitat restoration

Extensive patches of young and mature estuarine and terrestrial scrub were evident along sections of the estuary margins. These were partly due to ongoing Council, iwi and community riparian plantings. The restoration of areas bordering estuaries and particularly those grading into freshwater wetland habitats should therefore be encouraged where possible.

Aside from being potentially important habitats in themselves (*e.g.* whitebait spawning sites), supra-littoral fringe zones provide essential linkages between estuarine and terrestrial systems. Current planting projects led by NCC, and local community and iwi have resulted in dramatic native regrowth along the Wakapuaka River and associated wetland margins as well as along southern margins of Pepin Island (Appendix 5). Continuation of these projects is recommended as they will result in a more natural land to sea succession of plant communities.

7.4. Iwi estuary monitoring

We 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), NCC has encouraged 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.

8. ACKNOWLEDGEMENTS

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Mike Bailey (Cawthron) and Cable Bay resident, Julie McLintock assisted with field work and Cawthron's digitising team consisted of Simon Denton, Dana Clark and Olivia Johnston.

9. REFERENCES

Atkinson IAE 1985. Derivation of vegetation mapping units for an ecological survey of Tongariro National Park North Island, New Zealand. New Zealand Journal of Botany 23: 361-378.

Bull M 1981. Pacific oysters now in Tasman Bay. Catch 8: 12.

Clark KL, Gillespie PA 2007. Historical broadscale habitat mapping of Moutere Inlet (1947, 1988 and 2004). Prepared for Tasman District Council. Cawthron Report No. 1243. 19 p.

Clark KL, Stevens LM, Gillespie PA 2006. Broad-scale habitat mapping of Moutere Inlet. Prepared for Tasman District Council. Cawthron Report No. 1037. 14 p.

Clark KL, Gillespie PA, Forrest R, Asher R 2008. State of the Environment monitoring of Waimea Inlet: Broad-scale habitat mapping November 2006. Prepared for Tasman District Council and Nelson City Council. Cawthron Report No. 1473. 24 p.

Franko GD 1988. Vegetation map of the intertidal zone of Delaware Inlet, South Island, New Zealand. Scale 1:3750. Department of Scientific and Industrial research, Wellington.

Gillespie P 2009. Preliminary assessment of the environmental status of Delaware Inlet. Envirolink NLCC18. Cawthron Report No. 1549. 21 p + appendices.

Gillespie P**,** Clement D, Asher R 2009. Delaware Inlet fine-scale benthic baseline, 2009. Prepared for Nelson City Council. Cawthron Report No. 1594. 28 p.

Gillespie PA, MacKenzie AL 1981. Autotrophic and heterotrophic processes on an intertidal mud-sand flat, Delaware Inlet, Nelson, New Zealand. Bulletin of Marine Science 31 (3): 648-657.

Ministry for the Environment 2001. Environmental performance indicators: Confirmed indicators for the marine environment. ME No. 398, Ministry for the Environment, Wellington. 65 p.

Robertson BM, Gillespie PA, Asher RA, Frisk S, Keeley NB, Hopkins GA, Thompson SJ, Tuckey BJ 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93 p. Part B. 159 p. Part C. 40 p. + field sheets.

Robertson B, Stevens L 2008. Motupipi Estuary 2008 – Fine scale monitoring. Prepared for Tasman District Council. 20 p.

Stanton DJ, Bohlool BB, Beasley C 1977. Intertidal zone of Delaware Inlet, Nelson, New Zealand. NZ Journal of Marine and Freshwater Research 11(3):577-587.

Stevens L, Robertson B 2008. Motupipi Estuary 2007 – Broad-scale habitat mapping. Prepared for Tasman District Council.

Thrush SF, Hewwit JE, Norkkio A, Nicholls PE, Funnell GA, Ellis JI 2003. Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. Marine Ecology Progress Series 263:101-112.

10. APPENDICES

Appendix 1. Classification of estuarine habitat types (adapted UNEP-GRID classification).

Level I Hydrosystem	Level IA SubSystem	Level II Class	Level III Structural Class	Level IV Dominant Cover	Habitat Code
Estuary (alternating saline and freshwater)	Intertidal/ supratidal	Saltmarsh	Shrub/Scrub/Forest	*Beilschmiedia tawa* "Tawa"	Beta
				Cordyline australis "Cabbage tree"	Coau
				Cytisus scoparius "Broom"	Cysc
				Dodonea viscosa "Akeake"	Dovi
				Exotic scrub/shrub/trees	Esst
				Knightia excelsa "Rewarewa"	Knex
				Leptospermum scoparium, "Manuka"	Lesc
				Metrosideros excelsa " Pohutukawa"	Meex
				Myoporum laetum "Ngaio"	Myla
				Native scrub/shrub/trees	Nsst
				Paraserianthes lophantha " Brush wattle"	Palo
				Pinus radiata, "Pine tree"	Pira
				Ulex europaeus, "Gorse"	Uleu
			Estuarine Shrubland	*Plagianthus divaricatus*, "Saltmarsh ribbonwood"	Pldi
			Tussockland	*Carex* spp. "Sedge"	Casp
				Cortaderia selloana "Pampas grass"	Cose
				Cortaderia sp. "Toetoe"	Cosp
				Phormium tenax, "New Zealand flax"	Phte
				Stipa stipoides	Stst
			Grassland	*Ammophila arenaria* "Marram grass"	Amar
				Festuca arundinacea, "Tall fescue"	Fear
				Unidentified grass	Ungr
			Sedgeland	*Cyperus eragrostis* "Umbrella sedge"	Cyer
				Schoenoplectus pungens "Three-square"	Scpu
			Rushland	*Isolepis nodosa*, "Knobby clubrush"	Isno
				Juncus kraussii, "Searush"	Jukr
				Leptocarpus similis, "Jointed wirerush"	Lesi
			Reedland	*Typha orientalis* "Raupo"	Tyor
			Herbfield	*Carpobrotus edilus* "Ice Plant"	Caed
				Samolus repens, "Primrose"	Sare
				Sarcocornia quinqueflora, "Glasswort"	Saqu
				Selliera radicans, "Remuremu"	Sera
				Suaeda novae-zelandiae "Sea Blite"	Suno
			Introduced weeds	Unidentified Introduced Weeds	Inwe
		Eelgrass meadow	Eelgrass meadow	*Zostera sp*, "Eelgrass"	Zosp
		Macroalgal bed	Macroalgal bed	*Enteromorpha* sp.	Ensp
				Gracilaria chilensis	Grch
				Ulva sp, "Sea lettuce"	Ulri
		Pine Debris	Pine Debris		Pidb
		Artificial Structure	Man-made structure		MM
			Road		Road
			Wharf		WHF
		Mud/sandflat	Firm sand		FS
			Soft sand		SS
			Mobile sand		MS
			Firm mud/sand		FMS
			Soft mud/sand		SM
			Very soft mud/sand		VSM
		Stonefield	Cobble field		CF
			Gravel field		GF
			Boulder-field (man-made)		BFmm
		Shellfish field	Shell bank		Shel
		Worm field	Sabellid field		Tube
	Subtidal	Water	Water		Wter

Appendix 2. Definitions of classification Level III Structural Class

Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is >80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10cm dbh are classified as trees.
Treeland: Cover of trees in canopy 20-80%. Trees are woody plants >10cm dbh.
Scrub: Woody vegetation in which the cover of shrubs and trees in the canopy is >80% and in which shrub cover exceeds that of trees (*cf.* FOREST). Shrubs are woody plants <10 cm dbh.
Shrubland: Cover of shrubs in canopy 20-80%. Shrubs are woody plants <10 cm dbh.
Duneland: Vegetated sand dunes in which the cover of vegetation in the canopy (commonly Spinifex, Pingao or Marram grass) is 20-100% and in which the vegetation cover exceeds that of any other growth form or bare ground.
Tussockland: Vegetation in which the cover of tussock in the canopy is 20-100% and in which the tussock cover exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples of the growth form occur in all species of Cortaderia, Gahnia, and Phormium, and in some species of Chionochloa, Poa, Festuca, Rytidosperma, Cyperus, Carex, Uncinia, Juncus, Astelia, Aciphylla, and Celmisia.
Grassland: Vegetation in which the cover of grass in the canopy is 20-100%, and in which the grass cover exceeds that of any other growth form or bare ground. Tussock-grasses are excluded from the grass growth-form.
Sedgeland: Vegetation in which the cover of sedges in the canopy is 20-100% and in which the sedge cover exceeds that of any other growth form or bare ground. Sedges vary from grass by feeling the stem. If the stem is flat or rounded, it is probably a grass or a reed, if the stem is clearly triangular, it is a sedge. Sedges include many species of Carex, Uncinia, and Scirpus. Tussock-sedges and reed-forming sedges (*cf.* REEDLAND) are excluded.
Rushland: Vegetation in which the cover of rushes in the canopy is 20-100% and in which the rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in the rush growth form are some species of Juncus and all species of, Leptocarpus. Tussock-rushes are excluded.
Reedland: Vegetation in which the cover of reeds in the canopy is 20-100% and in which the reed cover exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either hollow or have a very spongy pith. The flowers will each bear six tiny petal-like structures – neither grasses nor sedges will bear flowers. Examples include *Typha, Bolboschoenus, Scirpus lacutris, Eleocharis sphacelata,* and *Baumea articulata.*
Cushionfield: Vegetation in which the cover of cushion plants in the canopy is 20-100% and in which the cushion-plant cover exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.
Herbfield: Vegetation in which the cover of herbs in the canopy is 20-100% and in which the herb cover exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not identified as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.
Lichenfield: Vegetation in which the cover of lichens in the canopy is 20-100% and in which the lichen cover exceeds that of any other growth form or bare ground.
Seagrass meadows: Seagrasses (including eelgrass) are the sole marine representatives of the class Angiospermae. They all belong to the order Helobiae, in two families: Potamogetonaceae and Hydrocharitaceae. Although they may occasionally be exposed to the air, they are predominantly

submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries.

Macroalgal bed: Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain chlorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae observable without using a microscope.

Firm mud/sand: A mixture of mud and sand, the surface appears brown, and many have a black anaerobic layer below. When walking on the substrate you will sink 0-2 cm.

Soft mud/sand: A mixture of mud and sand, the surface appears brown, and many have a black anaerobic layer below. When walking on the substrate you will sink 2-5 cm.

Very soft mud/sand: A mixture of mud and sand, the surface appears brown, and many have a black anaerobic layer below. When walking on the substrate you will sink greater than 5 cm.

Mobile sand: The substrate is clearly recognised by the granular beach sand appearance and the often rippled surface layer. Mobile sand is continually being moved by strong tidal or wind-generated currents and often forms bars and beaches. When walking on the substrate you will sink less than 1 cm.

Firm sand: Firm sand flats may be mud-like in appearance but are granular when rubbed between the fingers, and solid enough to support an adult's weight without sinking more than 1-2 cm. Firm sand may have a thin layer of silt on the surface making identification from a distance impossible.

Soft sand: Substrate containing greater than 99% sand. When walking on the substrate you will sink greater than 2 cm.

Stone field/Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) and/or bare stones (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. Stonefields and gravelfields are named based on which form has the greater ground cover. They are named from the leading plant species when plant cover of ≥1%.

Cobble field: Land in which the area of unconsolidated cobbles/stones (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. Cobble fields are named from the leading plant species when plant cover of ≥1%.

Boulder field: Land in which the area of unconsolidated bare boulders (>200 mm diam.) exceeds the area covered by any one class of plant growth-form. Boulderfields are named from the leading plant species when plant cover is ≥1%.

Rock/Rock field: Land in which the area of residual bare rock exceeds the area covered by any one class of plant growth-form. Cliff vegetation often includes rocklands. They are named from the leading plant species when plant cover is ≥1%.

Artificial structures: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates.

Cockle bed: Area that is dominated primarily by dead cockle shells.

Mussel reef: Area that is dominated by one or more mussel species.

Oyster reef: Area that is dominated by one or more oyster species.

Sabellid field: Area that is dominated by raised beds of sabellid polychaete tubes.

Appendix 3. Unvegetated substrata present in the Delaware Inlet, January 2009.

Class	Dominant Species	Primary Sub-dominant	Area (Ha) Intertidal	% Total Intertidal	Area (Ha) Supra-littoral
Bedrock			**0.68**	**0.26**	**0.49**
	Bedrock		0.21		0.14
		Cobble field	0.28		0.11
		Gelidium caulacantheum (macroalgae)	0.05		0.00
		Gravel field	0.14		0.25
Boulder Field			**0.17**	**0.06**	
	Boulder Field		0.03		
		Cobble field	0.13		
		Juncus kraussii (Searush)	0.00		
Cobble Field			**8.70**	**3.30**	**0.56**
	Cobble Field		0.18		0.07
		Boulder field	0.29		0.00
		Festuca arundinacea (tall fescue grass)	0.00		0.00
		Firm mud/sand (0-2cm)	0.45		0.00
		Gravel field	7.42		0.49
		Shell bank	0.36		0.00
Cockle Bed			**0.56**	**0.21**	
	Cockle Bed	Firm mud/sand (0-2cm)	0.48		
		Firm shell/sand (<1cm)	0.09		
Firm Mud/Sand			**54.63**	**20.72**	**0.33**
	Firm mud and sand		21.08		0.30
		Cobble field	0.26		0.01
		Firm shell and sand	18.18		0.00
		Gelidium caulacantheum (macroalgae)	0.35		0.00
		Gravel field	13.95		0.03
		Oyster Reef	0.02		0.00
		Ulva lactuca (macroalgae)	0.79		0.00
Firm Sand			**104.98**	**39.82**	**0.20**
	Firm Sand		18.00		0.04
		Cockle Bed	4.29		0.00
		Firm mud/sand (0-2cm)	62.83		0.12
		Firm shell/sand (<1cm)	15.61		0.00
		Gravel field	0.53		0.00
		Shell bank			0.04
		Ulva lactuca (macroalgae)	3.73		0.00
Firm Shell/Sand			**39.05**	**14.81**	**0.01**
	Firm Shell and Sand		21.03		0.00
		Firm mud and sand	1.04		0.01
		Gelidium caulacantheum (macroalgae)	2.07		0.00
		Gravel field	13.15		0.00
		Gracilaria secundata (macroalgae)	1.62		0.00
		Oyster reef	0.13		0.00
Gravel field			**18.82**	**7.14**	**15.93**
	Gravel field		0.50		0.01
		Cobble Field	3.98		0.12
		Firm mud and sand	2.79		0.06
		Firm Sand	3.55		14.42
		Firm Shell and Sand	3.75		1.31
		Shell bank	1.84		0.00
		Soft Mud	2.41		0.00
Man-Made Structures			**0.09**	**0.03**	**0.07**
	Man-Made Structures		0.03		0.04
		Wharf	0.01		0.00
		Rockfield Man-Made	0.04		0.03
Mobile Sand			**0.08**	**0.03**	
	Mobile sand (<1cm)	Shell bank	0.08		
Mussel Reef			**0.46**	**0.18**	
	Mussel reef	Firm Shell and Sand	0.28		
		Gravel field	0.14		
		water	0.04		

Class	Dominant Species	Primary Sub-dominant	Area (Ha) Intertidal	% of Total Intertidal	Area (Ha) Supra-littoral
Oyster Reef			**0.98**	**0.37**	
	Oyster reef	Firm mud and sand	0.32		
		Gravel field	0.19		
		Shell bank	0.18		
		Soft Mud	0.04		
		Ulva lactuca (macroalgae)	0.25		
		water	0.00		
Rockfield			**1.20**	**0.46**	**1.99**
	Rockfield	Bedrock	0.29		0.03
		Cobble field	0.92		1.95
Shell bank			**0.27**	**0.10**	**0.10**
	Shell bank		0.27		0.00
		Soft Sand			0.09
Soft Mud			**31.10**	**11.80**	**0.13**
	Soft Mud		12.78		0.06
		Gravel field	6.38		0.01
		Gracilaria secundata (macroalgae)	4.62		0.06
		Shell bank	2.74		0.00
		Soft sand	3.48		0.00
		Ulva lactuca (macroalgae)	1.10		0.00
Soft Sand			**0.29**	**0.11**	**7.04**
	Soft Sand		0.29		7.04
Very Soft Mud			**1.60**	**0.61**	
	Very Soft Mud		0.74		
		Gravel field	0.86		
Grand Total			**263.65**	**100.00**	**26.84**

Overall Summary		
Water	**21.81**	**1.36**
Unvegetated Substrata	**263.65**	**26.84**
Estuarine Vegetation	**67.48**	**41.27**
Grand Total	**352.94**	**69.47**

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Appendix 4. Vegetated substrata present in Delaware Inlet, January 2009.

Class	Dominant Species	Primary Sub-dominant	Area (Ha) Intertidal	% Total Intertidal	Area (Ha) Supra-littoral
Estuarine Shrubs			**2.20**	**3.26**	**0.81**
	Muehlenbeckia complexa (Maidenhair Vine)		0.03		0.00
		Festuca arundinacea (tall fescue grass)	0.05		0.00
		Phormium tenax (NZ Flax)	0.05		0.01
	Plagianthus divaricatus (Saltmarsh ribbonwood)		0.95		0.25
		Festuca arundinacea (tall fescue grass)	0.38		0.19
		Juncus kraussii (Searush)	0.61		0.28
		Leptocarpus similis (Jointed wirerush)	0.05		0.00
		Muehlenbeckia complexa (Maidenhair Vine)	0.01		0.08
		Phormium tenax (NZ Flax)	0.09		0.00
Grassland			**2.26**	**3.35**	**16.47**
	Ammophila arenaria (Marram grass)	*Cortaderia* sp. (Toetoe)	0.29		6.84
		Festuca arundinacea (tall fescue grass)	0.00		0.03
		Muehlenbeckia complexa (Maidenhair Vine)	0.43		4.49
	Festuca arundinacea (Tall fescue)		0.06		0.18
		Leptocarpus similis (Jointed wirerush)	0.37		0.00
		Native scrub	0.96		4.01
		Plagianthus divaricatus (Saltmarsh ribbonwood)	0.15		0.87
		Ulex europaeus (Gorse)	0.00		0.05
Herbfield			**6.45**	**9.56**	**0.46**
	Calystegia sepium (Pink bindweed)		0.01		0.00
		Gravel field	0.00		0.16
	Disphyma australe (NZ Ice plant, Horokaka)		0.03		0.01
	Mimulus repens		0.03		0.00
	Samolus repens (Primrose)		0.02		0.00
		Sarcocornia quinqueflora (Glasswort)	3.37		0.21
	Sarcocornia quinqueflora (Glasswort)		1.65		0.02
		Firm mud/sand (0-2cm)	0.52		0.00
		Firm sand (<1cm)	0.08		0.00
		Gravel field	0.18		0.00
		Juncus kraussii (Searush)	0.17		0.00
		Samolus repens (Primrose)	0.06		0.01
		Suaeda novaeûzelandiae (Sea blite)	0.22		0.03
	Suaeda novaeûzelandiae (Sea blite)		0.02		0.01
		Firm mud/sand (0-2cm)	0.01		0.00
		Sarcocornia quinqueflora (Glasswort)	0.07		0.02
Introduced Weeds			**0.36**	**0.54**	**2.68**
	Unidentified introduced weeds		0.01		0.00
		Ulex europaeus (Gorse)	0.35		2.68
Macroalgal bed			**33.68**	**49.92**	**0.03**
	Enteromorpha sp. (Green ribbon)	Cobble field	0.00		0.00
		Gravel field	0.01		0.00
		Ulva sp. (Sea lettuce)	0.32		0.00
		Water	0.33		0.02
	Gelidium caulacantheum	Gravel field	2.55		0.01
	Gracilaria chilensis	Firm mud/sand (0-2cm)	1.69		0.00
		Firm sand (<1cm)	0.26		0.00
		Gelidium caulacantheum	0.64		0.00
		Gravel field	0.07		0.00
		Soft mud/sand (2-5cm)	0.28		0.00
		Ulva sp. (Sea lettuce)	10.23		0.00
		Water	0.01		0.00
	Ulva sp. (Sea lettuce)	*Enteromorpha* spp. (Green ribbon)	0.13		0.00
		Firm mud/sand (0-2cm)	0.17		0.00
		Firm shell/sand (<1cm)	6.44		0.00
		Gelidium caulacantheum	0.17		0.00
		Gracilaria chilensis	9.18		0.00

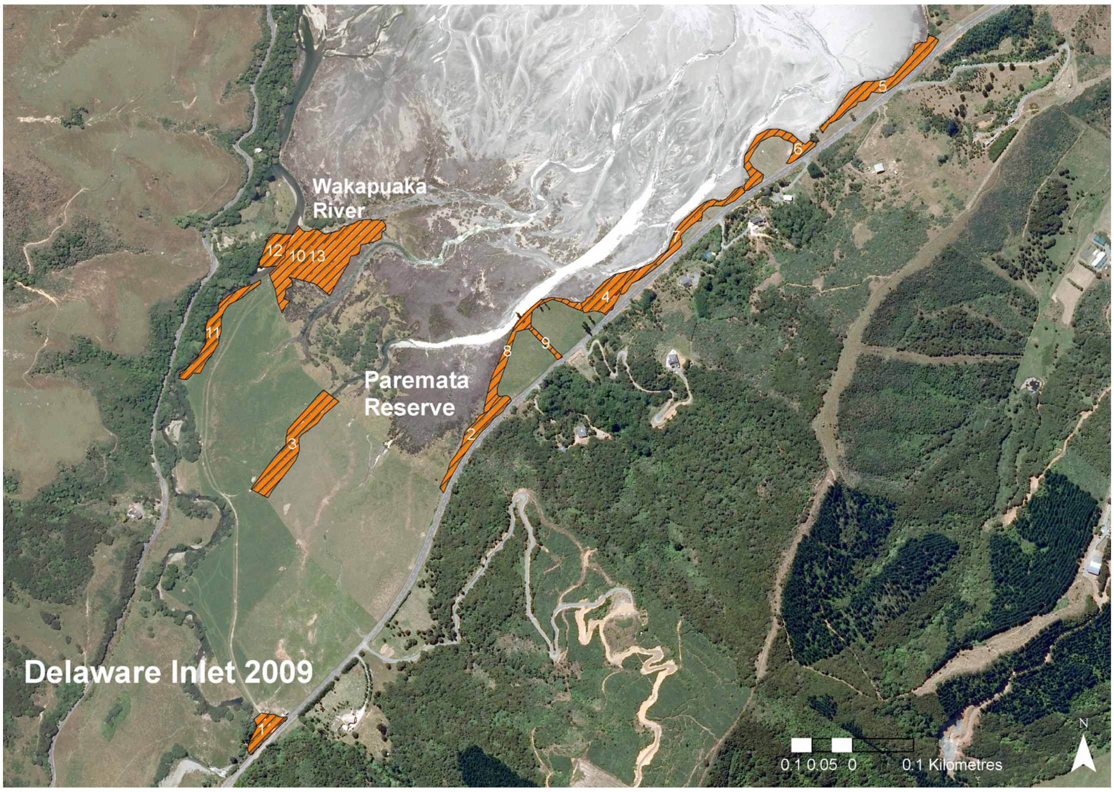
Class	Dominant Species	Primary Sub-dominant	Area (Ha) Intertidal	% Total Intertidal	Area (Ha) Supra-littoral
Macroalgal bed (conti)					
	Ulva sp. (Sea lettuce)	Soft mud/sand (2-5cm)	0.08		0.00
		Zostera sp. (Eelgrass)	1.14		0.00
		Water	0.01		0.00
Pine Debris			**0.02**	**0.03**	**0.07**
	Pine Debris		0.02		0.07
Reedland			**0.80**	**1.19**	**0.09**
	Typha orientalis (Raupo)		0.80		0.06
		Phormium tenax (NZ Flax)	0.00		0.03
Rushland			**15.72**	**23.30**	**0.91**
	Isolepis nodosa (Knobby clubrush)		0.00		0.00
	Juncus kraussii (Searush)		6.31		0.36
		Cobble field	0.01		0.00
		Gravel field	0.10		0.00
		Isolepis cernua (Slender clubrush)	0.05		0.00
		Juncus articulatus (Jointed rush)	0.04		0.01
		Leptocarpus similis (Jointed wirerush)	4.23		0.42
		Samolus repens (Primrose)	0.31		0.01
		Sarcocornia quinqueflora (Glasswort)	2.61		0.03
		Soft mud/sand (2-5cm)	1.11		0.04
	Leptocarpus similis (Jointed wirerush)		0.13		0.03
		Juncus kraussii (Searush)	0.81		0.00
Seagrass meadow			**4.49**	**6.66**	
	Zostera sp. (Eelgrass)	Firm mud/sand (0-2cm)	1.38		
		Firm shell/sand (<1cm)	1.21		
		Gravel field	0.03		
		Ulva sp. (Sea lettuce)	1.63		
		Water	0.24		
Sedgeland			**0.17**	**0.25**	
	Cyperus eragrostis (Umbrella sedge)		0.08		
	Isolepis cernua (Slender clubrush)		0.00		
	Schoenoplectus pungens (Three-square)		0.09		
Terrestrial Shrub/Scrub/Forest			**1.06**	**1.57**	**19.66**
	Dodonea viscosa (Ake ake)		0.00		0.06
	Myoporum laetum (Ngaio)		0.03		0.04
	Native scrub/shrub/trees		0.14		10.67
		Cortaderia sp. (Toetoe)	0.18		1.11
		Festuca arundinacea (tall fescue grass)	0.04		0.15
		Pinus radiata (Pine tree)	0.19		2.29
		Ulex europaeus (Gorse)	0.02		0.53
	Pinus radiata (Pine tree)		0.25		3.34
	Salix fragilis (Crack willow)		0.04		0.06
	Ulex europaeus (Gorse)		0.04		0.21
		Dodonea viscosa (Ake ake)	0.00		0.57
		Festuca arundinacea (tall fescue grass)	0.05		0.53
		Muehlenbeckia complexa (Maidenhair Vine)	0.05		0.00
		Typha orientalis (Raupo)	0.03		0.09
Tussockland			**0.28**	**0.41**	**0.09**
	Cortaderia jubata (Purple pampas grass)	*Phormium tenax (NZ Flax)*	0.00		0.04
	Cortaderia sp. (Toetoe)		0.00		0.00
		Phormium tenax (NZ Flax)	0.10		0.00
	Phormium tenax (NZ Flax)		0.12		0.03
		Juncus kraussii (Searush)	0.01		0.00
		Ulex europaeus (Gorse)	0.00		0.02
	Unidentified tussock		0.04		0.00
Grand Total			**67.48**	**100.00**	**41.27**

Overall Summary		
Water	**21.81**	**1.36**
Unvegetated Substrata	**263.65**	**26.84**
Estuarine Vegetation	**67.48**	**41.27**
Grand Total	**352.94**	**69.47**

Appendix 5. Council-initiated plantings of the estuary margin within Delaware Inlet.

NCC Scheduled Plantings with location estimates highlighted on the map below:

1. 2001 – Paremata Reserve entrance planting
2. 2002 – Maori Pa Road slopes above reserve
3. 2003 – Central Stream planting (natural spring fenced off)
4. 2004 – Estuary margin planting
5. 2005 – Estuary margin planting
6. 2006 – Estuary margin planting
7. 2006 – Estuary margin planting
8. 2007 – Estuary margin planting
9. 2007 – Stream planting
10. 2008 – Scenic Reserve planting
11. 2009 – Wakapuaka River margin planting
12. 2009 – Scenic Reserve planting and removal of willows
13. 2010 – Scenic Reserve planting and removal of willows



Appendix 6. DVD-ROM file containing a working version of the 2009 broad-scale habitat maps of Delaware Inlet (entitled "Broad-Scale Intertidal Habitat Mapping: Delaware Inlet January 2009").