CAWTHRON

Preliminary Assessment of the Environmental Status of Delaware Inlet

Cawthron Report No. 1549

January 2009

Preliminary Assessment of the Environmental Status of Delaware Inlet

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Prepared for

Nelson City Council

under a FRST Envirolink grant

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Recommended citation:
Gillespie P 2008. Preliminary Assessment of the Environmental Status of Delaware Inlet. Prepared for Nelson City Council. Cawthron Report No. 1549. 21 p. plus appendices.

EXECUTIVE SUMMARY

Nelson City Council requested advice and assistance in the compilation and evaluation of background information required for follow up determination of the degree of modification of the condition/health of Delaware Inlet. This information was required as a basis for future incorporation of Delaware Inlet into the overall State of the Environment (SOE) monitoring framework for the region. The work was funded by the Foundation for Research Science and Technology through Envirolink NLCC18.

The present report provides:

(1) A compilation of background information relevant to the ecological condition of Delaware Inlet,

(2) A digitised historical vegetation map of Delaware Inlet (1983), and

(3) A preliminary ranking of the ecological status and values of Delaware Inlet.

Evaluation of the general characteristics of the Delaware Inlet and its contributing catchment gives evidence to a complex, high-value estuarine environment. The Inlet has generally been considered to be a site of naturally high biodiversity with considerable ecosystem services attached. Nonetheless, during the past 160 years, the Delaware Inlet and its contributing catchment have been subjected to modifications that are likely to have had some effect on the functional integrity of the estuary environment. These are summarised below:

(1) In conjunction with European settlement during the mid to late 1800s, areas of dense native forest near the estuary were cleared for agricultural development by the felling and burning of timber. Much of this land was subsequently converted to grass for grazing. Although no clear records were found of the areas involved, these changes were likely to have been sufficient to result in some alteration in sediment and nitrogen discharges to the estuary.

(2) More than 400 ha coverage of the introduced nitrogen-fixing legumes, gorse and broom, within the Wakapuaka catchment and additional coverage surrounding the Inlet have likely contributed to nitrogen runoff and consequently the productivity of intertidal plant habitats.

(3) Although a past history of super phosphate aerial topdressing of adjacent pasture lands would have resulted in direct phosphorus runoff to the estuary, this is not expected to have had a significant enrichment effect due to the fact that nitrogen is proportionally more limiting for growth of intertidal vegetation.

(4) Conversion of large catchment areas to pine plantation and subsequent harvesting would also likely have had significant periodic effects on sediment loadings to the estuary. Considerable areas of pine forest have been harvested since the 1980s, when the last detailed investigations of intertidal habitat structure were undertaken.

(5) Development of agriculture, particularly adjacent to the eastern estuary arm is likely to have had some enrichment effects on intertidal habitats. Although this probably has contributed to the productivity of the estuary, previous investigations provide no evidence of adverse enrichment effects.

(6) Although historic removal of lowland freshwater wetland habitats has partially interfered with the continuity of terrestrial ↔ freshwater ↔ intertidal habitats in some places, this aspect has

not been fully explored. Roading along both sides of the estuary and flood control measures have added to this "hardening" of the land/sea interface.

(7) Adverse effects related to reduced water quality (*e.g*. elevated faecal bacterial loadings in shellfish, localised macroalgal blooms), may have occurred in conjunction with agricultural and residential development, however no monitoring data were found to assess this.

(8) The invasion and spread of the exotic bivalve *Crassostrea gigas* (Pacific oyster) poses a particular threat to the natural character and ecological integrity of Delaware Inlet. Although the Pacific oyster has potential value as a 'new' harvestable resource, it can also impact adversely on the previously existing indigenous resources. 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.

Since no formal monitoring programme has been implemented for the Inlet, there now exists a 20+-year gap in detailed ecological information. It is therefore difficult to accurately assess the present condition of the estuary environment.

Estuary-wide, broad-scale habitat mapping and fine-scale assessment of individual reference sites, are recommended. In addition to providing a means of updating historical information and assessing long-term change, the use of standardised methods would enable comparison with other estuaries in the region and serve as a point-in-time baseline for future monitoring. In conjunction with SOE monitoring, it is recommended that scoring of the appended estuary Decision Matrix (DM) spreadsheet be revised with community/iwi input and periodically updated to provide a working document for prioritising estuary management requirements.

No data were found describing water and shellfish faecal indicator concentrations in Delaware Inlet. In view of the possible risk with respect to the human consumption of shellfish, and the potential for increased future risks due to changes in land catchment and estuary uses, implementation of faecal indicator monitoring is recommended.

I also support the use of Delaware Inlet as a case study location for coordinated implementation of scientific and iwi cultural indicators of estuary condition. This could potentially have far-reaching benefits for the sustainable management of coastal environments in the region and other parts of New Zealand.

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1. INTRODUCTION

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 resulting Estuary Monitoring Protocol (EMP) recommends that a preliminary characterisation and assessment is carried out of each estuary considered for inclusion in a regional State of the Environment (SOE) management plan.

The EMP has been implemented within a series of estuaries on the Western side of Tasman Bay and in Golden Bay (Robertson *et al*. 2002; Gillespie & Clark 2006; Robertson & Stevens 2008). A long-term objective of the Nelson City and Tasman District councils is to coordinate all significant estuaries within the Nelson Bays into a coordinated SOE monitoring programme through implementation of the EMP. The Nelson City Council is considering inclusion of a number of estuaries in eastern Tasman Bay into this programme. Delaware Inlet (Figure 1) is one of the estuaries considered for inclusion.

Figure 1. Map of Delaware Inlet.

Nelson City Council seeks advice and assistance in compilation and evaluation of background information required for determination of the degree of modification of the condition/health of Delaware Inlet. This information is required in summary form as a basis for future incorporation of Delaware Inlet into the overall SOE monitoring framework for the region. The work was funded by the Foundation for Research Science and Technology through Envirolink NLCC18.

The present report provides:

(1) A compilation of background information relevant to the ecological condition of Delaware Inlet,

(2) A digitised historical vegetation map of Delaware Inlet, and

(3) A preliminary ranking of the ecological status and values of Delaware Inlet.

1.1. Methods

The assessment was undertaken in three steps as described in the following sections.

1.1.1. Summary of estuary characteristics

Relevant background information describing the estuary and its contributing catchment was compiled from the general literature, data held by the Nelson City Council, the former Nelson Catchment and Regional Water Board and Cawthron's previous research experience involving the estuary. The information was organised into broad categories as described in the EMP (Part B, Appendix A) and briefly summarised and evaluated in relation to estuary condition.

1.1.2. Historical vegetation map

A detailed vegetation map of the intertidal zone of Delaware Inlet (Franko 1988) was converted to digital format using Arcmap 9.0 GIS software. The areas of major vegetation types were then calculated using the software. The original map was based on June 1983 aerial photographs (altitude 760 m) and extensive ground-truthing between May 1983 and April 1984). Although some detail was unavoidably lost during the digitisation step, the revised vegetation map provides a point-in-time reference that can be used to assess change over time.

1.1.3. Decision matrix

The final step of the assessment was to prepare a flexible tool, the 'Decision Matrix' (DM), to give a rapid, broad overview of the condition/status of the estuary. The DM format was revised from that presented by Robertson *et al.* (2002) and modified for Delaware Inlet in order to place monitoring priority on pristine rather than modified environments. The revised spreadsheet uses three general categories of factors; a) existing estuary physical characteristics, b) natural character and resource values/uses and c) characteristics that indicate an existing adverse impact. Each of the various factors was assigned a score (or rating), a weighting (multiplier) and tabulated to arrive at an overall numerical assessment. The scores provided in this report were based on the authors' perspective only and are meant to provide context for engagement/consultation to achieve a broader outlook (*e.g.* from the community, iwi and various environmental interest groups). The DM scores can be re-evaluated periodically to assess changes reflecting new information (*e.g*. monitoring results) and/or changing values. It can also be useful to evaluate the present DM scores in the context of historical information (*e.g.* photographic records, reports, anecdotal perceptions) in order to determine whether changes in the various assessment factors indicate improvement, stability or degradation of estuary condition. Local knowledge can be particularly valuable by way of providing a reality check to the assigned scores and identifying changes over time that may influence interpretation.

1.1.4. Utility of the preliminary assessment

Once other estuaries within the region have been similarly assessed, review of the assembled information and application of the DM will enable prioritisation of efforts within a regional coastal management strategy. By ranking estuaries within a region, based on the combination of these factors, they can be evaluated in comparative terms, enabling a risk-based approach for deciding which estuaries require the most urgent consideration for more detailed assessment and monitoring.

In completing the DM for estuaries in a particular region, it is envisaged that managers will:

(a) Become more familiar with their estuaries,

(b) Identify knowledge gaps concerning their estuaries,

(c) Identify the significant values associated with their estuaries,

(d) Identify potential threats to estuarine values,

(e) Prioritise estuary monitoring requirements based on the perceived condition, potential threats, and significant values (*e.g.* ecological, cultural, recreational, economic).

2. RESULTS AND DISCUSSION

2.1. Estuary characteristics

2.1.1. Location, size and estuary type

Delaware Inlet (Figure 1) is a relatively small (336 ha) bar-built, fluvial erosion estuary on the eastern side of Tasman Bay. It is located at the mouth of the Wakapuaka River, approximately

19 km northeast of the city of Nelson. The estuary is enclosed by a 2 km long sandspit barrier along its eastern arm and a narrow strip of land, referred to as a boulder bank, connecting Pepin Island to the mainland that isolates estuary waters from Cable Bay. A narrow opening between the eastern shore of Pepin Island and the sandspit barrier provides the only access to tidal flushing from Tasman Bay.

2.1.2. *Morphology and hydrology*

Due to its broad, shallow configuration and large tidal ranges (from a minimum of <1.2 m during neap tides to >4.2 m during spring tides), the estuary is nearly completely drained with each ebb flow resulting in near-complete flushing with each tidal return. At extreme high tide, the estuary contains more than 5,300,000 m^3 of water, while at extreme low tide it contains only about 23,000 m^3 (calculated volume estimates provided by the Nelson Catchment and Regional Water Board, 1980). The main freshwater discharge to the Inlet is the Wakapuaka River (average flow 1.5 m^3/s) however minor contributions derive from a number of smaller streams (average total flow <0.1 m^3/s). Thus, during normal flows, significant reduction in salinity of estuarine waters is confined to the main channels at extreme low tide (Stanton *et al.* 1977; Gillespie, unpub.). During major flood events, river flows of around 300 m^3/s may be achieved resulting in significant salinity reduction throughout the Inlet and extending into Delaware Bay (MacMorland 1978).

2.1.3. *Seabed and general ecological characteristics*

Dominant features of the intertidal seabed of Delaware Inlet are extensive mud and sand flats, a complex, mixed-vegetation salt marsh (see Section 2.2) and abundant, diverse animal communities. Stanton *et al.* (1977) provides historical reference to the physical (Figure 2) and biological (Figures 3 and 4) structure of the intertidal zone. At that time, the seabed was comprised of approximately 55% sandflats, 15% mudflats, 15% gravel/cobble, 5% shell beds and 10% tidal channels. Extensive cockle (*Chione stutchburyi*) beds colonised sand, mud and fine gravels of tidal flats and slopes adjacent to the main channels. Although approximate, these records provide a useful comparison for future mapping investigations as a means of assessing change over a >30-year time span. In an illustrated guide to Delaware Inlet, Franko (1988), describes estuary biological communities, including birds, fish and intertidal plants and animals.

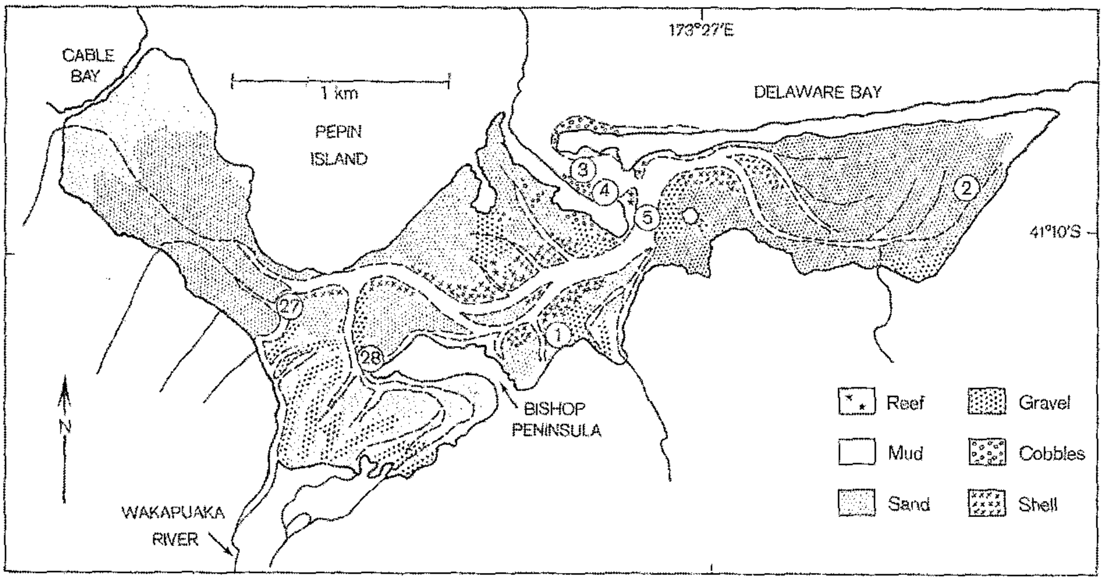

Figure 2. Historical sketch map of seabed textural composition in Delaware Inlet (from Stanton *et al* 1977).

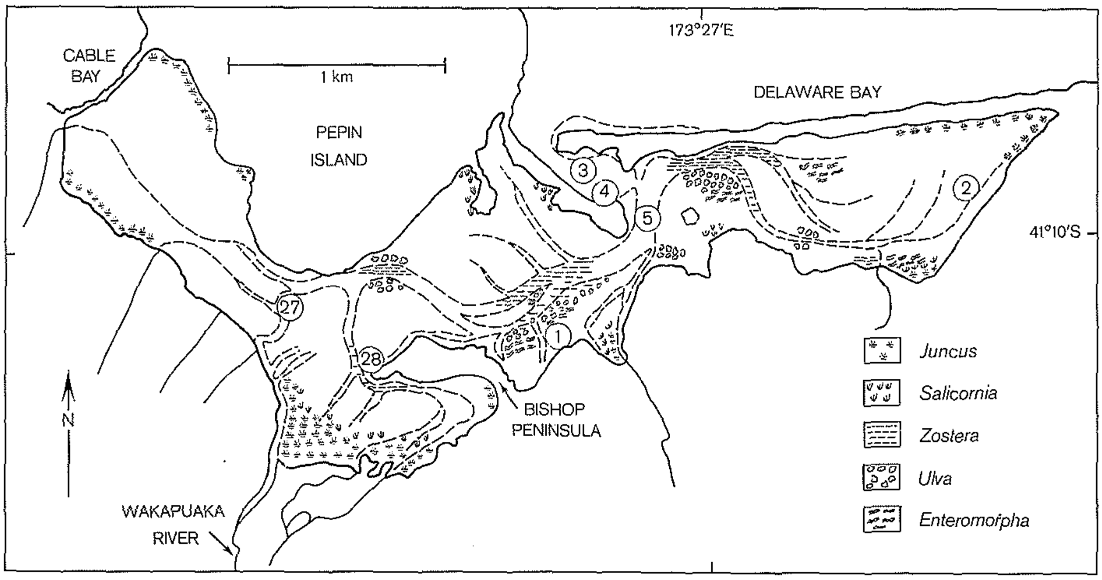

Figure 3. Historical sketch map of intertidal vegetation coverage in Delaware Inlet (from Stanton *et al* 1977).

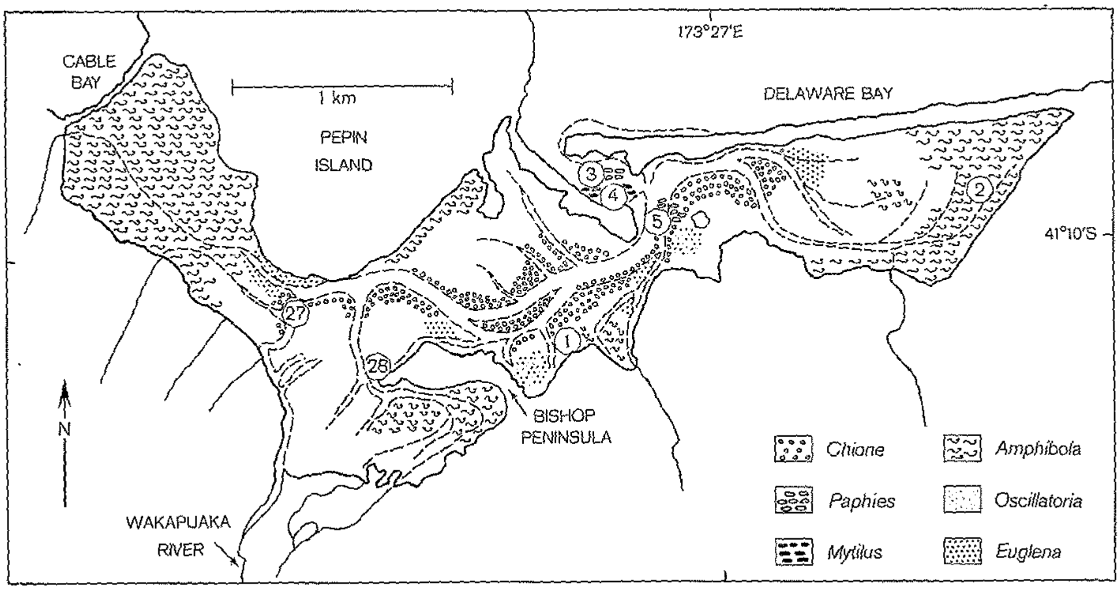

Figure 4. Historical sketch map of major intertidal biological habitats in Delaware Inlet (from Stanton *et al* 1977).

Gillespie & MacKenzie (1981) identified the major productive components of Delaware Inlet. The approximate net photosynthetic production of the estuary (summer maximum of salt marsh + eelgrass + macroalgae + benthic microalgae + phytoplankton) was estimated to be nearly one tonne C/day. Although, on an areal basis, this was equivalent to only about 0.3 g C/m^2/day, it was similar to a productive site in Tasman Bay during a spring phytoplankton bloom (Mackenzie & Gillespie 1986). This clearly indicates that Delaware Inlet provides an important link to the coastal food web of Tasman Bay. An interesting and potentially important ecological feature was identified at a number of locations within the sandflat habitat of the Inlet (Figure 4). It consisted of a yellow-green microbial film containing a filamentous cyanobacter (*Oscillatoria* sp.), a photosynthetic protozoan (*Euglena* sp.) and unidentified photosynthetic bacteria. These microbes migrate up and down in the sand depending on the state of the tide and the light intensity. In addition to the potential importance of this consortium to the carbon budget (and food web) it also contributes to the nitrogen budget due to the ability of the cyanobacter to fix atmospheric nitrogen (Bohlool & Wiebe 1978).

Other key physical and microbial processes that dictate ecosystem function in the estuary are described in Gillespie (1983a, b), Kaspar (1981, 1982), Juniper (1981, 1987a, 1987b) and Mountfort *et al.* (1980).

An important geographical feature of the Inlet is Bishops Peninsula, extending approximately 700 m westward across the eastern arm of the estuary (Figure 1). The peninsula strongly influences tidal current patterns resulting in the depositional accumulation of fine-grained, muddy sediments in the partially enclosed embayment below.

2.1.4. Human occupation

Based on archaeological evidence and oral history, the Delaware Inlet region, including the lower Wakapuaka catchment, may have been first settled as early as the 12th century (Sheridan 2007). Information provided in two volumes describing an account of the history of Maori of Nelson and Marlborough (Mitchell & Mitchell 2004, 2007) suggests that population densities have been generally low but variable in the vicinity of the estuary. Prior to the arrival of the first European settlers in early 1842, the Maori population in the Nelson Region was reduced to about 600. This was a result of the Tainui Taranaki incursions of the late 1820s and 1830s. Maori re-establishment occurred in the region along with the growing European communities. Varying census estimates for a pa located at the estuary indicate a population of between 90 and 150 during the year 1845 (Mitchell & Mitchell 2007).

A recent estimate of the population within the estuary catchment, based on the 2006 Statistics New Zealand - Census Usually Resident Population (CURP), is 642. This includes the Wakapuaka River catchment (545) and the Cable Bay (68) and Delaware Inlet regions (estimates provided by NCC).

2.1.5. Catchment characteristics

2.1.5.1. Area

The total catchment area of Delaware Inlet was estimated to be about 83 km^2 (Stanton *et al*. 1977). An area of 65 km^2 drains from the Wakapuaka River catchment with the remainder presumably from the eastern and western estuary arms.

2.1.5.2. Geology and soils

The geological structure and soil characteristics of the catchment contribute to the physico-chemical makeup of the seabed environment of Delaware Inlet. The Wakapuaka catchment, draining Nelson's ranges, is strongly influenced by a section of the Waimea Fault extending through the Lud Valley and along the eastern boundary of the lower Wakapuaka valley. Underlying bedrock within the Wakapuaka Valley is dominated by a belt of paleozoic volcanic rocks (the Brook Street Volcanics). Wakapuaka phyllonite within the River valley generates a range of fine- and coarse-grained sediments that can be found in the Inlet. Detailed geological description of the region is provided by Johnston (1981) and Rattenbury *et al.* (1998) and a simplified geological map showing major contributing fault zones is shown in Figure 5 (taken from Franko 1988).

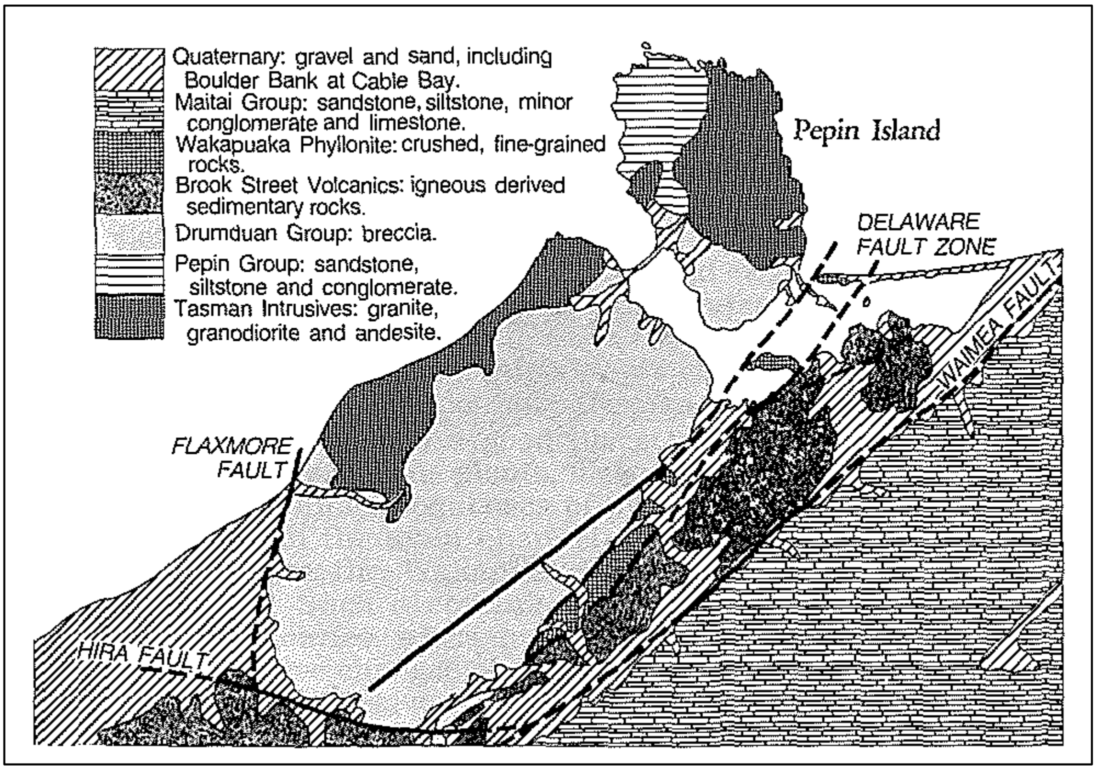

Figure 5. Simplified geological map of the Wakapuaka catchment (From Franko 1988).

The neighbouring Waimea and Maitai river catchments are known to be affected by erosional input from the Dunn Mountain mineral belt. This has resulted in unusually elevated sediment nickel and chromium contents within the Waimea (Gillespie *et al.* 2007) and Nelson Haven (Conwell 2007) estuaries. It is not presently known to what extent the Wakapuaka catchment has been similarly affected.

Wakapuaka sandy loam lines the Wakapuaka River below the Teal River convergence through the lower flood plain and estuary (Chittenden *et al.* 1966). It is formed on the alluvium derived from greywacke, argillite, sandstone and limestone rocks. This soil is of near-neutral pH with low to moderate phosphate, very low potassium and high calcium contents. The soil fertility is moderate but increasing towards the lower catchment. The fertility of the lower catchment probably contributes to the productivity of the salt marsh and tidal flat habitats of the Estuary. Ronga silt, bordering the Lud River, is similarly derived but without limestone influence. It is less fertile with moderate acidity and higher potassium content. Atawhai and Otu steepland soils of low to moderate fertility surround the western arm of the Inlet, including Pepin Island.

2.1.5.3. Land use

A breakdown of the land use classification of the Wakapuaka catchment as of 2002 (Figure 6, Table 2) shows the co-dominance of managed exotic forestry (42%) and native forest cover

(37%). Significant areas of grassland (14%) and gorse/broom (7%) coverage were also present. Because the latter introduced plants are legumes capable of fixing atmospheric nitrogen, they may have some influence on the rate of nitrogen runoff to the estuary.

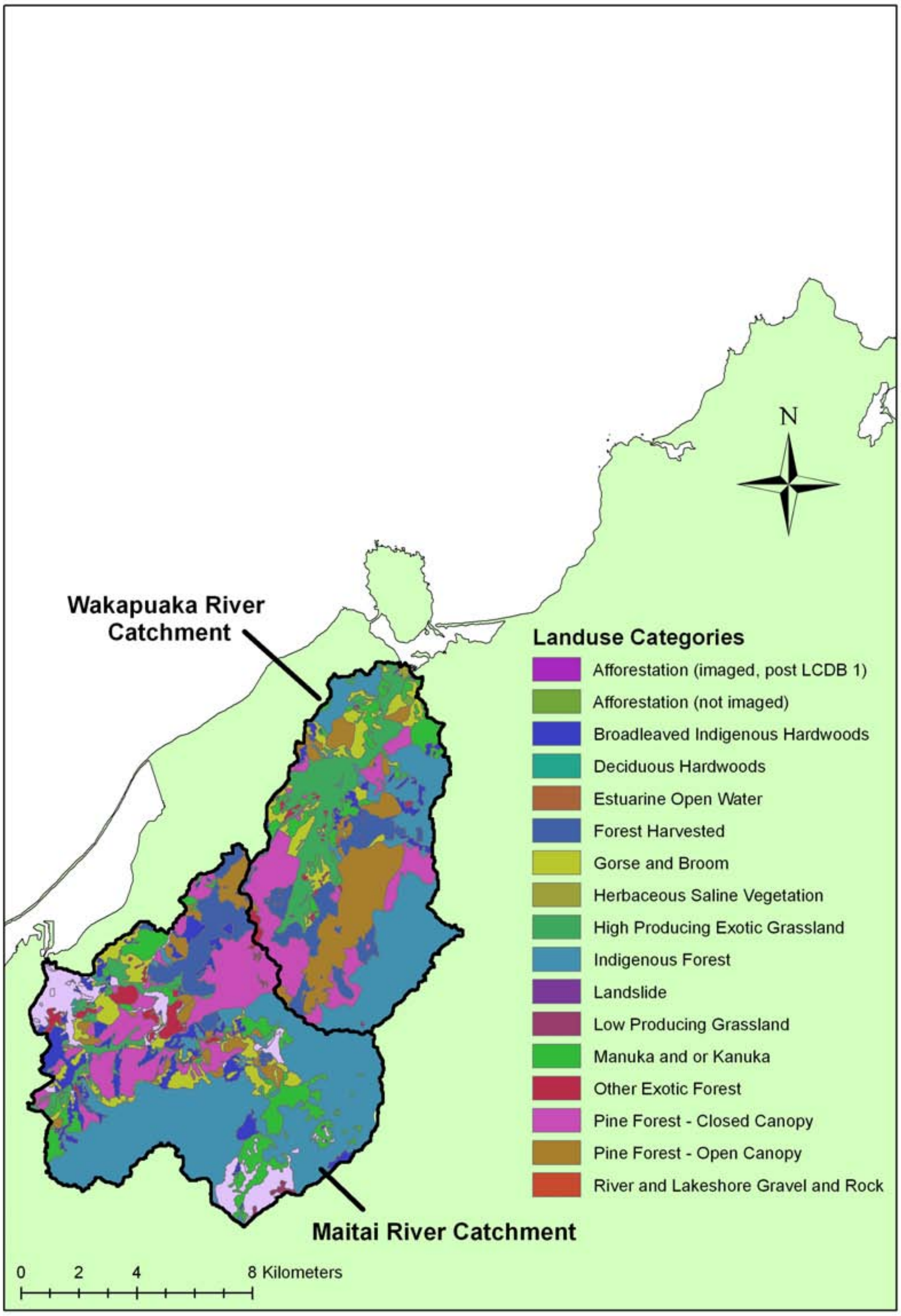

Figure 6. Land use classification map for the Wakapuaka and Maitai River catchments (data extracted from Landsat 7 satellite imagery, 2001-2).

Table 1. Land use classification of the Wakapuaka River catchment excluding estuary habitat (data extracted from Landsat 7 satellite imagery, 2001-2).

Land Use name	Area (Ha)
Pine Forest - Closed Canopy	974.0
Pine Forest - Open Canopy	1107.8
Other Exotic Forest	67.0
Forest Harvested	599.7
Indigenous Forest	1808.2
Manuka and or Kanuka	423.1
Broadleaved Indigenous Hardwoods	160.7
Deciduous Hardwoods	4.9
Afforestation	10.6
Gorse and Broom	423.6
High Producing Exotic Grassland	904.6
Low Producing Grassland	12.2
River and Lakeshore Gravel and Rock	2.5
Landslide	1.8
Total Catchment Area	**6500.7**

2.1.6 Estuary values and uses

Davidson *et al*. (1990) listed Delaware Inlet as a site of "National importance", primarily as habitat for the banded rail (*Rallis phillipensis assimilis*) and the banded dotterel (*Charadrus viscose*). It is also known to provide breeding and/or feeding habitat for a variety of other estuarine bird species such as the variable oystercatcher (*Haemopterus unicolor*). Davidson *et al*. (1990) also noted high biodiversity values relating to intact vegetation sequences from coastal forest (Bishops Peninsula) through mixed salt marsh communities. This sequence also extends further through productive macroalgal and eelgrass beds and seabed microalgal growth over extensive tidal flats (Mackenzie 1983). Sand dune habitat, recognised by the Department of Conservation as having particular conservation value, occurs on the Delaware and Cable Bay sandspits.

The productive habitats of Delaware Inlet nourish the coastal-sea food web of Tasman Bay in a variety of ways. They absorb and process terrestrial and marine nutrients and export them in a form that can contribute to the coastal food web. Estuarine environments such as Delaware Inlet are important to the life cycle of a variety of marine and freshwater species of fish (*e.g.* as protected habitat for breeding, nursery areas for juveniles, productive feeding grounds and conduits for migration to and from freshwater environments). These contributions from Delaware Inlet are potentially of critical importance because of the close proximity of the estuary to the Horoirangi Marine Reserve to the west and the Tiapure Management Area in Delaware Bay.

Although, in this report, I focus primarily on the ecological values of the estuary habitats, aesthetic, recreational and cultural values are also of recognised importance (Davidson *et al*. 1990; Sheridan 2007). Delaware Inlet has been highly valued by local iwi, in a cultural and traditional sense, as a source of kai moana. It has also been valued by the general public for the recreational collection of fish and shellfish. The extensive cockle beds, referred to earlier in this report, were once seen as having a potentially high commercial value however this resource is now under threat due to spread of the invasive Pacific oyster (see Section 2.1.8).

Activities surrounding and within the Inlet have been subject to protection/governance by:

- The Cable Bay Scenic Reserve,
- The Cable Bay Walkway,
- Paremata Foreshore Reserve,
- Private Protected Land (0.5 ha native bush near the Cable Bay Walkway entrance),
- Cable Bay Recreation Reserve,
- Esplanade Reserve (between residential sections and the western arm of the Inlet),
- Rahui (entire Inlet).

2.1.7 Water, and sediment quality

Historic nutrient water quality data for the lower Wakapuaka River (1979-1982) are held by Cawthron (Gillespie, unpub.). These data cover a range of river flows including multiple samplings over rainfall events and could be used to assess long term changes by way of comparison should this line of investigation be pursued in future.

Since 1999, the Wakapuaka Rivercare Group has been monitoring a range of ecological water quality parameters at six sites in the Wakapuaka River. The results show a general decline in water quality in a downstream direction, however there has been no noticeable reduction over time (Sheridan 2007). These interpretations are consistent those of Wilkinson (2007) who notes periodic slightly elevated nitrate and *E. coli* concentrations at a lower Wakapuaka River site and suggests an overall water quality classification of "moderate".

Bacteriological water quality characteristics of the lower Wakapuaka River (data provided by NCC) indicate occasional loadings that could have implications for the recreational and cultural harvesting of shellfish in Delaware Inlet. In general, however, the low volume of freshwater inflow and the high seawater flushing rate would minimise impacts on shellfish quality except during, and immediately after, rainfall events. No related shellfish quality data were found to further assess this relationship, although changing land uses (*e.g.* residential development) could result in an increased risk of faecal contamination of shellfish.

Investigation of Delaware Inlet water and sediment physical, chemical and biological properties during the late 1970s and 1980s suggested that the estuary was in a relatively productive, healthy condition at that time (Franko 1988; Gillespie 1983; Gillespie & MacKenzie 1981). The enrichment status of Delaware Inlet sediments was later compared with those from a variety of estuaries in the Tasman Bay region that had been affected to various degrees by nutrient inflows (Gillespie & Mackenzie 1990). Study locations in Delaware Inlet were used as references to relatively non-impacted seabed conditions. Since these sites have not been re-evaluated over the past 20+ years, however, it is not possible to verify their presently existing state.

2.1.8 Exotic plant and animal species

An invasion by an exotic bivalve, the Pacific oyster (*Crassostrea gigas*), was reported in the Nelson region during the early 1980s (Bull 1981). It is possible that Delaware Inlet may have been an early (possibly the first) invasion site in the region with the likely source being the offloading of ballast rocks by fishing vessels. Individual specimens of Pacific oyster were discovered in the main channel near the estuary entrance in the late 1970s (author's personal observation). It has now become well established in a number of intertidal locations within the northern South Island coastal region. A small (~0.5 ha) sparsely colonised Pacific oyster bed was observed off the tip of Bishops Peninsula by Asher (1999). Since that time, Pacific oyster coverage has increased dramatically at a number of locations in the Inlet (R Asher, Cawthron, pers. com., Figure 7). This developing habitat represents a significant departure from the natural character of the tidal flats and the invading bivalve is likely to compete for space and food with other suspension-feeding organisms (*e.g.* cockles). The resulting oyster beds and shell banks develop as raised mounds containing enriched, fine-grained sediments with an altered biological community structure.

There are numerous other potential invaders that have been detected in Nelson Bays estuaries and may or may not be present in Delaware Inlet. These include the sea squirts, *Didemnum vexillum* and *Styela clava* the Asian kelp, *Undaria pinnatifida*, and a variety of bryozoans and ascidians. Although a considerable number of introduced plant species are also present along the supratidal fringe (above the spring high tide height), these are not covered in this report.

Figure 7. Pacific oyster beds in Delaware Inlet (2005).

2.2. Historical vegetation map

The digitised 1983 vegetation map of the estuary (Figure 8.) provides more precise definition to the earlier sketch map presented in Figure 3, confirming the complex habitat structure of the estuary. A working copy of the map has been copied to CD and appended to this report (Appendix 2). Because the field mapping was undertaken during summer, macroalgal beds were a dominant feature of the vegetation habitats (Table 2). This is testament to the productive nature of the estuary, however it is important to note that these plants; *e.g.* sea lettuce (*Ulva* sp.) and agar weed (*Gracillaria* sp.) can grow rapidly with considerable seasonal and inter-annual variability. Hence interpretation of changes in macroalgal coverage would require detailed longer term monitoring. Other productive habitats were rushland, primarily searush (J*uncus kraussii*) and jointed wirerush (*Leptocarpus similis*), microalgal mat, eelgrass (*Zostera* sp.) meadow and herbfield, primarily glasswort (*Sarcocornia quinqueflora*). Eelgrass meadows are recognised as having high ecological and biodiversity values. Although their photosynthetic contributions are relatively modest, they provide stable physical habitat and a localised food source to support a diverse community of animals. Because eelgrass meadows are sensitive to sediment deposition and reduced water quality conditions, changes in area coverage over time can be a particularly good indicator of estuary health. The vegetation map and the area coverage of major vegetation types shown in Figure 9 provide the necessary tool to assess this through comparison with other points in time.

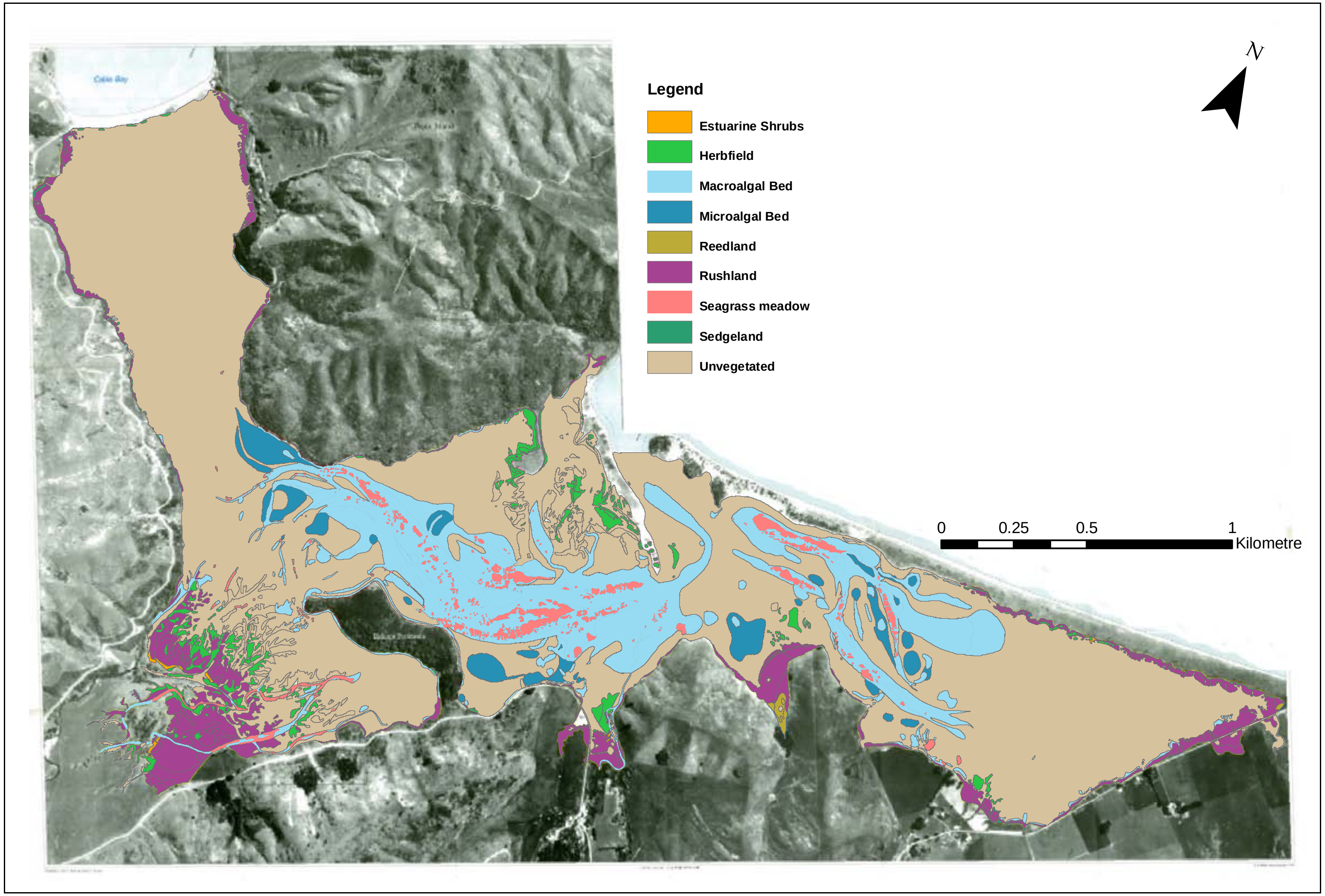

Figure 8. Historical vegetation map of Delaware Inlet (digitised from a 1983 base map published by Franko 1988).

Table 2. Vegetation coverage areas of Delaware Inlet (as of summer 1983-1984).

Class	Area (Ha)	Percentage of Estuary
Estuarine Shrubs	0.3	0.1
Herbfield	8.0	2.4
Macroalgal Bed	58.6	17.5
Microalgal Mat	9.9	2.9
Reedland	0.5	0.6
Rushland	23.5	7.0
Seagrass meadow	8.4	2.5
Sedgeland	0.2	0.0
Unvegetated	226.4	67.4
Total	**335.7**	**100.00**

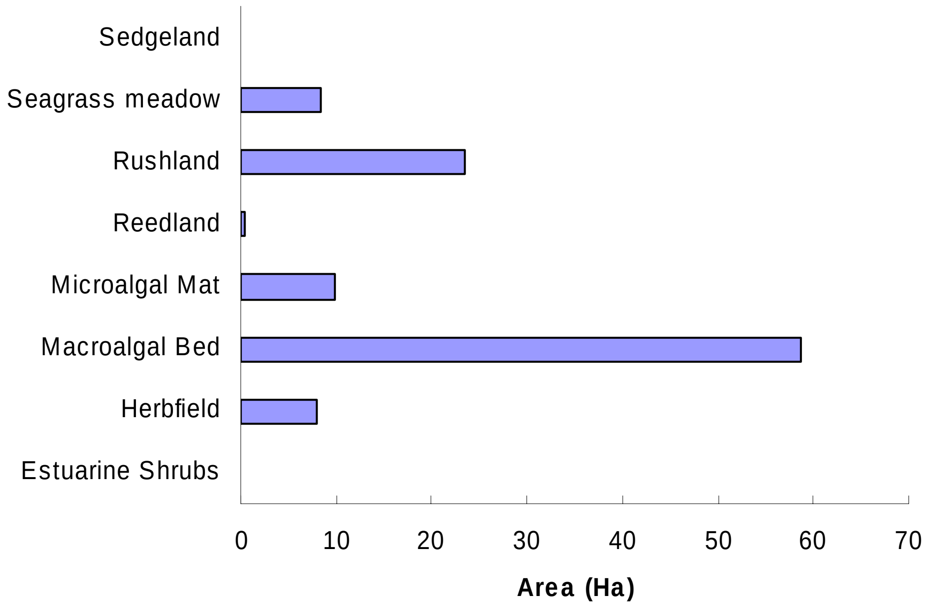

Figure 9. Vegetation coverage areas of Delaware Inlet (as of summer 1983-1984).

2.3. Estuary (Decision Matrix) ranking

The Decision Matrix (DM) spreadsheet appended to this report was modified from that presented in Robertson *et al*. (2002). The scores provided are based on the information in this report and the author's perspective. It is intended that these scores be considered an example only, and that the DM be used as a tool for estuary managers to engage with stakeholders. This will enable prioritisation of monitoring requirements for Delaware Inlet by comparison with other estuaries in the Nelson Bays region. A similar ranking exercise, carried out for the Nelson Haven, is described in Gillespie (2008).

3. ECOSYSTEM CONDITION

Summary of the general characteristics of Delaware Inlet and its contributing catchment gives evidence to a complex, high-value estuarine environment. The Inlet has generally been considered to be a site of naturally high biodiversity with considerable ecosystem services attached. Nonetheless, during the past 160 years, the Inlet and its contributing catchment have been subjected to modifications that are likely to have had some effect on the functional integrity of the estuary environment. These are summarised below:

1. In conjunction with European settlement during the mid to late 1800s, areas of dense native forest near the estuary were cleared for agricultural development by the felling and burning of timber. Much of this land was subsequently converted to grass for grazing. Although no clear records were found of the areas involved, these changes were likely to have been sufficient to result in some alteration in sediment and nitrogen discharges to the estuary.
2. More than 400 ha coverage of the introduced nitrogen-fixing legumes, gorse and broom, within the Wakapuaka catchment and additional coverage surrounding the Inlet have likely contributed to nitrogen runoff and consequently the productivity of intertidal plant habitats.
3. Although a past history of super-phosphate aerial topdressing of adjacent pasture lands would have resulted in direct phosphorus runoff to the estuary, this is not expected to have had a significant enrichment effect due to the fact that nitrogen is proportionally more limiting for growth of intertidal vegetation (Gillespie & MacKenzie 1990).
4. Conversion of large catchment areas to pine plantation and subsequent harvesting would also have had significant periodic effects on sediment loadings to the estuary. Considerable areas of pine forest have been harvested since the 1980s, when the last detailed investigations of intertidal habitat structure were undertaken.
5. Development of agriculture, particularly adjacent to the eastern estuary arm is likely to have had some enrichment effects on intertidal habitats. Although this probably has contributed to the productivity of the estuary, previous investigations provide no evidence of adverse enrichment effects.
6. Although historic removal of lowland freshwater wetland habitats has partially interfered with the continuity of terrestrial ↔ freshwater ↔ intertidal habitats in some places, this aspect has not been fully explored. Roading along both sides of the estuary and possibly flood control measures will have added to this “hardening” of the land/sea interface.
7. Adverse effects related to reduced water quality (*e.g.* elevated faecal bacterial loadings in shellfish, localised macroalgal blooms), may have occurred in conjunction with agricultural and residential development, however no monitoring data was found to assess this.
8. The invasion and spread of the exotic bivalve *Crassostrea gigas* (Pacific oyster) poses a threat to the natural character and ecological integrity of Delaware Inlet. Although the Pacific oyster may have potential value as a ‘new’ harvestable resource, it can also impact adversely on the previously existing indigenous resources. 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.

4. RECOMMENDATIONS

Since no formal monitoring programme has been implemented for the Inlet, there now exists a 20+-year gap in detailed ecological information. It is therefore difficult to accurately assess the present condition of the estuary environment without further assessment.

Estuary-wide, broad-scale habitat mapping and fine-scale assessment of individual reference sites, according to the methods set out in the EMP, are recommended. In addition to providing a means of updating historical information and assessing long-term change, this would enable comparison with other estuaries in the region and serve as a point-in-time baseline for future monitoring. In conjunction with SOE monitoring, it is recommended that scoring of the appended estuary DM spreadsheet be revised with community/iwi input and periodically updated to provide a working document for prioritising estuary management requirements.

No data were found describing water and shellfish faecal indicator concentrations in Delaware Inlet. In view of the possible risk with respect to the human consumption of shellfish, and the potential for increased future risks due to changes in land catchment or estuary uses, implementation of faecal indicator monitoring is recommended.

I also support the use of Delaware Inlet as a case study location for coordinated implementation of scientific and iwi cultural indicators of estuary condition. This could potentially have far-reaching benefits for the sustainable management of coastal environments in the region and other parts of New Zealand.

5. ACKNOWLEDGMENTS

The following contributions are gratefully acknowledged:

Nelson City Council
Paul Sheldon for providing relevant information from NCC records.
Ian Tyler, for calculation of the approximate population density of the catchment.

Cawthron

Rod Asher for observations of Pacific oyster coverage. Kim Clark, Reid Forrest, Kathryn Laurence, Paul Barter and Deanna Clement for conversion of the historical vegetation map to GIS format. Kathryn Laurence for preparation of figures and report formatting.

Iwi

Dean Walker, Project Manager, Tiakina Te Taiao Ltd. and Andrew Stephens, Te Huria Matenga Wakapuaka Trust, for discussions regarding the use of the report to facilitate Envirolink NLCC 27.

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7. APPENDICES

Appendix 1. Estuary decision matrix spreadsheet for Delaware Inlet.

DELAWARE INLET		DECISION MATRIX FOR PRIORITISING ESTUARIES FOR STATE OF ENVIRONMENT MONITORING							
	Estuary Assessment Factor	**Explanation**	**Scoring Schedule**	***Preliminary Scoring***			***Consultative Scoring***		
A. Existing Estuary Physical Characteristics				**Score**	**Weighting factor**	**Total**	**Score**	**Weighting factor**	**Total**
1	Area of Estuary (ha)	Value of an estuary increases with the area of the resource.	1 = <500 ha, 2 = 500-2500 ha, 3 =>2500 ha.	1	2	2			
2	Area of the estuary catchment	Estuaries with large catchment areas draining into them will be at greatest risk of land use effects.	1 = <100 km^2, 2 = 100-500 km^2, 3 = >500 km^2	1	3	3			
3	Flushing time (days)	Flushing time is the average period during which a quantity of freshwater derived from a stream or seepage remains in the estuary. The very well-flushed estuaries will be least at risk from build-up of contaminants.	1 = < 3 days, 2 = 3-10 days, 3 = >10 days	1	3	3			
4	Freshwater input (litres/s)/Area of estuary (ha) ratio	Estuaries with a high FW inflow/Area ratio have a large freshwater influence resulting in higher risk of catchment-related impacts.	1 = <10, 2 = 10-100, 3 = >100.	1	4	4			
B. Natural Character and Values									
5	Wetland and wildlife status	Estuaries are often important habitat for coastal fisheries and international migratory birds, and may be recognised as having significant conservation value. Estuaries with high wetland and wildlife status have a high perceived value and may have been assigned a regulatory status.	1 = low, 2 = medium, 3 = high wetland and wildlife status	3	5	15			
6	Recreational use	An estuary can be a significant social resource, used for water sports, food gathering, sightseeing, *etc.*	1 = low utilisation for recreation, 2 = moderate, 3 = high utilisation for recreation	2	3	6			
7	Cultural signifcance	The values of tangata whenua, including the issue of mana whenua (customary authority) may be significant to an estuary. Estuaries may have a high cultural value if they are or were a traditional food-gathering site, papa taakoro or of other cultural importance.	1 = low perceived cultural significance, 2 = medium, 3 = high perceived cultural significance	3	5	15			
8	Commercial use	An estuary can be a commercial resource with economic importance (*e.g* . for shellfish/fish harvesting, aquaculture, ecotourism, waste disposal *etc.*)	1 = low commerical use, 2 = moderate, 3 = high commercial use	2	2	4			
9	Perceived value by the communities in the region	Estuaries may have high aesthetic and amenity value to surrounding residential communites. They may also be important for education, tourism, or significant to the communities' natural character or identity.	1 = low perceived value by communities, 2 = medium, 3 = high perceived value by communities	3	5	15			
10	Diversity of intertidal habitat	Estuaries with the broadest array of intertidal habitats have the greatest potential for high intertidal biodiversity and therefore have greatest ecological value to a region. Habitats include: rushes, reeds, seagrasses, tussocks, herbfields, scrub, rock, cobble, gravel, mobile sand, sand, shell, muddy sand, soft muds, shellfish beds, sabellid beds.	1 = limited array of habitats, 2 = moderate array of habitats, 3 = most common habitats present and in good condition	3	5	15			
11	Extent of fish/shellfish resources	Occurrence of fish and shellfish resources in or near an estuary enhance its value. A drop in abundance and diversity could result from a deterioration of estuarine function.	1 = low , 2 = medium, 3 = High abundance and/or diversity of fish and shellfish resources	3	5	15			
12	Scientific investigation/education	Scientific understanding and community awareness are essential for managing estuaries sustainably. Some estuaries may provide useful study locations (e.g. due to location, estuary type, existing impacts, pristine qualities, etc.)	1 = low, 2 = medium, 3 = high scientific/education value	3	5	15			
13	Estuary effects on land prices	lands surrounding estuaries are often sought after for residential or industrial development and can therefore demand higher prices.	1 = little or no effect, 2 = moderate effect, 3 = strong effect on land prices	3	5	15			
C. Characteristics that Indicate an existing or potential adverse impact									
14	Proportion of urban/Industrial landuse in the estuary catchment	Modified catchments are likely to pose greatest risk of impact to an estuary. Urban and industrial contaminants include heavy metals, nutrients, organochloride pesticides *etc.*	1 = high , 2 = medium, 3 =low extent of urban/industrial landuse	3	3	9			
15	Proportion of agricultural landuse in the estuary catchment	Modified catchments are likely to pose greatest risk to each estuary from contaminant entry. Agricultural run-off has been attributed to increased sedimentation, nutrients and contaminants in estuaries.	1 = high , 2 = medium, 3 =low extent of agricultural landuse	2	3	6			
16	Proportion of exotic forest landuse in the estuary catchment	Modified catchments are likely to pose greatest risk to each estuary from contaminant entry. Exotic forestry can impact on estuaries by causing increased erosion of the catchment and increased sedimentation in the estuary.	1 = high , 2 = medium, 3 =low extent of exotic forest landuse	3	3	9			
17	Proportion of modified to unmodified estuary catchment	The least modified catchments are likely to pose least risk to an estuary from contaminant entry.	1 = high , 2 = medium, 3 =low extent of unmodified catchment	2	4	8			
18	Estuary margin alteration (*e.g.* reclamation)	Estuaries where margins have been altered and/or reclamation has been undertaken have less value and a decreased ability to assimilate contaminant entry and increased erosion and sedimentation processes.	1 = high , 2 = medium, 3 =low extent of margin alteration	3	4	12			
19	Point Source effluents	Presence of point source discharges of wastewater (municipal, industrial and/or agricultural) into an estuary pose a high risk of contaminant entry.	1 = extensive discharges, 2 = moderate discharges, 3 = very low or no discharges.	3	3	9			
20	Aquaculture Licences	Presence of aquaculture activities in an estuary provides a greater risk of contaminant entry and other impacts (*e.g.* biosecurity risk and impingement on the natural and aesthetic values of an estuary).	1 = existing aquaculture licences, 2 = none existing but potential for future development, 3 = none existing and no known potential .	2	4	8			
21	Extent of risk of accidental spills	Accidental spillage of hazardous wastes (*e.g* . oil) lowers values in an estuary.	1 = high risk, 2 = medium risk, 3 = low risk of accidental spills	3	3	9			
22	Percentage of intertidal area comprised of soft mud	Estuaries with a high proportion of muddy habitat are likely more prone to sedimentation effects.	1 =<5%, 2 = 5-20%, 3 = >20% mud habitat.	2 (?)	4	8			
23	Reduction of vegetated habitat	Estuaries where vegetated (*e.g.* saltmarsh, sea grass, mangrove, *etc* .) habitats have been reduced or reclaimed have lower ecolgical value, fewer feeding and nursery habitat for animal species, and a decreased ability to assimilate contaminant and sediment entry. These habitats act as coastal buffers.	1 = severely reduced, 2 = moderately reduced, 3 = unaltered saline wetland habitat.	3	3	9			
24	Extent of nuisance macro and micro-algal blooms	Excessive macrolgal (seaweed) growth (*e.g. Ulva* sp.) indicate nutrient enrichment. This can have widespread adverse ecological and aesthetic effects.	1 = frequent incidence and/or large areas, 2 = occasional incidence, 3 = no incidence of nuisance macroalgae.	3	3	9			
25	Extent of invasive species	Occurrence of exotic invasive species can threaten the natural character and biodiversity of an estuary (*e.g.* Pacific oyster, *Spartina* sp.)	1 = large colonisation of invasive species, 2 = low colonisation of invasive species, 3 = no known invasive species.	1	5	5			
26	Extent of modification of estuary hydrodynamic characteristics	The hydrodynamic processes of an estuary can be altered by gravel or sand extraction, roading, reclamation and structures, creating modified water circulation patterns, increased sedimentation, less flushing and an increase in contaminant loading.	1 = zero to low, 2 = moderate, 3 = large extent of modification of hydrodynamic characteristics.	3	3	9			
27	Extent of water clarity problems	Widespread water clarity problems (*e.g.* after heavy rain and/or wind events) lower the perceived value of an estuary, have an adverse social effect and adversely effect aquatic ecosystems.	1 = frequent, 2 = occasional, 3 = zero or rare water clarity problems.	2 (?)	3	6			
28	Extent of faecal contamination problems	Widespread faecal contamination problems lower estuary values. Problems are indicated by high faecal coliforms and enterococci in the water column and shellfish, illness or perceived health risk.	1 = high, 2 = moderate, 3 = zero or rare faecal contamination problems.	2 (?)	5	10			
29	Extent of nuisance odour problems	Nuisance odour problems, (e.g. from effluent, decomposing macroalgae, anaerobic sediments, *etc.)* lower estuary values.	1 = frequent, 2 = occasional, 3 = zero or rare nuisance odour problems.	3	3	9			
30	Extent of toxicity problems	Widespread sediment contamination (*e.g.* metals, organics, sulphide, ammonia) lower estuary values. Toxicity problems can occur in the water and/or sediment, and may have extensive adverse effects for the biological communities.	1 = high, 2 = moderate, 3 = zero or low incidence or extent of toxicity problems.	3 (?)	3	9			
31	Solid waste/litter	The presence of solid waste (*e.g.* refuse/litter) lowers estuary values.	1 = high, 2 = medium, 3 = zero or low occurrence of solid waste.	3	3	9			
	Total Score	**Notes: (1). In this estuary, monitoring priority is placed on pristine rather than modified characteristics. The higher the final score the higher the priority for SOE monitoring and/or management intervention. (2). Where there was insufficient information to confidently assign a score, the value was entered in red.**				**280**			

Appendix 2. CD-ROM file containing a working version of the historical vegetation map.