State of the Environment Monitoring of Waimea Estuary: Broad Scale Habitat Mapping 2007

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State of the Environment Monitoring of Waimea Estuary: Broad Scale Habitat Mapping 2007

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EXECUTIVE SUMMARY

Overview

Broad scale mapping of intertidal habitats was carried out in Waimea Inlet, based on aerial photographs collected in November 2006. This was the second of two State Of the Environment (SOE) mapping surveys conducted within the Estuary. It was originally intended that the survey be repeated at approximately 5-year intervals, in conjunction with fine scale monitoring of representative sites, as a means of identifying long-term changes in estuary condition. This report describes the mapping methodology and results along with observations of changes that have occurred over a 7-year monitoring interval. Implications for overall estuary ecological health are discussed and recommendations are made regarding possible management responses and ongoing Waimea Inlet SOE monitoring.

Mapping results

Unvegetated substrata covered 2,588 ha, approximately 77% of the total intertidal area. This was comprised largely of soft (59.5%) and firm (14.5%) muds with lesser but significant areas of firm sands (13.1%) and cobble fields (10.9%). The remaining 3% of unvegetated substrata was comprised of a mixture of man-made features, soft and mobile sands, shellbanks, mussel and oyster beds.

Vegetated substrata covered a total area of 362 ha, approximately 11% of the total intertidal area. The most common vegetated class was herbfield (43%) dominated by *Sarcocornia quinqueflora* (glasswort), found mainly along the estuary margins. Rushland, dominated by *Leptocarpus similis* (jointed wirerush) covered 28% of the vegetated habitat while macroalgal beds and eelgrass meadows covered 9 and 5.8%, respectively.

Changes 1999 versus 2006

Changes in the spatial coverage of some habitats were identified compared to the broadscale mapping previously carried out in 1999 using the same methodology. Of particular note were:

- The total estuary area mapped in 2007, 3,345 hectares, was slightly greater than the 3,206 ha digitised in the 1999 survey.
- The area of soft mud increased between 1999 and 2006 suggesting that the Inlet may be getting progressively muddier, however confirmation would require further investigation.
- Herbfield areas dominated by *Sarcocornia quinqueflora* (glasswort) were significantly greater in 2006 than 1999. This change was at least partially the result of a "softening" of the upper intertidal boundary in some regions (*e.g.* the Traverse) due to tidal erosion of supra-tidal shore gradients.
- Smaller expansions of Rushland (primarily *Juncus* marsh), Tussockland, Grassland and Estuarine shrub-covered areas were also documented.
- Coverage by eelgrass meadows decreased slightly, probably as a result of natural fluctuation.
- Within the Traverse area between Rabbit and Rough Islands increased flushing due to the removal of a causeway led to an expansion of intertidal habitats along the estuary margins and localised increases in biodiversity.

Estuary condition

The complex mixture of habitats within Waimea Inlet is representative of a relatively functional but partially modified estuarine system. Most of the changes in vegetated habitat areas observed over the 7-year monitoring interval (*e.g.* the small reduction in eelgrass coverage) were within ranges that may have been due to natural variation. The observed increases in coverage of Herbfield and Rushland habitats, however, suggest that there have been some localised improvements in ecological condition within the Inlet.

Two warning signals suggest a possible divergence from the pre-existing unmodified estuary ecosystem.

(1) The high percentage of muddy substrata comprising the intertidal zone and the observed areal increase of soft mud habitat 1999-2006 may be indicative of ongoing catchment erosional effects.

(2) Extensive modifications of the estuary margins indicate an interference of land- sea connectivity and consequently, estuarine function as compared to a historical unmodified condition.

Recommendations

- Continuation of Waimea Inlet SOE habitat mapping surveys at approximately 5-year intervals as a means of identifying long-term trends in estuary condition.
- Coordination of Waimea Inlet SOE monitoring with ongoing consent monitoring.
- Consideration of management options to address the potential issues identified.
- Investigation of the reorganisation of habitat structure following the eradication of *Spartina* in Waimea Inlet and implications for estuarine function.
- Coordination of future Waimea Inlet management initiatives using a GIS format that can be linked to habitat structure and estuarine function.

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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 the two-way land/sea exchange of materials and they function as nutrient processing zones that are critical for the nourishment of coastal ecosystems. Estuary intertidal zones often encompass habitats of high ecological value and contain resources of cultural, recreational and/or commercial importance. Broad scale habitat mapping 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 monitoring).

This report summarises the results of a detailed point-in-time spatial survey of major habitats in the intertidal regions of Waimea Inlet. 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 the completed habitat maps (titled "Broad Scale Intertidal Habitat Mapping: Waimea Inlet 2007");
- 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 March 1999 aerial survey;
- Interpretation of mapping results with regard to estuary condition; and
- Recommendations based on mapping results.

A separate fine scale benthic assessment of the dominant mud/sand habitat (carried out April 2006) is described in a companion report (Gillespie *et al.* 2007).

1.2. Study Area

Waimea Inlet is a shallow, bar-built estuary bordering southern Tasman Bay adjacent to the city of Nelson (Figures 1 and 2). Covering an area of about 33 km^2, it is one of New Zealand's largest estuaries with respect to intertidal seabed habitat. The estuary is predominantly unvegetated habitat dominated by soft mud. The catchment has a total area of 812 km^2 consisting primarily of planted forest, native bush and pasture with smaller areas of scrubland, tussock and horticultural and urban development. The Waimea River, with a mean flow of 20.8 $m^3 s^{-1}$, is the main freshwater inflow to the estuary, however nine small streams (<1 $m^3 s^{-1}$ in total) also contribute with the potential for localised impacts. The water quality of freshwater inflows is reported to be variable (Gillespie *et al*. 2001).

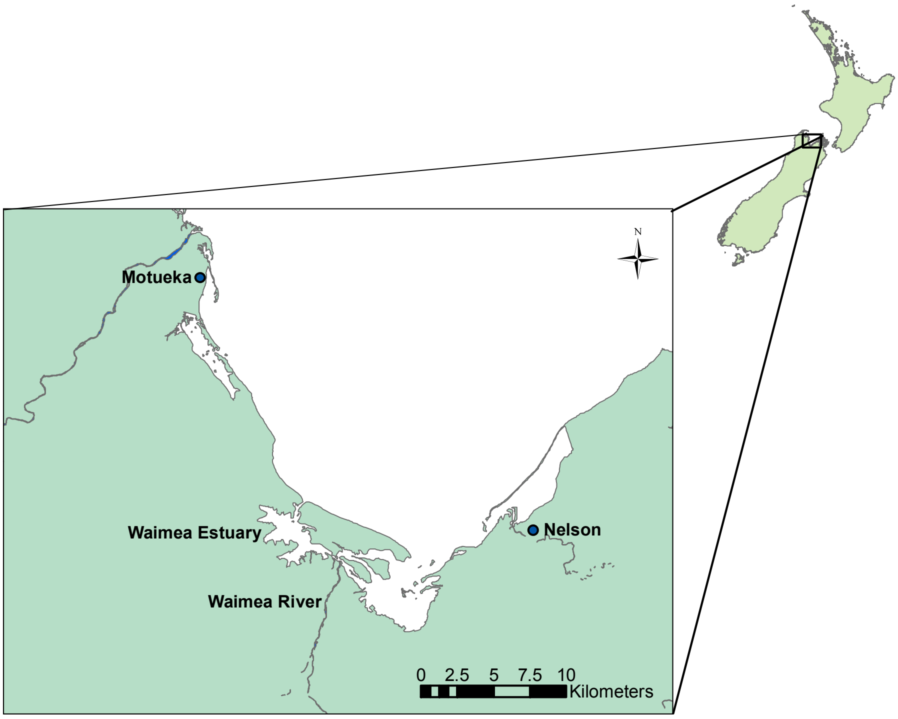

Figure 1. Study location.

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

Waimea Inlet is of significant regional, national and international value. Due to its large size and complex heterogeneous physical and biological structure, it has been classed as a wetland of national importance by the Department of Conservation (Robertson *et al*. 2002) and has also been ranked as an estuary of international importance for migratory birds (Schuckard 2002). Recreational and aesthetic values of the estuary are numerous and it is also used for wastewater discharge (Gillespie *et al*. 1992). For a more detailed description of Waimea Estuary and the surrounding regions see Davidson & Moffat (1990) and Robertson *et al.* (2002).

2. METHODS

2.1. Overview

The methodology used to collect data was based on the standardised Estuary Monitoring Protocol (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, tussocks, 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. This information can then be used to evaluate the implications of natural perturbations such as flood/climate 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. Colour aerial photography

Aerial photographs of Waimea Estuary were taken in November 2006 and provided to Cawthron as rectified "tif" files at scales of 1:10,000.

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. Dominant habitat types, including various categories of bare and vegetated substrate were recorded directly onto laminated copies of the aerial photographs (scale 1:5,000 to 1:10,000) using the codes listed in Table 1. The upper boundary was set at MHWS (Mean High Water Spring), unless supra-littoral fringe habitat was considered integral with the upper intertidal, in which case it was included. The lower boundary was set at MLWS (Mean Low Water Spring). A 10 m wide riparian strip was also assessed visually to enable general comment on the type of habitat surrounding the edge of the estuary. Although cockles were detected in a number of habitats, it was not possible to provide useful estimates of the spatial extent of their occurrence. Due to their subsurface position they were not visible on the aerial photographs. Therefore this incomplete data layer was deleted from the map.

2.4. Digitisation of habitat boundaries

Vegetation and substrate features were digitally mapped from the rectified photographs using Arcmap 9.0 GIS software. This procedure involved copying, as precisely as possible, the field-verified habitat features onto rectified aerial photographs within the GIS. The software was then used to produce maps and calculate the area cover of each habitat type.

3. CLASSIFICATION AND DEFINITIONS OF HABITAT TYPES

3.1. Habitat features

The classification of substrate and habitat features is based on the proposed estuarine national classification system (with adaptations), which was developed under a Ministry for the Environment SMF (Sustainable Management Fund) 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).

3.2. 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 substratum 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 have been labelled in the same manner as that described above.

4. RESULTS AND DISCUSSION

4.1. 2007 habitat and substrate characteristics

A total of 3,345 hectares, covering the intertidal zone of Waimea Inlet, was mapped in 2007 based on aerial photographs collected in November 2006. Detailed maps of the areas covered by the dominant substrata and vegetation types are presented in (Figures 3 and 4). We note that small habitat areas cannot be seen at the scale of the maps, however these areas are quantified in Tables 1 and 2 and individual GIS layers can be accessed and evaluated through the CD-ROM in Appendix 3. Of the total mapped area, 11.8% (396 ha) was subtidal at the time the aerial photographs were taken and the remaining intertidal area was predominantly unvegetated (77%).

The unvegetated habitats of Waimea Inlet were dominated by muddy substrata (59.5% soft mud and 14.5% firm mud). Firm sands (13.1%) and cobblefields (10.9%) also covered significant parts of the estuary, with the remaining 3% comprised of a mixture of man-made features, soft and mobile sands, shell banks, mussel and oyster beds.

Vegetated habitats within and surrounding the estuary showed considerable complexity with most classification categories present; including Grassland, Shrubland, Tussockland, Rushland, Herbfield, Eelgrass meadows, Sedgeland, Estuarine Shrubs and Terrestrial Shrubs and Trees. Within the vegetated habitats, the most common classification was Herbfield (154 ha, 43%), with the dominant species being *Sarcocornia quinqueflora* (glasswort) found mainly along the estuary margins. Also very common was Rushland (101 ha, 28%), dominated by *Juncus kraussii* (searush) and *Leptocarpus similis* (jointed wirerush). Macroalgal beds, dominated by *Enteromorpha* sp and/or *Ulva* sp. and *Gracilaria chilensis,* covered a moderate area at the time of the survey (33 ha, 9%), however it must be recognised that coverage of these species can fluctuate considerably over the short term (*i.e*. weeks to months). Eelgrass meadows (*Zostera* sp.), although relatively less abundant, covered an ecologically significant area of 21 ha or 5.8% of the vegetated substrata.

4.1.1. Estuary margin

The estuary margin was mapped only up to the MHWS level, however observations were made of the marginal vegetation up to approximately 10 m above MHWS. The vast majority of the estuary margin was modified to some extent for various uses including roading, flood control, recreational facilities, industry, private gardens, farming and forestry. Very little of the original estuary margins remain unmodified. This is common amongst New Zealand estuaries (Robertson *et al*. 2002; Clark & Gillespie 2007) and the resulting hardening of the land-sea interface can have a significant effect on estuarine function.

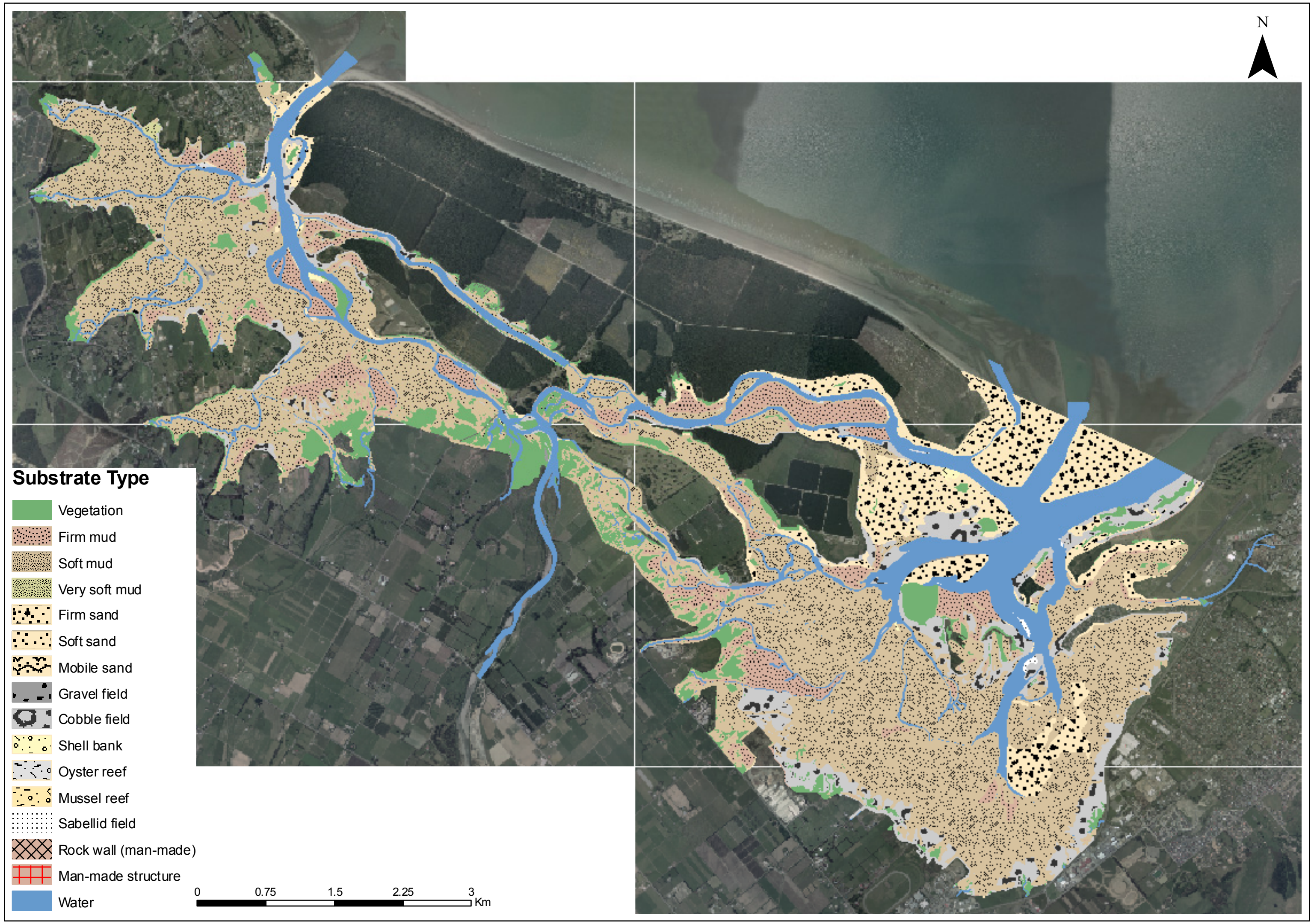

Figure 3. Aerial photograph of Waimea Inlet showing substrate characteristics in November 2006.

Figure 4. Aerial photograph of Waimea Inlet showing vegetation present in November 2006.

Table 1. Substrata present in the Waimea Inlet, November 2006.

Unvegetated Substrata

Class	Dominant Species	Primary Sub-dominant	Area (Ha)	% of Total
Cobble Field			280.7064	10.8487213
	Cobble Field		202.9773	
		Cocklebed	9.6334	
		Enteromorpha sp. (Green ribbon)	2.393	
		Firm Mud	4.7812	
		Firm Mud and Sand	7.1666	
		Firm Sand	2.949	
		Gracilaria chilensis	2.8092	
		Gravel field	3.5895	
		Juncus kraussii (Searush)	1.0764	
		Mussel Reef	1.0685	
		Oyster Reef	3.9788	
		Sabellid field	0.0642	
		Sarcocornia quinqueflora (Glasswort)	15.5651	
		Shell bank	1.0909	
		Soft Mud	17.2683	
		Stipa stipoides	0.0748	
		Suaeda novaeûzelandiae (Sea blite)	0.7991	
		Zostera sp (Eelgrass)	3.4211	
Firm mud and sand			375.0102	14.49336796
	Firm mud and sand		369.9105	
		Cobble Field	0.9812	
		Enteromorpha sp. (Green ribbon)	0.3193	
		Gravel field	0.5983	
		Juncus kraussii (Searush)	2.2172	
		Oyster Reef	0.0923	
		Sarcocornia quinqueflora (Glasswort)	0.8914	
Firm Sand			339.4622	13.11951134
	Firm Sand		315.5907	
		Ammophila arenaria (Marram grass)	0.1745	
		Carpobrotus edulis (Ice Plant)	1.1205	
		Gravel field	1.1367	
		Juncus kraussii (Searush)	0.2602	
		Oyster Reef	0.1853	
		Sarcocornia quinqueflora (Glasswort)	0.6112	
		Shell bank	11.5828	
		Zostera sp (Eelgrass)	8.8003	
Gravel field			5.8396	0.225688452
	Gravel field		3.5624	
		Cobble Field	0.1913	
		man-made	0.1318	
		Sarcocornia quinqueflora (Glasswort)	1.9541	
man-made			0.0286	0.001105331
	man-made		0.0286	
Mobile sand			11.4925	0.444161335
	Mobile sand		6.8606	
		Grassland	0.0959	
		Soft Mud	4.536	
Mussel reef			0.1668	0.006446475
	Mussel reef		0.1668	
Oyster reef			8.3184	0.321488941
	Oyster reef		6.8751	
		Cobble Field	0.3903	
		Shell bank	1.053	
Rockfield Man-made			1.6348	0.063181636
	Rockfield Man-made		1.6348	
Sabellid Reef			3.5777	0.138270699
	Sabellid Reef		3.5777	
Shellbank			10.1129	0.390842651
	Shellbank		6.6418	
		Firm Sand	3.4711	
Soft Mud			1538.5639	59.4623099
	Soft Mud		1413.0776	
		Cobble Field	0.166	
		Enteromorpha sp. (Green ribbon)	1.951	
		Firm Mud and Sand	7.3071	
		Gracilaria chilensis	107.6106	
		Gravel field	2.0292	
		Juncus kraussii (Searush)	1.9882	
		Oyster Reef	0.381	
		Sarcocornia quinqueflora (Glasswort)	0.077	
		Shell bank	2.3535	
		Water	1.6227	
Soft Sand			9.2678	0.358181286
	Soft Sand		8.5494	
		Ammophila arenaria (Marram grass)	0.3878	
		Sarcocornia quinqueflora (Glasswort)	0.3306	
Very Soft Mud			3.3075	0.127828028
	Very Soft Mud		3.3075	
Grand Total			**2587.5**	**100.0**

Table 2. Vegetation habitats in the Waimea Inlet, November 2006.

Estuarine Vegetation

Class	Dominant Species	Primary Sub-dominant	Area (Ha)	% of Total
Estuarine Shrubs			**22.63**	**6.26**
	Plagianthus divaricatus (Saltmarsh ribbonwood)		2.82	
		Phormium tenax (NZ Flax)	0.96	
		Juncus kraussii (Searush)	2.88	
		Leptocarpus similis (Jointed wirerush)	0.16	
		Leptospermum scoparium (Manuka)	0.14	
		Sarcocornia quinqueflora (Glasswort)	0.41	
		Stipa stipoides	1.02	
		Tussockland	0.18	
		Unidentified grass	14.06	
Grassland			**3.70**	**1.02**
	Ammophila arenaria (Marram grass)	*Carpobrotus edulis* (Ice Plant)	0.94	
		Stipa stipoides	0.12	
	Festuca arundinacea (Tall fescue)		0.02	
	Grassland		0.31	
		Sarcocornia quinqueflora (Glasswort)	0.12	
		Ulex europaeus (Gorse)	0.25	
	Unidentified grass		1.20	
		Gravel field	0.16	
		Juncus kraussii (Searush)	0.22	
		Ulex europaeus (Gorse)	0.24	
		Unidentified trees	0.11	
Herbfield			**154.36**	**42.68**
	Carpobrotus edulis (Ice Plant)		0.29	
		Juncus kraussii (Searush)	0.14	
		Sarcocornia quinqueflora (Glasswort)	0.01	
		Stipa stipoides	0.13	
	Samolus repens (Primrose)		0.03	
	Sarcocornia quinqueflora (Glasswort)		70.12	
		Boulder-field (man made)	0.05	
		Carpobrotus edulis (Ice Plant)	0.26	
		Cobble Field	24.68	
		Firm Mud	0.12	
		Firm Mud and Sand	1.41	
		Firm Sand	0.37	
		Grassland	0.10	
		Gravel field	0.44	
		Juncus kraussii (Searush)	12.01	
		Leptocarpus similis (Jointed wirerush)	0.05	
		Plagianthus divaricatus (Saltmarsh ribbonwood)	3.85	
		Samolus repens (Primrose)	1.22	
		Selliera radicans (Remuremu)	19.09	
		Soft Sand	0.05	
		Stipa stipoides	3.22	
		Suaeda novaeûzelandiae (Sea blite)	16.38	
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	0.03	
	Suaeda novaeûzelandiae (Sea blite)		0.33	
Macroalgal bed			**32.76**	**9.06**
	Enteromorpha sp. (Green ribbon)		1.80	
		Firm Sand	13.43	
	Gracilaria chilensis		5.30	
		Enteromorpha sp. (Green ribbon)	0.13	
		Soft Mud	5.26	
		Ulva sp. (Sea lettuce)	0.85	
		Very soft mud	0.01	
	Ulva sp. (Sea lettuce)		4.65	
		Cobble Field	0.47	
		Gracilaria chilensis	0.85	
Pine Debris			**0.72**	**0.20**
	Pine Debris	Unidentified grass	0.72	
Rushland			**101.73**	**28.12**
	Isolepis nodosa (Knobby clubrush)		0.27	
	Juncus kraussii (Searush)		22.74	
		Cobble Field	3.21	
		Firm Mud and Sand	3.70	
		Grassland	0.19	
		Leptocarpus similis (Jointed wirerush)	29.72	
		Leptospermum scoparium (Manuka)	1.29	
		Plagianthus divaricatus (Saltmarsh ribbonwood)	5.80	
		Samolus repens (Primrose)	0.09	
		Sarcocornia quinqueflora (Glasswort)	26.43	
		Soft Mud	0.04	
		Stipa stipoides	2.72	
	Leptocarpus similis (Jointed wirerush)		1.44	
		Phormium tenax (NZ Flax)	0.11	
		Juncus kraussii (Searush)	3.44	
		Leptospermum scoparium (Manuka)	0.40	
		Samolus repens (Primrose)	0.02	
		Sarcocornia quinqueflora (Glasswort)	0.11	
Seagrass meadow			**20.95**	**5.79**
	Zostera sp. (Eelgrass)		3.37	
		Cobble Field	14.67	
		Ulva sp. (Sea lettuce)	2.92	

Table 2. cont.

Sedgeland			**0.11**	**0.03**
	Cyperus eragrostis (Umbrella sedge)		0.01	
		Sarcocornia quinqueflora (Glasswort)	0.10	
Terrestrial Shrub/Scrub/Forest			**5.76**	**1.59**
	Leptospermum scoparium (Manuka)	*Stipa stipoides*	0.10	
		Ulex europaeus (Gorse)	2.06	
	Pinus radiata (Pine tree)		0.10	
		Juncus kraussii (Searush)	0.02	
		Sarcocornia quinqueflora (Glasswort)	1.79	
	Ulex europaeus (Gorse)		0.44	
		Juncus kraussii (Searush)	0.06	
		Plagianthus divaricatus (Saltmarsh ribbonwood)	0.13	
		Stipa stipoides	0.66	
		Unidentified grass	0.06	
	Exotic scrub/shrub/trees		0.33	
Tussockland			**18.99**	**5.25**
	Carex spp. (Sedge)		0.44	
		Juncus kraussii (Searush)	0.06	
		Suaeda novaeûzelandiae (Sea blite)	0.31	
	Stipa stipoides		14.00	
		Carpobrotus edulis (Ice Plant)	0.14	
		Firm Sand	0.08	
		Juncus kraussii (Searush)	2.38	
		Pinus radiata (Pine tree)	0.12	
		Plagianthus divaricatus (Saltmarsh ribbonwood)	0.31	
		Samolus repens (Primrose)	0.12	
		Sarcocornia quinqueflora (Glasswort)	0.17	
		Unidentified grass	0.15	
	Tussockland		0.13	
		Plagianthus divaricatus (Saltmarsh ribbonwood)	0.53	
		Sarcocornia quinqueflora (Glasswort)	0.03	
Grand Total			**361.71**	**100.00**

5. CHANGES SINCE 1999

5.1. Substrata

The total estuary area mapped in 2007 was 3,345 hectares; slightly greater than the 3,206 ha digitised in the 1999 survey. This was probably due partly to an inconsistency in the upper intertidal boundary, and the lower tidal height coinciding with the 2006 aerial photographs (*i.e.* water coverage was 96 ha greater during 1999). However some areas of increased estuary coverage have been noted, as described later in this section, where tidal action has eroded shoreline barriers.

The area of soft mud was significantly increased from 1999 to 2006 (Figure 5), however, during the same period, the area recorded as firm mud/sand decreased significantly. Similarly gravel field areas decreased while cobble fields increased. Although these changes may be at least partly due to slight differences in methodology between years, it is likely that the Inlet has become muddier over time.

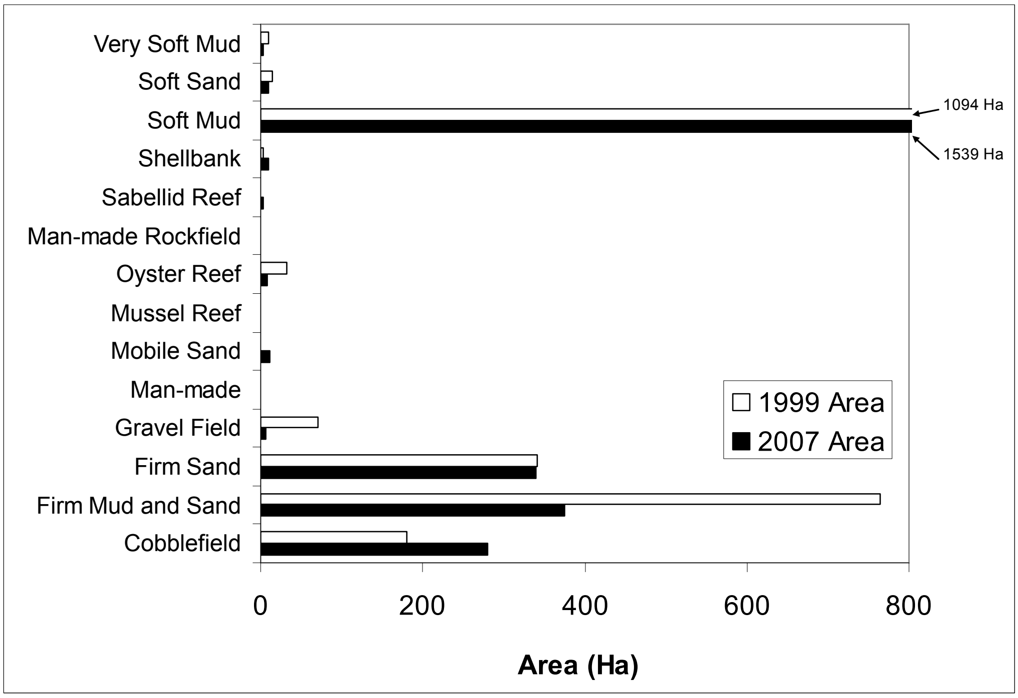

Figure 5. The area of unvegetated class habitats (based on dominant substrate type) in the Waimea Inlet in 1999 and 2006.

5.2. Vegetation

Herbfield areas dominated by *Sarcocornia quinqueflora* (glasswort) were significantly greater in 2006 than the previous survey (Figure 6). This change was at least partially the result of a “softening” of the upper intertidal boundary in some regions (*e.g.* the Traverse) due to tidal erosion of supra-tidal shore gradients.

Rushland (primarily *Juncus* marsh), Tussockland, Grassland and Estuarine shrub-covered areas also increased 1999 to 2006 but to a lesser extent. Although these increases may have been partly due to personnel changes between the two surveys, they are likely also partly related to the same erosional mechanism.

Macroalgal beds were reduced from the 1999 survey as was the total area of unvegetated substrate. Since macroalgal beds can vary considerably both seasonally and between years their reduction is not surprising. Of more concern would be a major increase in macroalgal coverage that could be indicative of over enrichment. Although this was not observed, interpretation of such changes would require a targeted, more detailed monitoring approach.

A small reduction in the areal coverage of eelgrass meadows was also observed. This is probably explainable by natural variation, however long-term continuation of this trend in conjunction with later surveys could be indicative of a negative impact. A more focused assessment of changes in eelgrass habitat in the Bell Island region, using the maps produced during the present study, is described in Gillespie *et al*. (2008). That study similarly indicated a small reduction in eelgrass area and also concluded that it was likely due to natural variation.

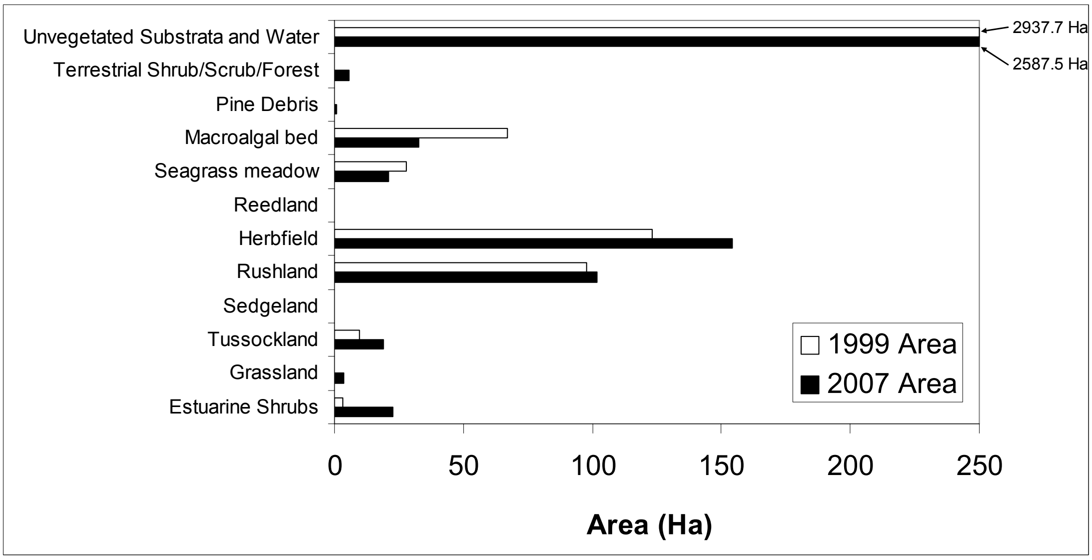

Figure 6. The area of structural class habitats (based on dominant vegetative cover) in the Waimea Inlet in 1999 and November 2006.

5.3. Traverse

The Traverse area, between Rabbit and Rough Islands (Figure 2), has changed markedly over the last 20 years. Prior to 1998, causeways between Rabbit and Rough Islands blocked each end of the Traverse with pipe culverts, allowing only restricted tidal movement of water. The lagoon within the Traverse consequently had limited water exchange resulting in growths of large mats of *Enteromorpha* sp. and the development of shallow muddy ponds dominated by thick growth of *Gracilaria* sp. (Gillespie & Asher 1997). In late 1998, the causeway across the western end of the Traverse was removed, enabling greater flushing at the western end. The road which previously ran parallel to the Traverse on the Rabbit Island side, cutting off several embayments, has gradually eroded. Terrestrial vegetation (mainly pine trees) has been removed from the embayments allowing the estuary edge to extend further inland in several places.

During field work to ground-truth the aerial photographs for this mapping project, a biologically diverse sponge-associated community was found in the Traverse. This sponge-associated habitat had not been observed during various estuary monitoring surveys in the Traverse between 1996 through 2003 (Gillespie & Asher 1997, 2003), suggesting it had only recently developed subsequent to removal of the causeway and the resulting improvement to tidal flushing. A detailed description of the sponge garden and some of the changes in surrounding vegetation, determined from the broadscale mapping, are reported separately in Asher *et al*. (2008).

6. SUMMARY OF ESTUARY ECOLOGICAL CONDITION

The complex mixture of habitats documented within Waimea Inlet are representative of a relatively functional but partially modified estuarine system. Most of the changes in habitat areas observed over the 7-year monitoring interval (*e.g.* the small reduction in eelgrass coverage) were within ranges that may have been due to natural variation.

The observed increases in coverage of a number of vegetated habitats, however, suggest that there have been some localised improvements in ecological condition within the Inlet. An interesting and perhaps ecologically significant change in estuary habitat was seen in a localised region of the Traverse area between Rabbit and Rough Islands. Changes in flow regime due to the removal of a causeway and physical changes along the estuary margins were followed by an increase in intertidal area and an improvement in the ecological condition of this region.

We also note the following two warning signals that could suggest a continued divergence from the pre-existing unmodified estuary ecosystem:

(1) The high percentage of muddy substrata comprising the intertidal zone and the observed areal increase of soft mud habitat 1999 -2006 may be indicative of ongoing catchment erosional effects.

(2) Extensive modifications of the estuary margins indicate an interference to land-sea connectivity and, consequently, estuarine function as compared to a historical unmodified condition.

These two warning signals are discussed in more detail in the following sections.

Additional description of estuary condition based on the assessment of fine scale indicators may be found in Gillespie *et al.* (2007).

6.1. Expansion of muddy substrata

The deposition of terrigenous sediments in estuarine intertidal zones is a natural process that occurs wherever there is a significant 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 Waimea catchment) human activities have resulted in increased erosion and flushing of fine-grained terrigenous sediments into the coastal environment. Consequently, the resulting acceleration of sedimentation rates and increases in habitat "muddiness" is considered to be a serious threat to estuarine health (Robertson *et al*. 2002; Thrush *et al*. 2004).

The unvegetated soft mud habitat in Waimea Inlet covered approximately 46% of the total estuary area in 2006. This is the highest amongst the nine estuaries mapped by Robertson *et* *al*. (2002) and it represents an expansion of 12% compared to that observed in 1999. These results suggest that sediment depositional rates may be increasing, resulting in adverse ecological effects to some estuary habitats. Alternatively, historical accretion of fine sediments within areas of invasive *Spartina* marsh (and subsequent remobilisation after eradication during the mid 1980s) may also have contributed to the increased "muddiness".

6.2. Hardening of the land/sea interface

In most estuaries in New Zealand, where modification or development of the surrounding land has occurred, this has resulted in a loss of connectivity with freshwater wetland habitats. These wetland regions are important sources of nutrients (*e.g.* dissolved and particulate organic materials) for estuaries and they provide habitat for a wide range of species, including fish that migrate across salinity gradients and a variety of birds. 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) these "riparian" zones provide essential linkages between estuarine and terrestrial systems.

There are a number of small streams bordering Waimea Inlet where this connectivity has been compromised due to roading, flood control or infilling. Through this loss in land- sea connectivity these have likely had a significant impact on estuarine function. 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

Further scheduling of repeat Waimea Inlet SOE surveys at approximately 5-year intervals would enable evaluation of long-term trends, providing a more thorough understanding of any major issues relating to estuary health. This would also aid the identification of particular problem areas/subcatchments in order to provide focus for land use management decisions.

7.2. Application to consent monitoring

Both the broad- and fine-scale components of the SOE monitoring, described here and in Gillespie *et al.* (2007), can be successfully used to augment standard consent monitoring. For example, changes to estuary habitats in the vicinity of the Bell Island wastewater outfall were assessed through coordinated consent monitoring based on the SOE broad scale maps to determine whether there was any impact from the discharge (Gillespie *et al.* 2008). We recommend that every effort be made to coordinate ongoing consent monitoring with SOE monitoring in order to provide a more complete picture of overall estuary health.

7.3. Management of sediment impacts

Although the high proportion of muddy habitats in Waimea Inlet and the apparent increase in "muddiness" indicate a potential impact originating from erosion within the catchment, additional monitoring surveys will be required to confirm the seriousness of the problem. In the meantime, however, it would be prudent to explore catchment management options designed to minimise sediment loading rates to the estuary. It would also be useful to establish interim monitoring sites at strategic locations in order to collect data describing sediment accretion rates. This would aid the identification of particular problem areas/subcatchments in order to provide focus for land use management decisions.

7.4. Investigation of habitat reorganisation after *Spartina* removal

Although beyond the scope of this study, we note that there have been large scale changes in estuary vegetative cover over the years due to the introduction and subsequent spread of the invasive grass *Spartina anglica*, followed by its successful removal through a targeted herbicide eradication programme in the mid 1980s (Franko *et al*. 1987). Broad scale changes in vegetation coverage have been documented by historical habitat mapping (Tuckey & Robertson 2003) and associated short-term changes in habitat structure during and after the eradication programme were described by Gillespie *et al*. (1990). Casual observations since 1990 suggest that sediment redistribution has occurred gradually due to the slow rate of decomposition of the *Spartina* root system that continued to hold sediments in place. This may have been partly responsible for the apparent increase in coverage of muddy habitats noted during the present survey. A further, more focused study of changes in sediment height and habitat reorganisation in the areas where *Spartina* removal was achieved would provide documentation of the long-term changes in estuary function resulting from the large-scale herbicide application programme. Such an investigation would provide guidance for management of *Spartina* infestations in other parts of New Zealand.

7.5. Habitat restoration

There are numerous sites in Waimea Inlet where habitat restoration could potentially be achieved. Some of these are presently being considered or pursued. A discussion of some of the options can be found in the proceedings of an estuary restoration workshop recently convened by Tasman District Council (James 2008). Restoration projects either in progress or planned should be coordinated for the entire Inlet. This could be facilitated by using the habitat maps provided here and superimposing additional GIS layers containing planned/achieved alterations.

8. ACKNOWLEDGEMENTS

The rectified aerial photographs for this study were provided by the Tasman District and the Nelson City councils. Robin Holmes (Cawthron) and Allan Smith (Royal Society of New Zealand Teaching Fellow) assisted with field verification of habitat boundaries. Paul Barter (Cawthron) provided GIS software support and Kathryn Laurence assisted with document formatting and figure preparation.

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10. APPENDICES IN AND THAT I CAN DO THE AREA IN THE

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	Intertidal/	Saltmarsh	Shrub/Scrub/Forest	*Beilschmiedia tawa* "Tawa"	Beta
(alternating	supratidal			*Cordyline australis* "Cabbage tree"	Coau
saline and				*Cytisus scoparius* "Broom"	Cysc
freshwater)				*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	Macroalgal bed	*Enteromorpha* sp.	Ensp
		bed		*Gracilaria chilensis*	Grch
				Ulva sp, "Sea lettuce"	Ulri
		Pine Debris	Pine Debris		Pidb
		Artificial	Man-made structure		MM
		Structure	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. CD-ROM file containing a working version of the 2007 broad scale habitat maps of Waimea Inlet