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ESTUARINE HABITAT MAPPING IN THE DERWENT – INTEGRATING SCIENCE AND MANAGEMENT

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Estuarine Habitat Mapping in the Derwent – Integrating Science and Management

A.R. Jordan, M. Lawler and V. Halley

Summary

The Derwent Estuary is a large drowned river valley situated in south-east Tasmania that extends for a distance of 52 kilometres and covers an area of around 198 km^2 between Iron Pot and New Norfolk. The physical structure of the estuary varies substantially along its length, with the upper reaches highly stratified due to consistent freshwater input from the Derwent River and the lower reaches generally well mixed. The freshwater tends to flow on the surface along the eastern shore with saline water travelling upstream on the bottom. While several studies have examined the physical setting of the estuary, there is little information on the distribution and structure of benthic habitats.

In 1988, the Derwent Estuary Program (DEP) was initiated to prepare an environmental management strategy for the Derwent Estuary, together with an associated long-term monitoring program and agreements for implementation of specific environmental improvement programs. Management of estuarine habitats, particularly seagrasses, macroalgae and tidal wetlands have been identified as a priority within this project. It is clear that such management will be most effective if the current distribution of estuarine habitats is known at the appropriate spatial scale.

The distribution of sub-tidal habitats between Iron Pot and New Norfolk were identified through a combination of field mapping using echo-sounders, grab sampling and video assessment, and digitising habitat boundaries from geo-rectified aerial photographs. Habitats were classified as either seagrass, aquatic macrophytes, rocky reef, sand, silt/sand or silt. In addition, one hundred and four sites were sampled for sediments to obtain a qualitative assessment of sediment type (sand, silt/sand and silt) in order to delineate sediment boundaries and to collect samples for analysis of sediment particle size, heavy metals and redox. A number of video transects were also conducted on rocky reef habitats in order to describe the dominant macroalgae.

The estuary was classified into lower, middle and upper reaches due to differences in the physical aspects of shoreline morphology, bathymetry and salinity. Rocky reef habitats occurred primarily in the lower reaches of the Derwent Estuary, although some narrow margins of reef were also present in the middle reaches. The two regions had a combined reef area of approximately 1.97 km^2, which represents around 1% of the overall habitats in the estuary. The structure of the macroalgae assemblages that occurred on these reefs varied substantially between eastern and western shorelines, position along the estuary and depth. In general, the habitat was dominated in the shallow depths by *Lessonia corrugata* and *Ecklonia radiata* while *Carpoglossum confluens*, *E. radiata*, *Caulerpa* sp., and unidentified

red algae dominated the deeper section. Parts of the reef along the western shoreline also had a canopy *Macrocystis pyrifera*. The diversity and abundance of macroalgae decreased in the northern part of the lower reaches, with only small amounts of red and brown algae present on the rocky substrates within the middle reaches.

Seagrass habitats were restricted to small beds within the lower (Halfmoon Bay and Opossum Bay and middle parts (Cornelian Bay, Wilkinsons Point, Dogshear Point, Woodville Bay and Old Beach) of the Derwent Estuary that had a combined area of around 0.22 km^2. The beds consist primarily of *Heterozostera tasmanica*, although small amounts of *Zostera muelleri* were present on the inner margin of beds in the middle reaches. No beds of seagrass were found in either the northern or southern end of Ralphs Bay. As the surveys were conducted during late winter, the area estimate represents distribution during the period of low biomass and cover.

Aquatic macrophytes occurred in large beds in the northern part of the middle section and southern part of the upper section of the Derwent Estuary. In the middle section, extensive beds occurred in the mouth of the Jordan River, southern side of the channel at Granton and northern side of the channel adjacent to Woods Point, usually from the shoreline to around 3 m deep. These beds had a combined area of around 3.04 km^2, with *Ruppia* sp. being by far the dominant species. The density of *Ruppia* spp. was high and evenly distributed across the beds in all areas, with often a large biomass of filamentous algae also present in the beds.

Unvegetated habitats were the most dominant habitat type within the Derwent Estuary representing around 96% of all subtidal habitats, although large differences occurred in the distribution of sediment type between the lower, middle and upper reaches. The lower reaches were represented by sand all depth zones in the mouth, the northern and southern parts of Ralphs Bay and in shallow depths on both eastern and western shores. Sand/silt occurred in the deeper section from around Halfmoon Bay to Gellibrand Point and the northern end of Ralphs Bay and in middle depths on the western shore from Cartwright Point to Sullivans Cove. On the eastern shore north of Droughty Point, sand/silt occurred adjacent to the sand beach habitats up to Kangaroo Bluff. The silt habitat occurred in the deeper parts of the lower reaches north of Gellibrand Point.

The middle reaches of the estuary was dominated by silt habitat, although areas of sand occurred in shallow depths on the western shore up to Cornelian Bay and the eastern shore almost continuously up to Woodville Bay. A large area was also present between Dogshear Point and the eastern shoreline. Sand/silt was restricted to several small areas including Elwick Bay and east of Dogshear Point. The channel region of the upper reaches was found to contain mostly sand/silt, although silt most likely dominated the deeper sections. Results of the distribution of sediment particle size, heavy metals and redox will be published in a subsequent report of the Derwent Estuary Program.

Additional information is presented on the distribution of intertidal habitats and wetlands. The spatial distribution of wetlands presented reflects that identified in the mapping layers from the TASVEG 2000 project (Tasmanian Parks and Wildlife Service), defined as habitat codes Sw (tall-wet scrubs), Mg (graminoid saltmarsh) and Ws (sedge/rush wetland). The Tasmanian coastline and tidal zone data layer information was supplied by the Land

Information Services Tasmania, Department of Primary Industry Water and Environment which categorised habitat into rock, sand, unvegetated mudflat and vegetated mudflat.

The techniques and problems associated with the design of monitoring programs for macroalgae, seagrass and aquatic macrophytes are discussed. It is clear that it will be difficult to define a cost-effective monitoring regime that examines both the processes that determine the spatial and temporal patterns in these habitats and quantifies the amount of change that results from human induced impacts. In order to detect both large and small scale change, a combination of aerial photograph assessment, ground truthing and fixed sampling may be most appropriate. Recommendations are made on the appropriate number and location of monitoring sites for macroalgae, seagrass and aquatic macrophytes.

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1. Introduction

The Derwent Estuary is a large drowned river valley that extends for a distance of 52 kilometres and covers an area of around 198 km^2 between Iron Pot and New Norfolk. The estuary can be broadly classified into lower, middle and upper reaches that differ considerably in the physical aspects of shoreline morphology, bathymetry and salinity.

The lower reaches (between Iron Pot and the Tasman Bridge) are around 4-6 km wide with a relatively straight western shore, marine dominated and mostly 10-20 m deep. A single large embayment (Ralphs Bay) is present on the eastern shore which is mostly <10 m deep. The middle reaches (between the Tasman Bridge and Bridgewater Causeway) are narrower at 1-2 km wide, but contains numerous small shallow embayments on both shores. While marine dominated at the Tasman Bridge, the water column becomes increasingly stratified with low salinity water often flowing on the surface, particularly on the eastern shore. The upper reaches (from Bridgewater Causeway to New Norfolk) are narrow and characterised by a well defined channel that often contains a highly stratified water forming a salt wedge.

The Derwent Estuary has a large catchment (~ 8,900km^2), primarily from the Derwent River, with smaller amounts from the Jordan River and numerous small creeks and streams in the middle and lower reaches. The land use within the catchment is primarily woodland, forest, heath and scrub (67%), agricultural use (27%), water storage (3%) and urban and industrial use (<1%) (Coughanowr, 1997). The urban and industrial use consists of around 190,000 people and a number of heavy and light industries, mostly concentrated in the Hobart metropolitan area. A significant part of the shoreline in the middle and lower reaches of the estuary is identified as urban usage (TASVEG 2000).

The Derwent Estuary has a long history of water and sediment contamination including pathogens, nutrients, total suspended solids (TSS), biochemical oxygen demand (BOD), heavy metals, fluoride, arsenic and resin acids (Coughanowr, 1997). Inputs into the estuary can be categorised as either point-source (sewage and industrial discharges) or diffuse-source (primarily urban and agricultural runoff), both of which directly affect the water and sediment quality of the river. The majority of nutrients come from sewage and urban runoff, although the contribution of some bioavailable nutrients in the lower and middle reaches from southern ocean water can be significant at times. The total suspended solids are contributed mainly from land disturbance within the upper Derwent catchment and urban areas, particularly during flood conditions.

The estuarine sediments in the upper and middle reaches of the estuary have been degraded due to significant inputs of nutrients, organic matter and heavy metals (Coughanowr, 1997). Concentrations of zinc, cadmium, lead and mercury have been found to be consistently high in both sediments (Bloom, 1975; Pirzl, 1996) and biota (see Coughanowr, 1997). The nutrient and organic matter inputs have resulted in significant changes to the sediment structure and macroinvertebrate communities, although some improvements have been noted over the past decade (Moverley and Garland, 1995). Recent studies showed a significantly decline in the abundance and species richness in the macro-benthic faunal community at three sites downstream of the Boyer mill outfall to 800 m downstream (Aquenal 2000). There has also been a considerable decline in the densities of benthic invertebrate species in the lower Derwent Estuary, largely as a result of the presence of introduced marine pests (particularly, seastars *Asterias amurensis* and *Patiriella regularis*, gastropod *Maoricolpus roseus*, chiton *Amaurochiton glaucus*, ascidian *Ascidiella aspersa*, crab *Cancer novaezelandiae*) (Morrice, 1995).

Although substantial areas of tidal wetlands and macroalgae are known to exist in the Derwent Estuary, no systematic surveys of these habitats have been conducted. Some limited mapping of seagrass in the lower reaches was conducted in the early 1990s (Rees 1993) and at that time there was evidence of total seagrass loss (~400 ha) in that area. Giant kelp (*Macrocystis*) has also been identified as a species that has declined in its distribution. There have also been few comprehensive sediment surveys of the Derwent Estuary, with most studies concentration on specific areas or contaminants (see Coughanowr, 1997). The most recent survey of sediments throughout the estuary is by Pirzl (1996) who examined sediment type and a range of chemical parameters.

In late 1998, the Derwent Estuary Program (DEP) was initiated with support from Coast and Clean Seas, a component of the Natural Heritage Trust. The goal of this 2-year management initiative is the preparation of an environmental management strategy for the Derwent Estuary, together with an associated long-term monitoring program and agreements for implementation of specific environmental improvement programs. Management of estuarine habitats, particularly seagrasses, macroalgae and tidal wetlands have been identified as a priority within this project. Such management will be most effective if the current distribution of estuarine habitats is known at the appropriate spatial scale.

As recommended in the State of the Environment Environmental Indicator Report – Estuaries and the Sea (Ward *et al*. 1998), the management plan will also seek to incorporate indicators for estuarine habitat extent. These will be included as part of an associated monitoring program to assess performance of the management plan over the longer term. As seagrass and macroalgae have been identified as key indicators of estuarine health, the establishment of monitoring sites are required to assess environmental performance.

2. Objectives

The project objectives were to:

- incorporate habitat information within the DEP management plan (e.g. management benchmarks, performance monitoring);
- map existing areas of seagrass, tidal wetlands and macroalgae in the Derwent Estuary;
- identify and establish representative long-term seagrass and algal monitoring sites;
- collate and enhance existing spatial data sets for other estuarine habitat types (e.g. beaches, dunes, saltmarsh, intertidal flats, reefs);
- compile a spatial database (GIS) for all estuarine habitat types and publish maps on the Derwent Estuary Program (DEP) internet site, and
- communicate findings to stakeholders and the community.

3. Methods

3.1 Field ground-truthing

The field data produced point locations of habitat type. These points were used as the basis to generate habitat polygons. At the scale of 1:2000, points were connected to form polygons of similar habitat type. The outer boundary of the polygon was identified in the field and the polygon line deflected from the outer point no more than 5 m. In some instances, reefs covered by sand and not seen in the aerial photograph were picked up by echo sounder, and low plant biomass areas that could be observed on the photograph were sometimes reflected as predominantly sand by the echo sounder.

The use of echo sounder data with a differential GPS unit provided an efficient method for surveying the extensive area. A Furuno 600L colour sounder was used for habitat discrimination. Different substrate types provided differing traces based on their roughness and hardness. This signal was interpreted in the field and logged against depth and position. The exact location of boundaries between patches of differing habitat and the depth that they occurred was recorded using a Garmin 135 GPS map unit coupled with a RACAL differential correction unit. The accuracy of the GPS was assessed by recording position at fixed points over extended time periods. It varied by no more than 12 m over a three-hour period. The habitat types were classified as seagrass, aquatic macrophytes, sand, silt/sand, silt and rocky reef.

A submersible video camera was deployed at selected sites in order to verify echo-sounder classifications and obtain more detailed information on habitat attributes. Such attributes reflect the dominant algal, seagrass and sessile invertebrates present on reef and soft-sediment substrates. On reef habitats co-dominant species and/or dominant understory species were also noted. Given the objective of habitat mapping at the spatial scale of 1:25,000 or larger, the relative abundance of attribute species were not quantified.

3.2 Aerial photography

The aerial photography archives of the Department of Primary Industry, Water and Environment were searched to identify photographs that covered the Derwent Estuary and were suitable in terms of water clarity, sun glint and camera angle.

Nine colour aerial photographs of the Derwent Estuary taken during 1995 and 1999 were selected to map reef habitat and benthic vegetation (Table 1). From the nine aerial photographs, five were taken in December and four in March. The photographs were scanned at 600dpi (dots per inch) and the images stored as 24 bit colour TIFF images. Each image was geo-rectified using Arc Info (Environmental Systems Research Institute - ESRI) to the LIST (Land Information Services Tasmania) coastline coverage in AGD66. To rectify, a minimum of 15 ground control points were selected for each image. The RMS (root mean square) error is an indicator of the position of each pixel relative to its location in the real world. The average RMS error calculated for the images was X 8.157 and Y10.246.

Table 1. Aerial photographs used for habitat boundary interpretation

Date	Film	Run No.	Negative No.	Scale	Scanning Res (DPI)
11.3.1995	1234	5	118	1:12,500	600
11.3.1995	1234	5	120	1:12,500	600
3.3.1995	1233	6	211	1:12,500	600
3.3.1995	1233	6	212	1:12,500	600
14.12.1999	1320	35	155	1:42,000	600
14.12.1999	1320	35	156	1:42,000	600
14.12.1999	1320	35	157	1:42,000	600
14.12.1999	1320	35	158	1:42,000	600
14.12.1999	1320	35	159	1:42,000	600

3.3 Computer mapping

Maps were generated through on screen digitising of habitat boundaries in Arc View (ESRI). Habitat boundaries were recognised firstly from aerial photographs and polygons drawn to capture habitat categories. All spatial layers (polygons) produced from the aerial photographs were overlaid onto the field collected data points and checked for continuity.

Vegetation maps at 1:25000k of New Norfolk (5026), Richmond (5226), Hobart (5225) Taroona (5224) and Blackmans Bay (5223) were supplied by the TASVEG2000 project (Tasmanian Parks and Wildlife Service). These maps sheets were first combined to form one layer in ArcView and then clipped to a 500 m buffer of the Derwent Estuary (for codes see Appendix 1).

The Tasmanian coastline and tidal zone data layer information was supplied by the Land Information Services Tasmania, Department of Primary Industry Water and Environment. The Tasmanian Tidal Zone 1:250 000 depicts large areas between Mean High Water Mark and Mean Low Water Mark. The data was originally captured from aerial photography at 1:42000 by graphical photogrammetric plotters to create the 1:100 000 TASMAP series.

Where reef habitat was identified from field ground truthing adjacent to intertidal rock habitat it was clipped to the coastline layer, therefore subsuming the tidal zone polygon. However, where subtidal sand, sand/silt or silt was found to be adjacent to tidal zone habitats, the polygons remained distinct. There are also parts of the middle reaches of the estuary that the tidal zone has not been mapped and therefore all habitats were clipped to the coastline. In this section of the estuary the shoreline type was identified from field ground truthing consistent with the tidal zone classifications and represented as a line feature over the coastline layer. In most parts of the middle estuary a small amount of subtidal reef occurs adjacent to the intertidal rock. However, as it is often too narrow to represent as a distinct polygon in the smallest spatial scale maps, the two habitats are presented as a single line feature.

Spatial data of this type can possess errors of two various types, positional error and attribute error. Positional error is the offset of points, lines and polygons from their true location in the real world. Attribute accuracy related to the non-positional characteristic of a spatial data entity, which is the information stored on a feature. This accuracy is determined by comparing the category description or value assigned in the mapping to that recorded in the field. Accuracy assessment often requires extensive field surveys to verify interpreted information, and this can pose problems in the marine environment as the physical setting can sometimes restrict detailed mapping being completed. Though the field data produced a reliable record of the benthic habitats, the nature of the field transects must be accounted for in the assessment of the positional error of the habitat. For example, some areas of the river were too shallow to survey by boat.

Depth measurements taken from a Garmin sounder were used to construct a contour layer. These depths were corrected for tidal variation using existing tide tables using the formula:

$$D_i = D[h_1+(h_2-h_1)*(\cos(\pi*((t-t_1)/(t_2-t_1)+1))+1)/2]$$

where $h_{1,2}$ correspond to the heights of the high and low tides, $t_{1,2}$ are the times of the high and low tides with t being the current time. All depth measures were then corrected to Mean Sea Level.

The z values were sampled at a regular distance for 80% of the field work. The points were used to construct a TIN (Triangular Irregular Network) in ArcView. A TIN is a terrain model that uses a sheet of irregularly spaced sample points to produce a continuous surface of triangles using the depth points as the corners of the triangle. This interpolation method is based on the common observation that values at points closer together in space are more likely to be similar than points further apart. Isometric mapping in constructing contours from a TIN surface requires the consideration of two edges of the same triangle facet (Burrough and McDonnell, 1998) (Fig. 1).

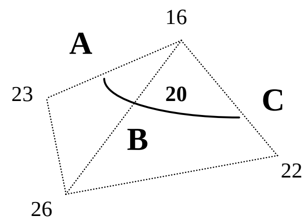


Fig. 1. A contour linking points A, B and C constructed from a TIN.

When point A is identified, the next point is selected from the other two edges of the same triangle. In this case point B is identified because the values at the two ends of the other edge do not contain the value 20. The process continues to identify the point C. Again, a line connects the three points A B C of the same value (20) to define part of the isoline (Chew, 1997). Due to extraneous circumstances, insufficient data points were collected from the Tasman Bridge area and depth contours from this region have been omitted. Contours at depths of 2 m, 5 m, 10 m through to 40 m at 10 m intervals were generated.

3.4 Sediment sampling

A survey of soft-sediment habitats was conducted in the estuary as part of the field mapping. The purpose of the mapping was twofold – firstly to obtain a qualitative assessment of sediment type (sand, silt/sand and silt) to delineate sediment boundaries, and secondly to collect samples for analysis of heavy metals, redox and sediment particle size. One hundred and four samples in the lower and middle part of the estuary were collected by either benthic core or Smith-MacIntyre grab (Fig. 2a,b, Appendix 2). Replicate core samples were taken at each site with the first core used for redox measurements and the second core frozen for later analysis.

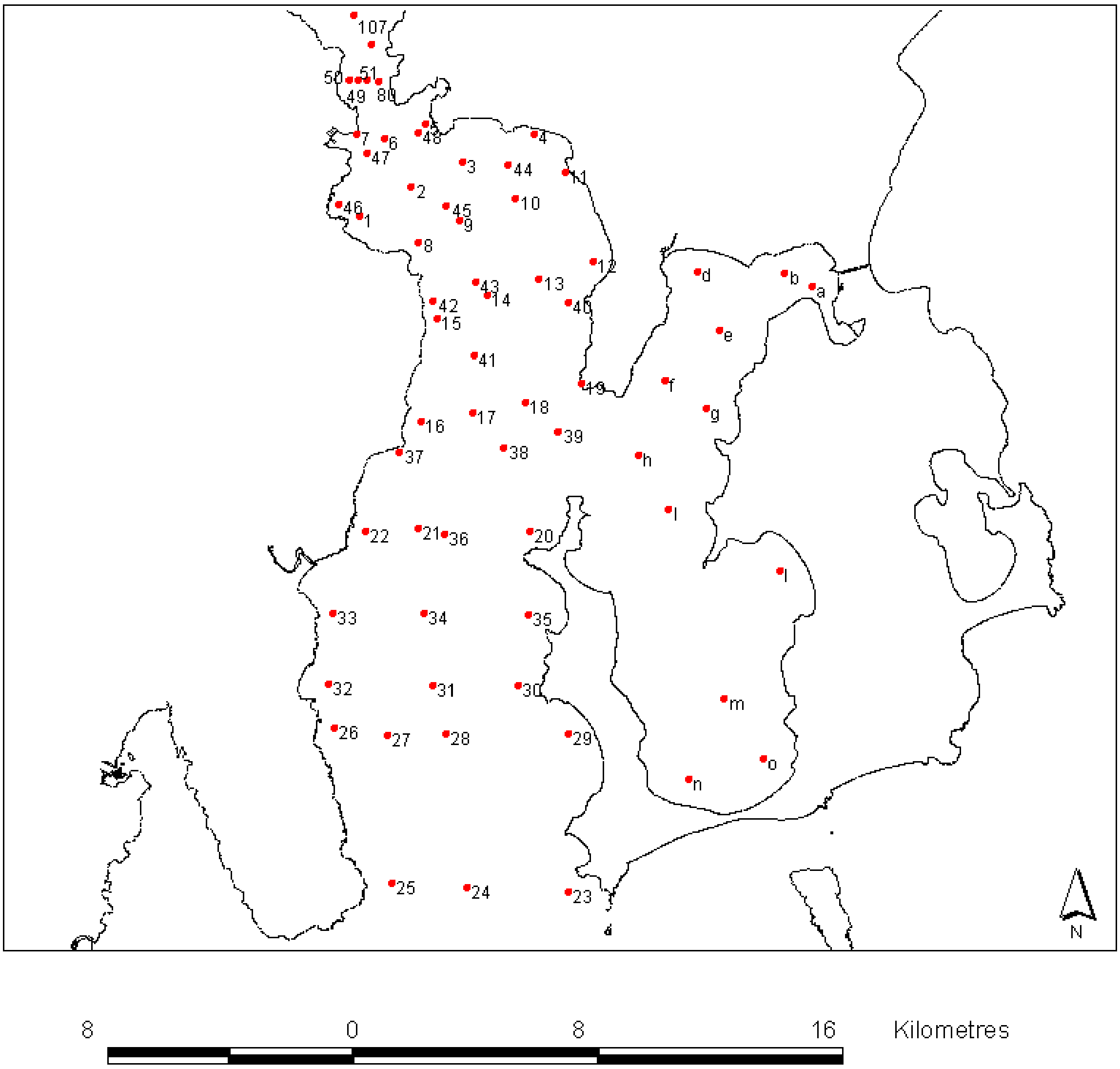


Fig. 2a. Sediment sampling sites in the lower reaches of the Derwent Estuary

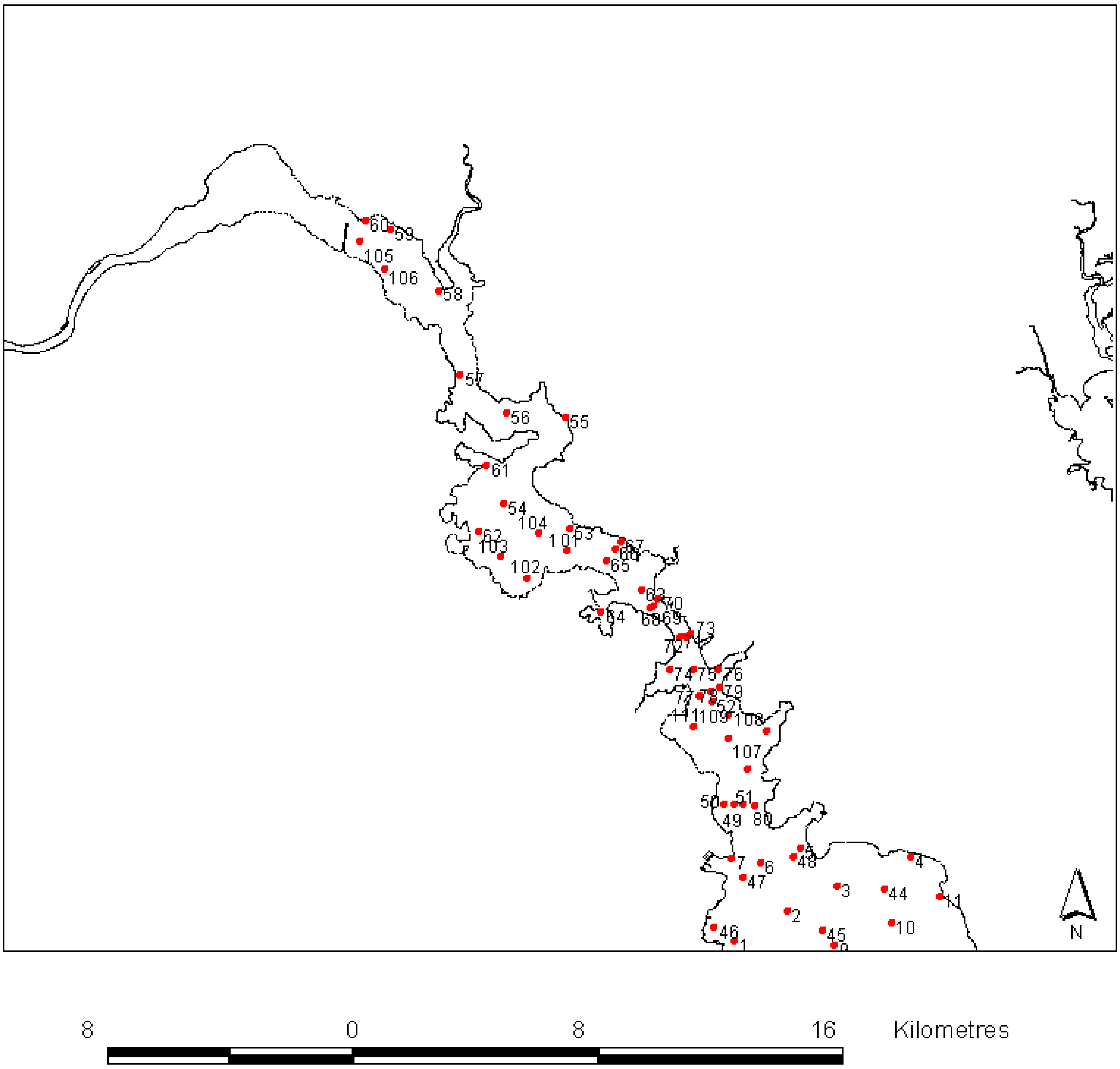


Fig. 2b. Sediment sampling sites in the middle reaches of the Derwent Estuary

4. Results

4.1 Rocky Reefs

Rocky reef habitats occurred primarily in the lower reaches of the Derwent Estuary, although some narrow margins of reef were also present in the middle reaches (Fig. 4a,b). The two regions had a combined reef area of approximately 1.97 km^2, which represents around 1% of the overall habitats in the estuary (Table 2). As the reef was clipped to the coastline, this area also includes that covered by intertidal rock.

The structure of the macroalgae assemblages that occurred on these reefs varied substantially between eastern and western shorelines, position along the estuary and depth. In order to more adequately describe the variability, the dominant macroalgae were identified and percentage of the overall assemblage estimated from video transects at a series of stations (Fig. 3a,b, Table 3).

The reefs along the western shoreline between Piersons Point and Blackmans Bay consisted of a narrow band of mostly continuous habitat occurring down to depths of 11-14 m (Fig. 5a,b). The habitat was dominated in the shallow depths by *Lessonia corrugata* and *Ecklonia radiata* while *Carpoglossum confluens*, *E. radiata*, *Caulerpa* sp. and unidentified red algae dominated the deeper section. Much of the reef along this shoreline also had a canopy *Macrocystis pyrifera* across all depths.

From Blackmans Bay to Crayfish Point the reef was mostly continuous along the shore, apart from the sand beaches of Blackmans Bay, Kingston Beach and Taroona Beach (Fig. 5c,d). The reefs occur down to a depth of around 6 m, although it is patchy in places, particularly along the Alum Cliffs. The habitat was dominated by *L. corrugata*, *E. radiata*, *C confluens* and unidentified red algae. From Crayfish Point to Blinking Billy Point the reef is present as a narrow strip mostly adjacent to a rocky shoreline and is dominated by small amounts *L. corrugata* and unidentified red and brown algae (Fig. 5e,f).

Along the eastern shoreline from Cape Deliverance to Gellibrand Point reef habitat is most restricted to the prominent headlands separated by sand beach habitats (Fig. 5h-k). The reefs were dominated by a mixture of *L. corrugata*, *E. radiata*, *C confluens* which tended to unidentified red algae and *Cystophora* sp. in deeper water. Between Droughty Point and Howrah Point the reef habitats were mostly continuous, narrow down to depths of only 2-4 m and often patchy (Fig. 5q-s). The algal abundance was consistently less the reefs further seaward and dominated by a mixture of unidentified red algae, *Codium* sp. and *Cystophora* sp. The reefs between Howrah Beach and Montague Bay were restricted to the headlands of Second Bluff, Kangaroo Bluff and Rosny Point and was dominated by *E. radiata* and unidentified red algae (Fig. 5s, 6a). Small amounts of *Ulva* sp. were present in shallow depths along the rocky shoreline in this area.

North of the Tasman Bridge the reefs consisted mostly of a narrow strip of rock rubble adjacent to a rocky shoreline (Fig. 6a-g). In many areas, such as Geilston Bay, the habitat is not wide enough to represent as a distinct polygon in the smallest spatial scale maps presented in this study. In the southern parts of the middle reaches of the estuary small amounts of unidentified red and brown algae occur on the reefs while north of about Cornelian Bay the reefs were mostly absent of algal growth.

Table 2. Area in km^2 of habitat types within the upper, middle and lower reaches of the Derwent Estuary

Habitat type	Upper Derwent	Middle Derwent	Lower Derwent	Total
Sand	0.00	1.83	63.68	65.51
Sand/silt	3.19	3.83	54.52	61.54
Silt	0.00	21.45	32.37	53.82
Reef	0.00	0.24	1.73	1.97
Seagrass	0.00	0.12	0.10	0.22
Aquatic macrophytes	2.83	3.04	0.00	5.88

4.2 Seagrass

Seagrass habitats were restricted to small beds within the lower and middle parts of the Derwent Estuary that had a combined area of around 0.22 km^2 (Fig. 4a,b; Table 2). This area estimate is based on surveys conducted during late winter and therefore represents distribution during the period of lowest biomass and cover. Beds in the lower Derwent occurred exclusively within the northern part of Halfmoon Bay and middle and northern parts of Opossum Bay (Fig. 5i,j). These beds consisted entirely of *Heterozostera tasmanica*, were present in depths down to around 5 m and had a combined area of around 0.10 km^2.

In the middle reaches, small seagrass beds were present in Cornelian Bay (Fig. 6a), Wilkinsons Point, the northern end of Dogshear Point, Woodville Bay and Old Beach (Fig. 6e). These beds had a combined area of around 0.12 km^2, with limited sampling of the beds indicating that they consist primarily of *H. tasmanica*. The density and biomass of the beds differed considerably throughout the middle reaches, however they all were restricted to a maximum depth of around 3 m.

4.3 Aquatic macrophytes

Aquatic macrophytes occurred in large beds in the northern part of the middle section and southern part of the upper section of the Derwent Estuary. In the middle section, extensive beds occurred in the mouth of the Jordan River (Fig. 4b), southern side of the channel at Granton and northern side of the channel adjacent to Woods Point (Fig. 6f,g). These beds had a combined area of around 3.04 km^2 (Table 2), with *Ruppia* sp. being by far the dominant species. They were distributed from the shoreline to around 3 m deep, which represented the edge of the channel. The density of the *Ruppia* sp. was high and evenly distributed across the beds in all areas, with often a large biomass of filamentous algae also present in the beds.

The beds in the upper section were essentially continuous with those adjacent in the middle section and occurred in large beds on both sides of the channel (Fig. 4c). These beds had a combined area of around 2.83 km^2 (Table 2). While *Ruppia* sp. was the dominant species throughout the beds, there were small areas where the additional species of *Lepilaena cylindrocarpa*, *Myriophyllum salsugineum*, *Triglochin striata* and *T. procera* were high in abundance.

4.4 Subtidal unvegetated habitats

Unvegetated habitats were the most dominant habitat type within the Derwent Estuary representing around 96% of all subtidal habitats (Table 2). Large differences, however, occurred in the distribution of sediment type between the lower, middle and upper reaches. In the lower reaches, sand dominated all depth zones in the mouth, the northern and southern parts of Ralphs Bay and in shallow depths on both eastern and western shores (Fig. 4a, Fig. 5a-s). In the middle estuary, sand habitat occurred in shallow depths close to shore on the western shore up to Cornelian Bay and the eastern shore almost continuously up to Woodville Bay (Fig. 4b, Fig. 6a-g). A large area was also present in an area between

Dogshear Point and the eastern shoreline. Throughout the estuary it had a combined area of approximately 65.51 km^2 (Table 2).

The sand/silt habitat type dominated the middle of the estuary from around Halfmoon Bay to Gellibrand Point, the deeper section of the northern end of Ralphs Bay and from the shore to around 15 m deep on the western shore from Cartwright Point to Sullivans Cove (Fig. 4a,b). On the eastern shore north of Droughty Point, sand/silt occurred adjacent to the sand beach habitats up to Kangaroo Bluff. In the middle estuary sand/silt was restricted to several small areas including Elwick Bay and east of Dogshear Point. Throughout the estuary the sand/silt habitat had a combined area of approximately 61.54 km^2 (Table 2). The channel region of the upper reaches was found to contain mostly sand/silt, although silt most likely dominated the deeper sections.

The silt habitat occurred in the deeper parts of the lower section of the estuary from Gellibrand Point north and dominated almost the entire area of the middle reaches generally adjacent to sand habitats along the eastern shore up to Dogshear Point. The habitat had a combined area of approximately 53.82 km^2 (Figs. 4a,b; Table 2).

More detailed information of sediment distribution will be presented in a subsequent report of the Derwent Estuary Program which will include data on sediment particle size, redox and heavy metals concentrations.

4.5 Intertidal habitats

Information on the distribution of intertidal habitats (those between Mean High Water Mark and Mean Low Water Mark) in parts of the Derwent Estuary was collated from the Tasmanian coastline and tidal zone data layer information supplied by the Land Information Services Tasmania, DPIWE. The region has been categorised into the four habitat types, rock, sand, unvegetated mudflat and vegetated mudflat. In parts of the estuary where the intertidal zone has not been mapped, the shoreline type was identified from field ground truthing consistent with the tidal zone classifications and represented as a line feature over the coastline layer. In addition, the vegetated mudflat category has been subsumed within the aquatic macrophyte habitat category detailed in Section 4.3.

As the tidal zone data is incomplete for the entire Derwent estuary the area that this represents has not been determined. However, it is clear that the majority of intertidal habitats are within Ralphs Bay due to the presence of large areas of shallow sandflats, particularly from South Arm Neck to Shelley Beach, Mortimer Bay and Lauderdale (Fig. 5i-p). The other main area of intertidal sand occurs in the embayments in the lower reaches of the estuary.

There are also considerable areas of intertidal rock within the Derwent Estuary. Within the lower reaches this is almost always adjacent to subtidal rocky reef habitats, which on the eastern shore is generally located on headlands, but on the western shore is mostly continuous (Fig. 5a-s). This pattern is similar in the middle reaches where intertidal rock is generally adjacent to a narrow strip of subtidal reef that is often too narrow to represent as a distinct polygon in the smallest spatial scale maps. In these areas the two habitats are presented as a single line feature (Fig. 5

Small areas of unvegetated mudflats occur in the middle reaches, mostly at the head of the numerous small shallow embayments on both shores. While these habitats are mostly unvegetated, there appears to be small areas of the seagrass, *Zostera muelleri* present, particularly in the summer months. Field ground-truthing in January identified such areas in Cornelian Bay, south end of Elwick Bay, Berridale Bay, Lowestoft Bay, Conneware Bay, Windermere Bay and Risdon Cove. As these habitats are generally too narrow to represent as a distinct polygon in the smallest spatial scale maps, they remain classified as unvegetated mudflat.

4.6 Wetlands

The spatial distribution of wetlands presented here reflects that identified in the mapping layers from the TASVEG 2000 project defined as habitat codes **Sw** (tall-wet scrubs), **Mg** (graminoid saltmarsh) and **Ws** (sedge/rush wetland). The habitat code **Was** (saline aquatic plants) has not been included as it has been subsumed within the aquatic macrophyte habitat category detailed in Section 4.3. Species composition information is collated from the wetlands surveys presented in Aquenal (2000) where vegetation communities were categorised into TASVEG 2000 mapping units.

The upper reaches of the Derwent Estuary contains the most extensive area of wetlands throughout the estuary, particularly concentrated downstream of the Boyer papermill (Fig. 7a-d). Extensive areas of sedge/rush wetland were present both shorelines and dominated by *Leptocarpus brownii*, *Juncus kraussii* and *Baumea arthrophylla* (Aquenal, 2000). Adjacent to this habitat were areas of tall-wet scrub that was primarily *Leptospermum lanigerum*. Small area of sedge/rush wetland were also identified at the mouth of the Jordan River (Fig. 6f). The graminoid saltmarsh habitat is present in small areas on both shorelines and is dominated by *Phragmites australis* and *Deschampsia cespitosa* (Aquenal, 2000). Further details on species composition and percentage cover from four main areas of wetlands in the upper reaches of the estuary are presented in (Aquenal, 2000).

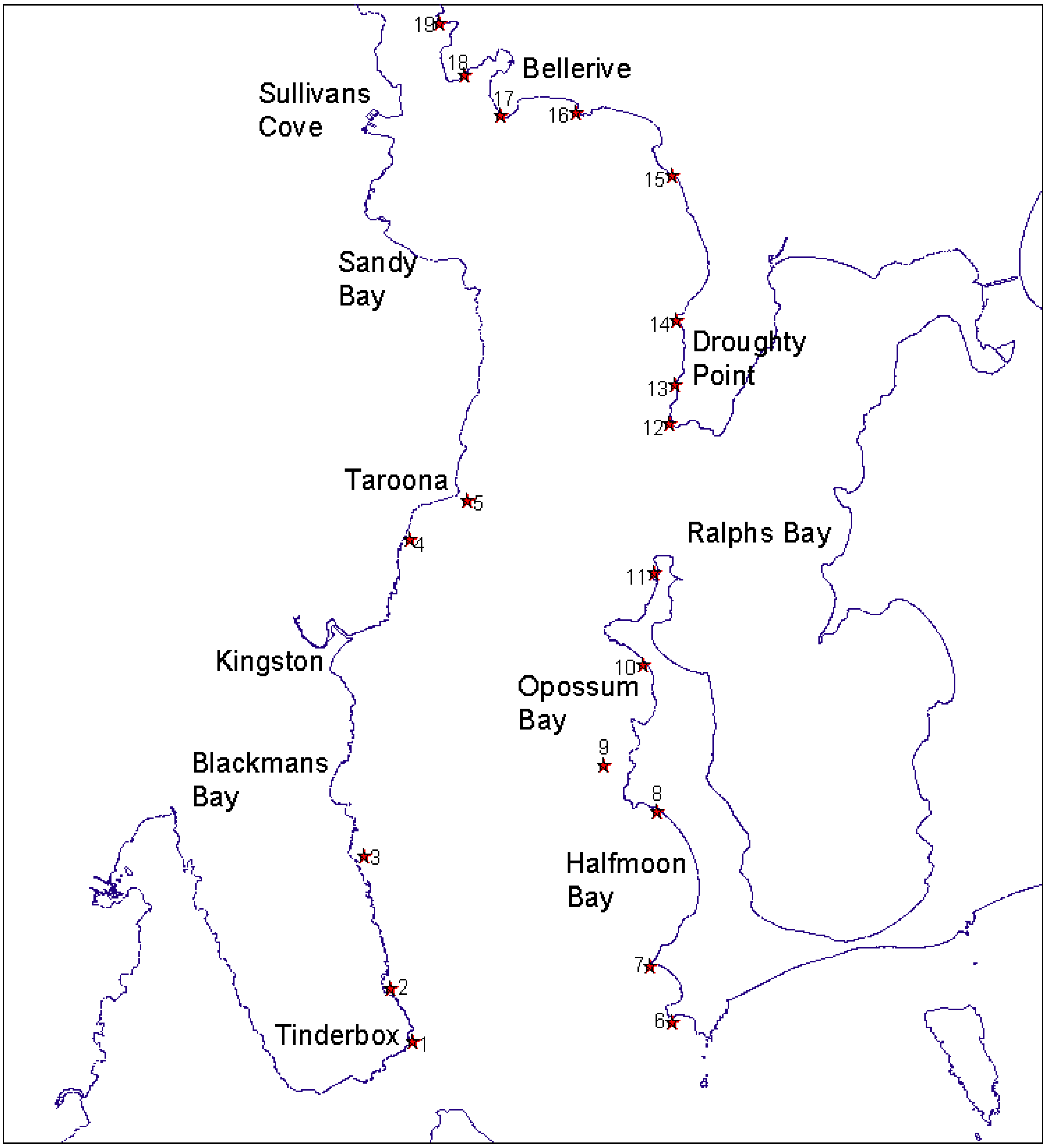


Fig. 3a. Position of video stations in the lower reaches of the Derwent Estuary

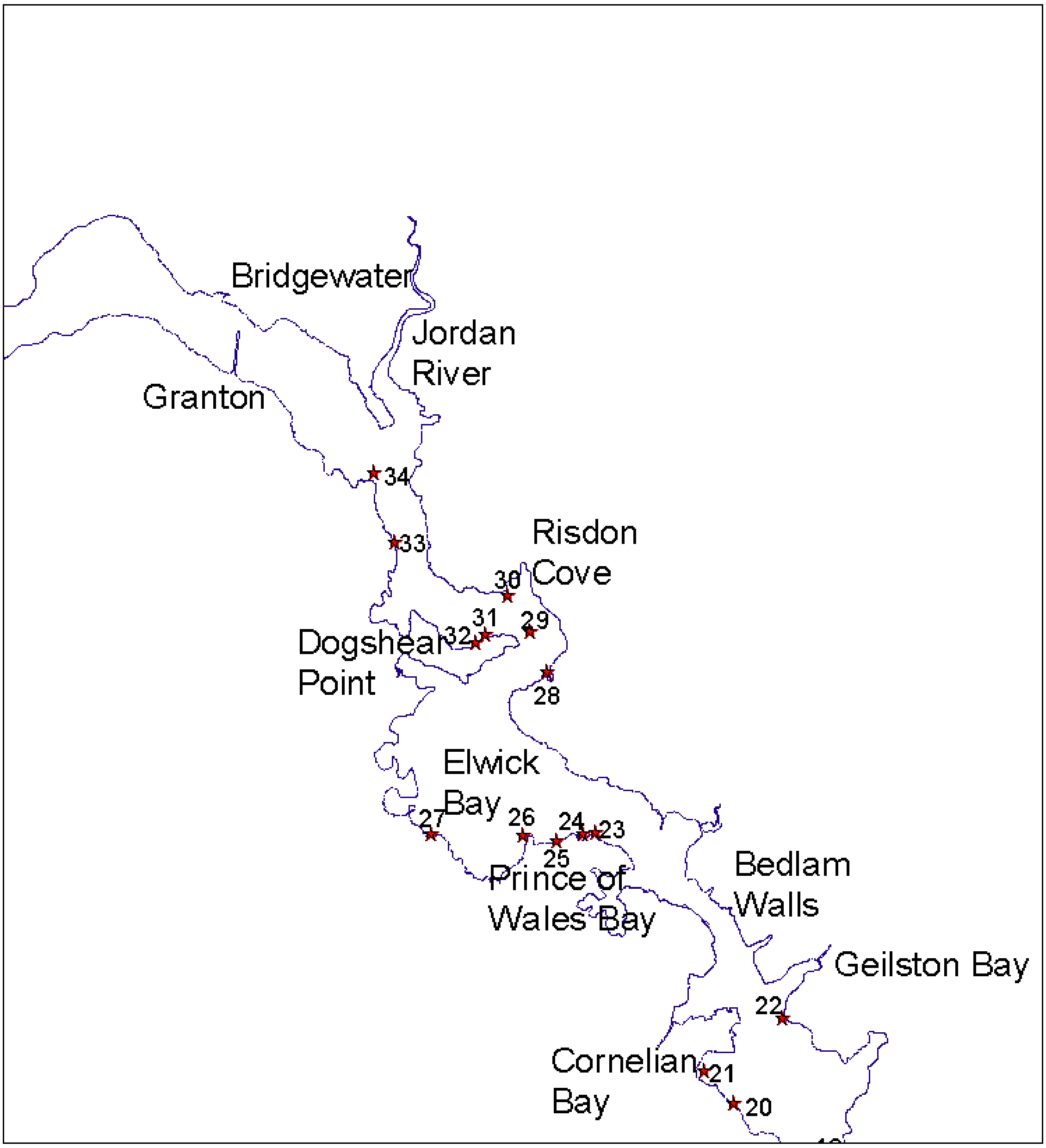


Fig. 3b. Position of video stations in the middle reaches of the Derwent Estuary

Table 3. Details of station position, depth and habitat attributes of habitats in the Derwent Estuary defined from video stations

Video #	Latitude	Longitude	Depth	Observation
1	-43.05299	147.34366	3-12m	Medium profile reef (1-3m relief) into sand. Shallow reef dominated by *Lessonia corrugata* (80%) with some *Ecklonia radiata* (10%). Reef below 5m dominated by *Ecklonia radiata* (25%), *Carpoglossum confluens* (15%) and unidentified red algae (5-10%), with a *Macrocystis pyrifera* canopy. *Cystophora* sp. was also present. Reef/sand boundary at 10 m. Sand coarse with some shell grit.
2	-43.04313	147.33804	5-12m	Low profile reef (<1m relief) into sand. Shallow reef dominated by *Ecklonia radiata* (35%). Reef below 6m dominated by *Carpoglossum confluens* (10%), unidentified red algae (10%) with *Ecklonia radiata* and *Caulerpa* sp. also present. Reef/sand boundary at 11 m. Sand coarse with some shell present.
3	-43.01901	147.33126	8-15m	Low profile reef (<1m relief) into sand. Reef below 6m dominated by unidentified red algae (25%), with some *Carpoglossum confluens* (10%), *Ecklonia radiata* and *Caulerpa* sp. also present. Reef edge at 14 m, patchy with some sponge (5%). Reef/sand boundary at 14 m. Sand coarse with some shell.
4	-42.96138	147.34230	3-5m	Medium profile reef (1-3m relief) into sand. Reef dominated by *Lessonia corrugata* (40%) and *Ecklonia radiata* (10%), with unidentified red algae (5%) and a little *Carpoglossum confluens* on the reef fringes. Reef/sand boundary at 6 m. Sand coarse with shells. The seastar *Coscinasterias muricata* present on reef.
5	-42.95431	147.35654	3-13m	Medium profile reef (1-3m relief) into sand. Shallow reef with a little *Carpoglossum confluens* and unidentified red algae (5%). Reef dominated by *Ecklonia radiata* (20%), *Lessonia corrugata* (20%) and unidentified red algae (20%). Reef/sand boundary at 6 m. Sand coarse with some patches of shell.
6	-43.04909	147.40778	2-9m	Medium profile reef (1-3m relief) into sand. Shallow reef dominated by *Lessonia corrugata* (100%). Reef below 3 m with *Carpoglossum confluens* (30%), unidentified red algae (5%) and *Pyura* sp. Reef/sand boundary at 7m. Sand rippled with shell.
7	-43.03892	147.40225	2-3m	Low profile reef (<1m relief). Reef with *Carpoglossum confluens* (60%) and unidentified red algae (5%) in shallow. Deeper reef covered with unidentified red algae (40%).
8	-43.01058	147.40392	2-5m	Sand with seagrass bed (*Heterozostera*). Seagrass dense (70-80%) in 2-3 m, becoming sparse (20%) in 5 m of water. Seagrass blades ~10cm long.
9	-43.00232	147.39052	7-12m	Low profile reef (<1m relief) some medium profile patches. Reef with little algal growth, patches of *Ecklonia radiata* (20%) and *Carpoglossum confluens* (60%) with some unidentified red algae (5%). Offshore reef with reef/silt boundary at 11 m. Evidence of some urchins (*Heliocidaris erythrogramma*) and New Zealand screw shells (*Maoricolpus roseus*).
10	-42.98415	147.40002	4m	Sand with some sparse seagrass (*Heterozostera*) (10%). Seagrass blades <10cm,
11	-42.96735	147.40288	3-6m	Medium profile reef (1-3 m relief). *Ecklonia radiata* (50%) dominant in shallow parts of reef. Deeper parts covered with *Ecklonia radiata* (15%), *Cystophora* sp. (15%), unidentified red algae (15%) and some *Carpoglossum confluens.* Urchins (*Heliocidaris erythrogramma*) present in crevices. Reef/sand boundary at 6 m. Sand coarse with some shell grit.
12	-42.94018	147.40647	6m	Patchy low profile reef (<1m) with sand. Reef with scungy algal growth and some sponge (<5%). Shell grit in sand patches.
13	-42.93305	147.40773	3-5m	Low profile reef (<1m relief) into sand. Reef with little algal growth. Reef/sand boundary at 4 m. Sandy/silt with some shell. The introduced seastar *Asterias amurensis* and the New Zealand piecrust crab *Cancer novaezealandiae* were present.

Table 3. Continued

14	-42.92137	147.40823	1-2m	Low profile reef (<1m relief). Dominated by unidentified red algae (25%), some *Codium* sp. (5%) and *Cystophora* sp. also present. Starfish (*Patiriella* sp.) present at this location. Reef/sand boundary at 2 m. Sand with some shell grit.
15	-42.89495	147.40676	1-2m	Low profile reef (<1 m relief). Dominated by unidentified red algae (20%) and *Codium* sp. (10%) in the shallows. Deeper reef with little algal growth. Starfish (*Patiriella* sp.) abundant in the shallows, with *Coscinasterias muricata* also present at this location. Reef/sand boundary at 2 m.
16	-42.88346	147.38278	3-5m	Low profile reef (<1 m relief) with some medium profile reef in the shallower water. Shallow waters dominated by unidentified red and brown algae (80%). Deeper part with *Ecklonia radiata* (20%) and unidentified red algae (10%). Reef/sand boundary at 5 m. Sand with some silt and shell particles. The seastar *Asterias amurensis* present at this site.
17	-42.88407	147.36471	2-4m	Medium profile reef (1-3 m relief) with sand gutters. Red algae (10%) and *Ecklonia radiata* (5-10%) dominant in shallows with only reds (40%) in deeper parts of reef. Reef/sand boundary at 3 m. Sand gutters in reef with shell particles. Seastars (*Patiriella* sp.) very common.
18	-42.87678	147.35554	3-5m	Low profile reef (<1 m relief) into sand. Reef dominated by unidentified red algae (30-80%) with some *Ecklonia radiata* (5%), *Carpoglossum confluens* (5%) and unidentified brown algae (10-20%). Reef/sand boundary at 4 m. Sandy/silt with some shell grit.
19	-42.86714	147.34924	1-3m	Medium profile reef (1-3 m relief) into silt. Reef/silt boundary 2.5 m. Unidentified red algae (30%) dominant in shallows, with little algal growth below 1 m. Reef/silt boundary at 3 m. The seastar *Asterias amurensis* common at this site.
20	-42.86070	147.32600	1-4m	Low profile reef (<1 m relief) into silt. Reef with a covering of fine red and brown algae (15-40%). Reef/silt boundary 2 m. Some seastars (*Patiriella* sp.) present at this site.
21	-42.85595	147.31978	0-2m	Silty sand with algal mat and burrows. Some sparse seagrass (10%) in less than 1 m (*Heterozostera*). Some shell grit in patches. The seastar *Asterias amurensis* present at this site.
22	-42.84792	147.33590	6m	Silt with some shell. Seastar *Asterias amurensis* at this site.
23	-42.82003	147.29727	1-3m	Patchy low profile reef (<1 m relief) into fine silt. Reef with no algal growth. Reef sand boundary at 2 m. Some sparse seagrass (*Heterozostera*) and shell in shallow silt patches (<1.5 m). The seastar *Patiriella* sp. was present.
24	-42.82022	147.29475	1-3m	Fine silt substrate. Dense seagrass (*Heterozostera*) in <1.5 m.
25	-42.82115	147.28948	1-3m	Patchy low profile reef (<1 m relief) into fine silt. Reef with no algal growth. Reef/silt boundary at 2.5m, shell grit present.
26	-42.82042	147.28277	2m	Fine silt substrate. No evidence of biota.
27	-42.82026	147.26391	1m	Fine silt substrate. Sparse seagrass (<10%). Seagrass (*Heterozostera*) with blades ~30cm.
28	-42.79599	147.28714	1-3m	Silt with seagrass (*Heterozostera* - 40%) in <2 m of water.
29	-42.78979	147.28406	2-5m	Silt with large patches of live oyster shells, little other biota.
30	-42.78439	147.27948	1-2m	Silty substrate with patches of scungy seagrass (*Heterozostera*).
31	-42.79033	147.27482	1.5m	Silty substrate with dense (100%) seagrass (*Heterozostera*). Seagrass with long blades <30cm.
32	-42.79154	147.27278	1-3m	Silty substrate with burrows. Sparse seagrass (*Heterozostera*) in less than 1.5 m depth.
33	-42.77645	147.25623	1.5m	Silt with mollusc tracks. Little evidence of other biota.
34	-42.76590	147.25197	1-2m	Silt with mollusc tracks. Dense seagrass (*Heterozostera*) with some shell present.

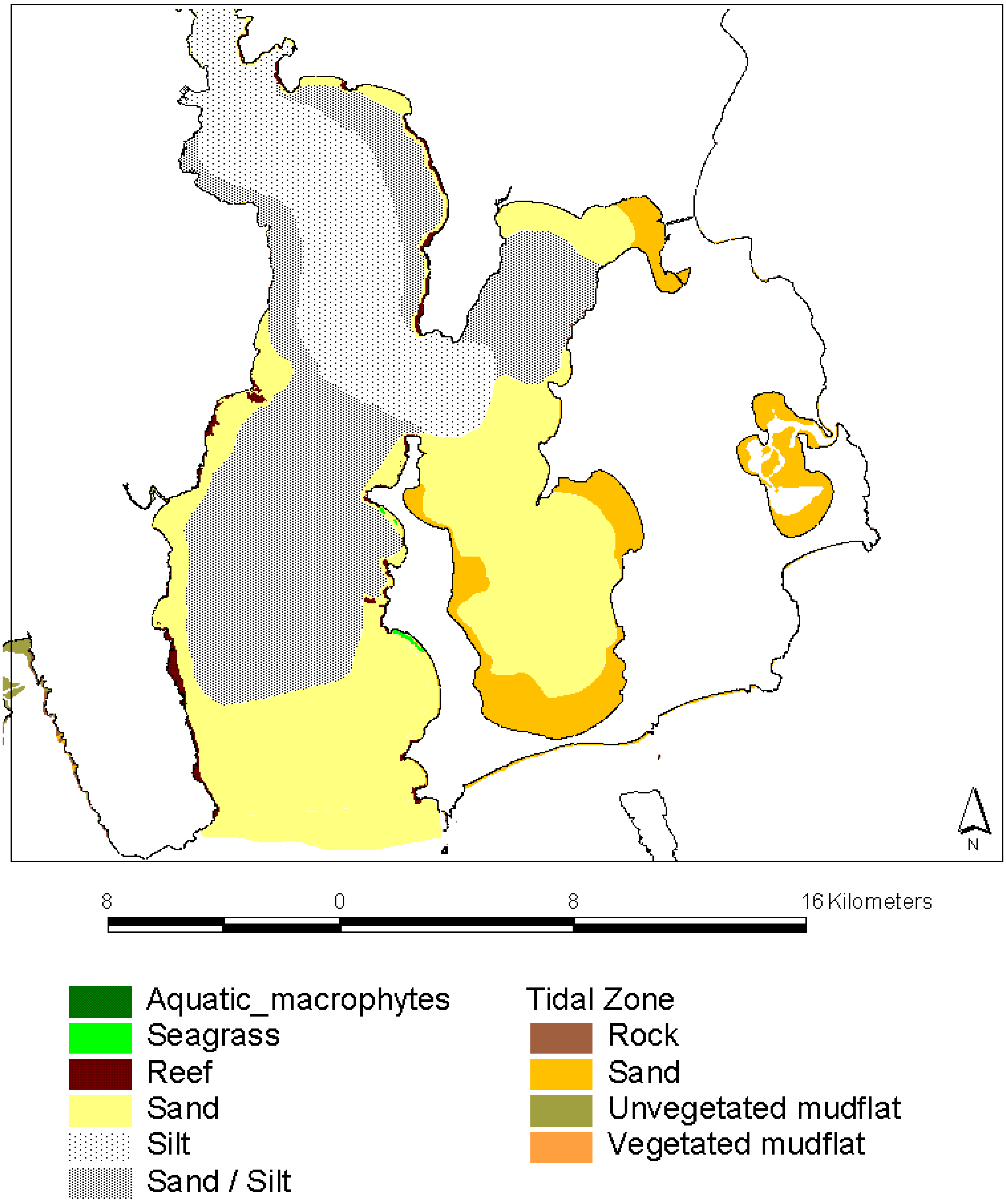


Fig. 4a. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:100,000.

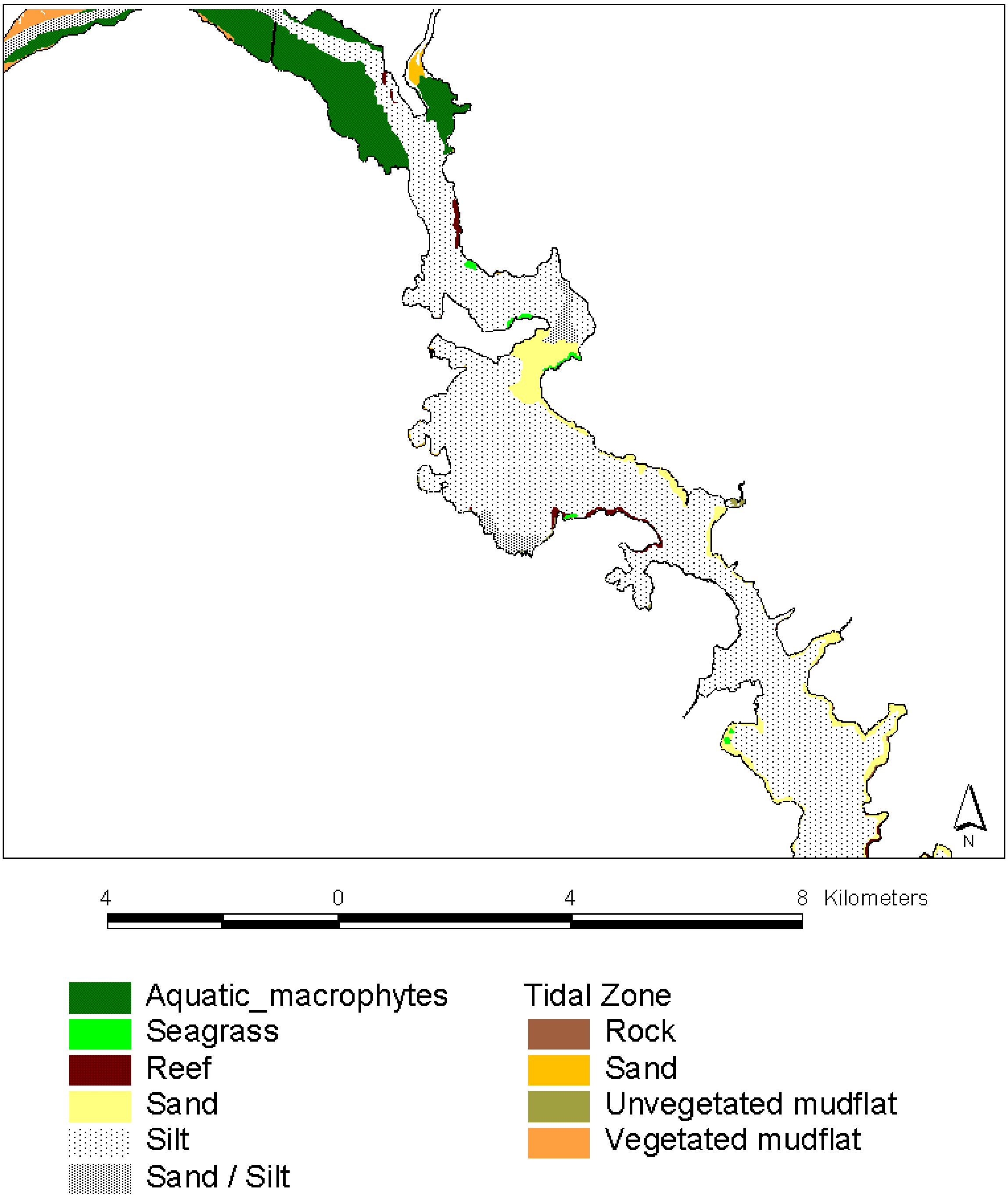


Fig. 4b. Distribution of habitat types in the middle reaches of the Derwent Estuary at 1:100,000.

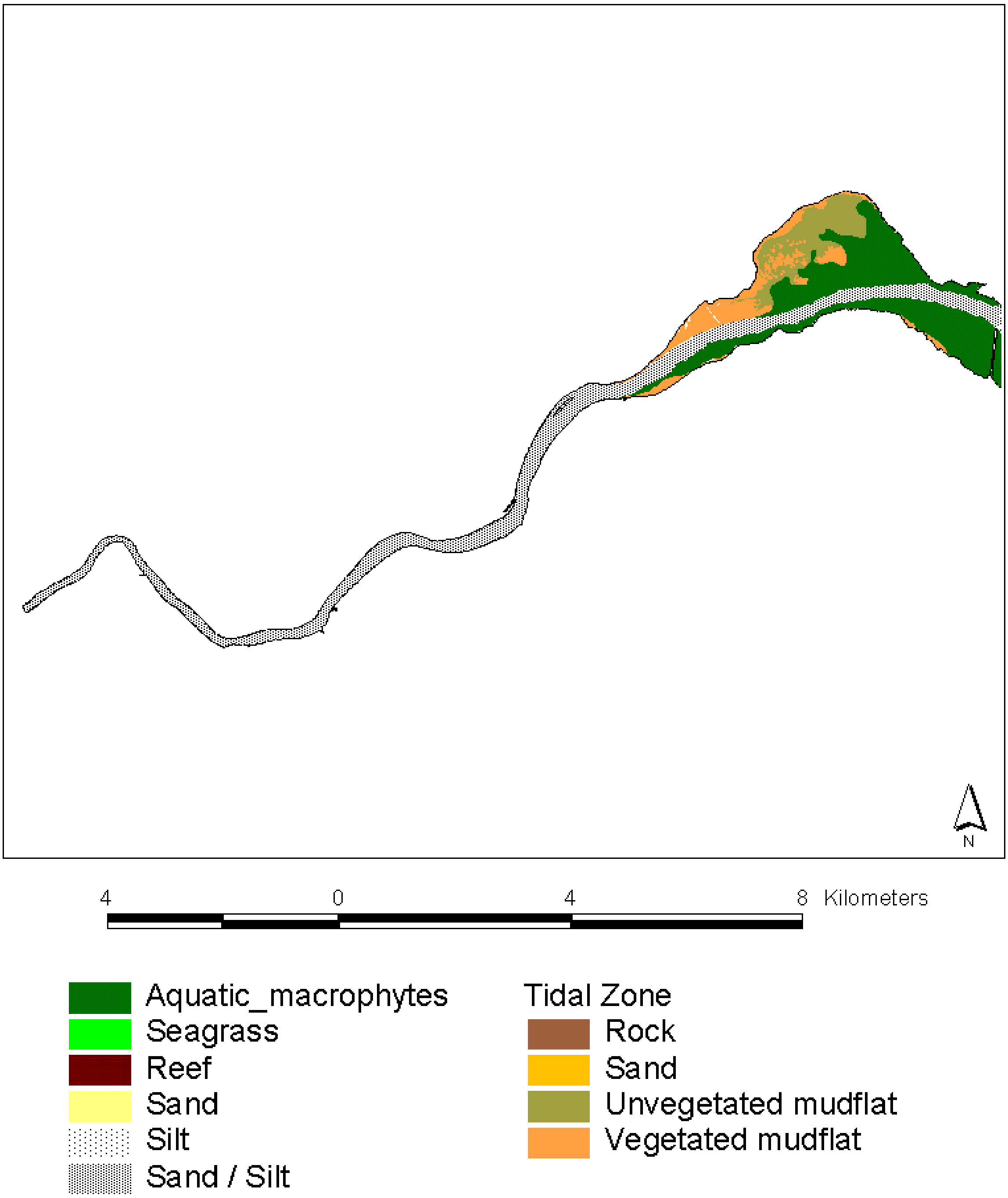


Fig. 4c. Distribution of habitat types in the upper reaches of the Derwent Estuary at 1:100,000.

5. Discussion

5.1 Habitat assessment

5.1.1 Rocky Reefs

Rocky reefs play an important role in the marine environment as they are one of the more productive marine ecosystems and provide food and habitat for a wide range of marine invertebrates and fishes. These include many commercially and recreationally important species such as abalone, rock lobster, bastard trumpeters, wrasses and banded morwong that utilise the habitat throughout their life-cycle. There are also species such as striped trumpeter that only use the habitat as a nursery area, moving off into deeper water after several years. While much of the productivity from the algae on the reefs is used directly or indirectly by the animals on the reef, considerable amounts also gets washed off the reef to become part of the detrital food chain which plays an important role in coastal productivity.

Reef habitats were found to occur primarily in the lower reaches of the Derwent Estuary and represented approximately 1% of all subtidal habitats in this section. This reflected the dominance of sand beaches on the eastern shore and the fact that the reef is on both shores mostly a narrow strip often only 5-10 m wide. The algal assemblage varied substantially in structure between eastern and western shorelines, by depth and by position along the estuary. Most of the variability was consistent with changes in algal structure in reef habitats throughout temperate Australia that are influenced by physical factors including depth and relief, level of exposure, siltation, light and hydrographic conditions and biological factors such as sea urchin grazing and availability of algal recruits (see Kennelly, 1995).

Much of the reef habitat in the lower reaches of the Derwent Estuary was dominated by kelp forests which included brown algae of the order Laminariales and fucoid algae of the order Fucales. The most dominant brown algae were the common kelp (*Ecklonia radiata*), giant kelp (*Macrocystis pyrifera*), strapweed (*Lessonia corrugata*) and the fucoid algae (*Carpoglossum confluens* and *Cystophora* sp.). Beneath the canopy of these kelps there was often a large number of foliose, filamentous and encrusting red algal species. The distribution of these was patchy and varied considerably at a small spatial scale, a pattern common in understory species (Steinberg and Kendrick, 1999). The structure of the algal assemblages changed from kelp to red algal dominated in the northern part of the lower reaches (mostly north of Crayfish and Droughty Points). Within the middle reaches, apart from small amounts of red and brown algae in the shallow depths most rocky substrates showed no algal cover. These algal species compositions reflect that observed during spring when the field surveys were conducted. It does not, therefore, examine the extent of seasonal changes that may occur through growth, dieback and recruitment.

The algal assemblages present near the mouth of the estuary were generally consistent with those of similar exposure and depths throughout southern Tasmania. There were, however, differences within this part of the estuary, primarily the presence of *Macrocystis* on the western shore and its absence on the eastern shore. Coastal aspect was important in determining the size or viability of *Macrocystis* beds (Reed and Foster 1984; North 1991), with *Macrocystis* favouring regions offering some shelter from the prevailing storm or swell direction (Bushing, 1997). Such factors may be responsible for determining the observed distributions in the Derwent, however, anectodal information suggests that *Macrocystis* beds once existed along the eastern shore as far up as Lindisfarne Bay (Sanderson *per. comm*.), so its absence from this area may also be influenced by the siltation that has occurred along this shoreline.

Loss of *Macrocystis* elsewhere has also been attributed to pollution, sea urchin grazing, elevated sea temperatures and other causes (Harger 1983; North 1991). Growth and survival of *Macrocystis* is adversely affected by warm water episodes (e.g. Dayton and Tegner 1984; Gerard 1984), directly by higher temperatures resulting in physiological stress, or indirectly due to associated reduction of nutrients and/or increased storm exposure. Such conditions, however, allowed the persistence of understory populations. There is evidence of significant periodic changes in *Macrocystis* abundance throughout eastern and southern Tasmania over the past 50 years (Sanderson, 2000), that may be related to periods of warm sea temperatures.

The temperature and productivity of south-eastern Tasmanian shelf waters shows considerable interannual variability due to the changing influence of warm, nutrient-poor East Australian Current (EAC) water and cool, nutrient-rich water of subantarctic origin (Harris *et al*. 1987). The relative importance of the two water masses from year to year is determined by a combination of zonal westerly wind strength and large-scale oceanographic circulation associated with El Niño/Southern Oscillation (ENSO) events (Harris *et al*. 1987). Such variations in oceanography have profound effects on the physical and biological structure of south-eastern Tasmanian coastal and shelf waters with little recycling or influx of nutrients during years of increased EAC influence (Harris *et al*. 1991). Such events will have a major influence of *Macrocystis* abundance and distribution throughout south-eastern Tasmania, including the Derwent Estuary. Alternatively, years of reduced EAC influence are likely to result in an increase in abundance of *Macrocystis*. While there may be some localised reduction due to sea urchin grazing and impacts from pollution and sedimentation, it is unlikely that the relative significance of these impacts can be separated from the other physical factors.

Given the large range of physical and biological processes act together to determine the spatial and temporal patterns of algal assemblages, and that the assemblages are dynamic at a small spatial scale, the human induced impacts on the algal community are difficult to quantify. The primary impacts are likely to include increased siltation resulting from land clearance and urban and rural runoff, and increased nutrient loads from sewage, agricultural fertilisers and urban and industrial effluent. As well as the direct effects on the habitats, both these impacts will decrease water clarity and therefore light availability to macroalgae in the deeper parts of the reef habitat. Any reduction in these impacts are likely to result in an increase in the health of the algal communities in the Derwent Estuary.

5.1.2 Seagrass

Seagrasses are marine flowing plants that are adapted to soft-sediment habitats in coastal waters. They are known to play an important role in maintaining sediment stability and water quality, particularly within estuaries. Throughout Tasmania, seagrass beds have been found to be an important habitat for small, resident fishes with abundance and diversity significantly higher than adjacent unvegetated habitats (Jordan *et al*. 1998). This is generally consistent with seagrass habitats throughout Australia (see Bell and Pollard, 1989), although in Tasmania few of the seagrass associated fish species are commercially exploited. They are also particularly important areas of primary and secondary productivity, with most seagrass production not utilised *in situ* but exported from the beds.

Seagrass in the Derwent Estuary (primarily *Heterozostera tasmanica*) was restricted to small areas of Half Moon Bay, Opossum Bay, Cornelian Bay and isolated beds in the middle reaches. These areas represented less than 0.2% of the subtidal habitats throughout the lower, middle and upper sections of the Derwent estuary. However, as this estimate is based on surveys conducted during late winter when biomass is expected to be at its lowest, this may be an underestimate of its coverage during summer/autumn.

There were considerable differences between beds in the shoot density and biomass of seagrass and amount of algal epiphytes. While qualitatively this appeared to reflect a decrease in the relative ‘health’ of the beds at sites progressively further from the estuary mouth, it is not possible to attribute this entirely to human induced impacts. Similar to those affecting macroalgal habitats, the primary impacts on seagrass are likely to be increased siltation and nutrient loads that results in a decrease light availability through increased turbidity and increased algal epiphyte growth, respectively. Despite the lack of historical information on the abundance and distribution of seagrass beds in the middle reaches of the Derwent Estuary, as these siltation and nutrification are highest in this region of the estuary, it is highly likely that a decrease in seagrass extent and health has occurred. This would be consistent with a significant reduction in seagrass habitats throughout Tasmania over the past 50 or so years (Rees, 1993).

Loss of seagrass beds in the lower reaches of the Derwent Estuary has previously been identified through the analysis of historical aerial photographs (Rees, 1993). Around 400 ha were identified to have disappeared in Ralphs Bay since the 1950s, with additional losses within Opossum Bay and Half Moon Bay. Given that most areas in Ralphs Bay previously identified to have seagrass is now intertidal, there has either been significance sedimentation within the bay over this time or a misinterpretation of the photographs from 1950 and 1970. There is also evidence that the photographs of Half Moon Bay and Opossum Bay from 1990 did not reveal the continued presence of seagrass beds in these areas, although a re-establishment of these beds during the last ten years cannot be discounted. The beds in the middle reaches were not previously mapped either due to lack of suitable aerial photographs or high levels of turbidity.

Given the significance of seagrass habitats for fishes and invertebrates, the loss of seagrass habitats can have a significant impact on abundance, diversity and overall productivity. For example, continued loss of seagrass in Prosser Bay in eastern Tasmania over the past four decades (Rees, 1993), has led to the present situation in which seagrass densities are low in summer, with almost total dieback during winter. It appears that in such areas the seasonal presence of seagrass is in itself either not sufficient to attract high numbers of fish, post-settlement mortality is high or abundances of pre-recruits is low (Jordan *et al*. 1998).

Similar to Prosser Bay, as few seagrass beds exist for some tens of kilometres from the beds in the Derwent Estuary it is likely that larval supply of seagrass associated species may be limited. Such variations in larval supply may actually influence the relative abundance of most species that are closely associated with *Heterozostera* habitats, particularly leatherjackets and pipefish, which were uncommon in the low density beds in Prosser Bay. This suggests that the decline in density of fishes in isolated seagrass beds may result in a consistent decrease in abundance of seagrass associated species. There is also evidence that regardless of the density and size of seagrass beds, the position of the bed in the estuary is often important in determining the abundances of fishes in the bed (Jenkins *et al*. 1997). The situation may also be the same for recruitment of seagrass itself, with the low number of seeds available in the estuary or from adjacent areas partially determining the total area of beds.

In the present study a number of methods were used to map the distribution of habitats in the Derwent Estuary. This including digitising beds from aerial photographs and field mapping using a combination of acoustic and video sampling. These techniques are essentially consistent with that used in projects conducting assessment and monitoring of seagrass habitats (eg. Lee Long *et al*., 1997; Norris *et al*., 1997; Kendrick *et al*. 2000; Meehan and West, 2000). The method used is often dependent on the scale and site of the habitat, the objectives of the study and the particular expertise of the researchers. A discussion on the use of these, and other techniques for long-term monitoring of seagrass habitats in the Derwent Estuary is presented in Section 5.2.2.

5.1.3 Aquatic macrophytes

Aquatic macrophytes were found to be a significant habitat in the middle and upper sections of the Derwent Estuary. While over the entire estuary it represented approximately 3% of all subtidal habitats, it was significantly higher in the upper estuary. As they are not true seagrasses they have been mapped as a separate habitat category, despite the fact that there are likely to be small beds that contain both seagrass and aquatic macrophyte species.

The habitat was dominated by *Ruppia* spp., although several other species progressively increased in abundance in the upper estuary. The beds were restricted to shallow sections on either side of the main channel in depths less than approximately 3 m. Acoustic and visual observations of the beds indicated a continuous cover of macrophytes in the beds even in the deeper margins where light would be limited due to the high turbidity levels. Limited grab sampling also revealed a high biomass of algal epiphytes. It appears that despite the decrease light availability due to high turbidity and epiphyte levels, the *Ruppia* beds are extensive as that may not be light limited (Carruthers and Walker 1999).

Aquatic macrophyte habitats have been shown to have higher fish densities than adjacent unvegetated habitats although diversity was lower (Humphries *et al*. 1992). They also play a very significant role in the primary productivity in estuaries both directly and indirectly by adding to the amount of material available to the detrital food chain. Shallow *Ruppia* beds are also an important and reliable feeding area for a wide range of bird species, particularly waterfowl.

5.1.4 Subtidal unvegetated habitats

Subtidal unvegetated habitats were the most dominant habitat type within the estuary, representing approximately 96% of all subtidal habitats throughout the lower, middle and upper sections of the Derwent Estuary. As a result of catchment factors (eg. soil type, erosion characteristics) and water movement (tidal, flood and wind derived) there are large differences in the distribution of sediment type between the lower, middle and upper reaches. Despite this, there was little difference in the area of the sand, silt/sand and silt habitats.

The estuarine sediments, particularly in the upper and middle reaches of the estuary, have been degraded due to significant inputs of nutrients, organic matter and heavy metals (Coughanowr, 1997). Significant changes have also occurred to the sediment structure, with large inputs of fine sediments resulting in many sand habitats converting to sand/silt or silt habitats.

In the upper Derwent Estuary, the inputs of sediment and organic matter have resulted in a decrease in macroinvertebrate abundance, although some improvements have been noted over the past decade in the upper estuary (Moverley and Garland, 1995). Recent studies, however, have shown a significantly decline in the abundance and species richness in the macro-benthic faunal community at three sites downstream of the Boyer mill outfall to 800 m downstream Aquenal (2000). A recent study by Edgar *et al*. (1999) sampled macroinvertebrates and sediments at three sites in the middle Derwent Estuary and one in the Browns River. While the sampling was conducted primarily to obtain baseline data, the change in the sediment structure from sand to mud dominated in many Tasmanian estuaries has been shown to result in a pronounced shift in the macroinvertebrate faunal composition (Edgar *et al*. 1999). Given the changes in sediment structure in the Derwent Estuary, such changes could be expected to have occurred widely throughout the estuary.

There has also been a considerable decline in the densities of benthic invertebrate species in the lower Derwent Estuary as a result of the presence of introduced marine pests, particularly the seastars *Asterias amurensis* and *Patiriella regularis*, gastropod *Maoricolpus roseus*, chiton *Amaurochiton glaucus*, ascidian *Ascidiella aspersa* and crab *Cancer novaezelandiae* (Morrice, 1995).

Unvegetated habitats are also an important habitat for juvenile fishes (Jenkins *et al*. 1997; Edgar and Shaw, 1995; Jordan *et al*. 1998), particularly for species that are protected by either camouflage or schooling behaviour. At shallow unvegetated habitats in the Derwent Estuary the dominant fish species include atherinids, flounders, leatherjackets, mullets and eastern Australian salmon (Jordan *et al*. 1998). Both adults and juveniles are caught in these habitats indicating that these areas serve more than just a nursery function (Last, 1983). Fish sampling in the deep unvegetated habitat in the lower reaches showed leatherjackets, gurnards, skates and stingarees to be the dominant species (Jordan, 1997).

The lack of comprehensive sediment surveys of the Derwent Estuary precludes an assessment of the extent of change of these habitat types due to organic matter and nutrient inputs. Most studies have focussed on specific areas or contaminants (see Coughanowr, 1997). However, sediment characteristics were examined in 38 cores collected throughout the estuary by Pirzl (1996). In addition, concentrations of zinc, cadmium, lead and mercury have also been found to be consistently high in both sediments (Bloom, 1975; Pirzl, 1996) and biota (see Coughanowr, 1997). A comparison of earlier surveys with sediment particle size data and heavy metal concentrations collected during the current survey will be presented in a subsequent report of the Derwent Estuary Program. This report will also address the issue of long-term monitoring of sediment condition in the Derwent Estuary.

5.1.5 Intertidal habitats

Intertidal habitats in the Derwent Estuary contain a large range of habitat types from rocky shores through to the full range of soft-sediment types. The properties of the soft-sediment areas are largely determined by depth, position in the estuary and level of exposure, with a general gradient of coarse sediments in the lower reaches to finer mud sediments in the middle reaches. While these are important areas for human recreation they are also important habitats for benthic invertebrates, fish and a large number of permanent and migratory bird species such as the pied oystercatcher (*Haematopus longirostris*), red-capped plover (*Charadrius ruficapillus*) and sandpiper (*Tringa hypoleucos*) that feed along the shoreline and intertidal flats. They are also important areas for intertidal seagrass species, particularly *Zostera muelleri*, which was present in small patches in the middle estuary during the late winter survey period, but is likely to be much higher in biomass in summer/autumn.

Similar to subtidal habitats, much of the intertidal habitats in the Derwent estuary, particularly the upper and middle reaches, have been degraded due to significant inputs of nutrients, organic matter and heavy metals (Coughanowr, 1997). Significant changes have occurred to the sediment structure, with large inputs of fine sediments resulting in sand habitats converting to sand/silt or silt habitats. The lack of intertidal sediment surveys of the estuary means that changes can only be examined from anecdotal information. For example, in the 1940's Cornelian Bay had a sandy beach, but continued inputs of fine sediments had resulted in the dominance of mud on the beach (SDAC, 1996). In the lower reaches, the intertidal unvegetated habitats are dominated by the sand beaches of Ralphs Bay and those on the eastern shore.

The increase in mud dominated sediments in many Tasmanian estuaries has resulted in a pronounced shift in the intertidal macroinvertebrate faunal composition (Edgar *et al*. 1999). Organisms in soft-sediment intertidal habitats are known to be particularly susceptible to human impacts, particularly siltation and pollution from organic enrichment and heavy metals. Hence, within the Derwent Estuary, particularly in the middle reaches, the fauna of such areas are likely to impacted as a result of these factors.

5.1.6 Wetlands

Estuarine wetlands occupy the transitional zone between land and sea and include a broad range of habitat types. All wetlands are characterised by the presence of water, either permanently or periodically, and this is reflected in their unique vegetation, soils and fauna. They provide valuable wildlife habitat, fish spawning grounds and nurseries, flood and erosion control, pollution abatement as well as visual and recreational amenities. Many wetland plants actively regulate hydrology through a range of mechanisms such as transpiration, water-shading and sediment trapping.

The most extensive area of wetlands the Derwent Estuary occurs in the upper reaches, particularly concentrated downstream of the Boyer papermill. Areas of sedge/rush wetland are present both shorelines and dominated by *Leptocarpus brownii, Juncus kraussii* and *Baumea arthrophylla* (Aquenal, 2000). Adjacent to this habitat are areas of tall-wet scrub that was primarily *Leptospermum lanigerum*. Small area of sedge/rush wetland were also identified at the mouth of the Jordan River. The graminoid saltmarsh habitat is present in small areas on both shorelines and is dominated by *Phragmites australis* and *Deschampsia cespitosa* (Aquenal, 2000).

Many of the original wetlands of the Derwent Estuary have been destroyed, particularly those at the heads of small bays in the middle estuary, which were historically used as rubbish dumps and later transformed into parks or building sites. Goulds Lagoon and Otago Lagoon represent some of the last remnants of this type of wetland. The upper Derwent Estuary marshes and Goulds Lagoon are regarded as wetlands of national importance. The conservation status of these wetland areas is described in the Habitat and Species Issues Paper of the Derwent Estuary Program. The values of Tasmanian wetlands and threats are also more broadly outlined in the Tasmanian Wetlands Strategy, which also describes protection and implementation strategies.

5.2 Habitat monitoring

5.2.1 Rocky reefs

Given the lack of understanding of spatial-temporal variability in macroalgal communities in the Derwent Estuary, it is difficult to determine a cost-effective monitoring regime that examines the processes that cause such patterns and quantifies the amount of change that results from human induced impacts. What is achievable is an assessment of the percentage cover and contribution of the dominant algal species on reefs in the estuary on an annual or bi-annual basis. This would be best done through video assessment at 3 sites in the lower reaches of the estuary (Tranmere Point, Crayfish Point and adjacent to the treatment plant south of Blackmans Bay). A more detailed discussion on the techniques and problems associated with the design of such monitoring protocols and potential use of remote techniques is presented in the next section on seagrass.

A project specifically focusing on the conservation, monitoring and recovery of *Macrocystis* in Tasmania has also been funded by the Natural Heritage Trust. It involves determining the extent of loss of *Macrocystis* (using aerial photos, sea charts and anecdotal information), causal factors, a conservation assessment of existing stands (e.g. reservation, threat assessment), a recovery program using Seacare, and establishing clear lines of management responsibility.

5.2.2 Seagrass

The primary method used in most studies of large-scale changes in seagrass cover is aerial photography and remote sensing. While aerial photography is a useful technique, there are many factors that influence the quality required for mapping, including water (turbidity) and atmospheric (cloud cover, sun angle) conditions, choice of filter and height. In addition, both the rectification and digitisation can impact the quality of the results, particularly when using historical photographs to reconstruct seagrass distribution. Irrespective of these problems, there are regional constraints in using aerial photography for baseline mapping of seagrasses. The method is also often not appropriate for mapping or monitoring beds in deep waters or species of low biomass such as *Halophila*.

There has been little use of satellite remote sensing for mapping seagrass habitats in Australian waters. Landsat TM data has been used to map *Thalassia testudinum* beds (Armstrong, 1993), and seagrass distribution in an area of southern Queensland (Lennon and Luck, 1990). Recent research has involved the use of aerial imaging radiometers, such as the Compact Airborne Spectrographic Imager (CASI) system or Geoscan Multi Spectral Scanner (Bajjouk *et al.* 1996; Mumby *et al*. 1997) which avoid problems such as high altitude cloud interference. Similar to other satellite methods, the technique is of limited use in turbid waters and site-specific empirical algorithms can only be obtained through extensive ground-truthing. Acoustic surveys of seagrass beds have also been trialed using 420 KHz, although the technique appears to require further development before they can be used reliably to map seagrass beds (Lee Long *et al.* 1998). Physical mapping and sampling of seagrass beds is often done in combination with other techniques, usually as a ground-truthing exercise. This can involve using divers or videographic techniques (eg. Norris *et al.* 1997). A comprehensive review of mapping methodologies is presented in Thomas *et al*. (1999).

In regard to long-term monitoring of seagrass habitats, many studies have involved Before/After/Control/Impact statistical analyses (Long *et al.* 1996) or repeated measures analyses (McKenzie *et al.* 1996; Lanyon and Marsh, 1995). Several studies also contain power analyses based on analysis of variance applied to random sampling of seagrass parameters (Long *et al.* 1996; Hillman *et al.* 1994). Intensive sampling often results in designs with low power, because of the large amount of spatial/temporal variation which can result in missing changes of seagrass habitats at a larger scale.

Without an understanding of the spatial-temporal patterns of the particular seagrass species it is difficult to decide if random or fixed locations are most appropriate. Fixed locations have some attractions when attempting to detect change as it is possible to return to exactly the same location (Lanyon and Marsh, 1995; Abal and Dennison, 1996). There are, however, difficulties in interpreting these transects as they may not be representative of the entire area and assume that there is little natural variability. It has been suggested that beds may best be described by their edge to area ratios, patch size and spatial structure (Thomas *et al*. 1999).

It is clear that baseline studies must contain information on spatio-temporal variation and interaction before changes can be assessed, which requires repeat sampling at the appropriate temporal scale. Studies of seasonal changes in temperate Australian seagrass beds, including *Heterozostera tasmanica* (Bulthuis and Woelkerling 1983; Mills 1992), invariably show a unimodal seasonal variation in standing crop, with peak values in summer to early autumn, and minima during winter (Larkum *et al*. 1984). While many studies examine seasonal changes in seagrass beds (McKenzie, 1994; Lanyon and Marsh, 1995), the seasonal variation is usually not incorporated into the design of longer term monitoring.

The issue of whether control and impact sites differ is also often examined using the significance test, when the questions is not whether such differences exist, but how large they are, where they occur and when they occur. It has been suggested that a determination of interval estimates of differences or change would be more meaningful by providing information about the maximum credible change, given the observed data (Thomas *et al*. 1999). This review also suggests that analyses based on generalised linear models or generalised linear mixed models may be a useful analytical technique.

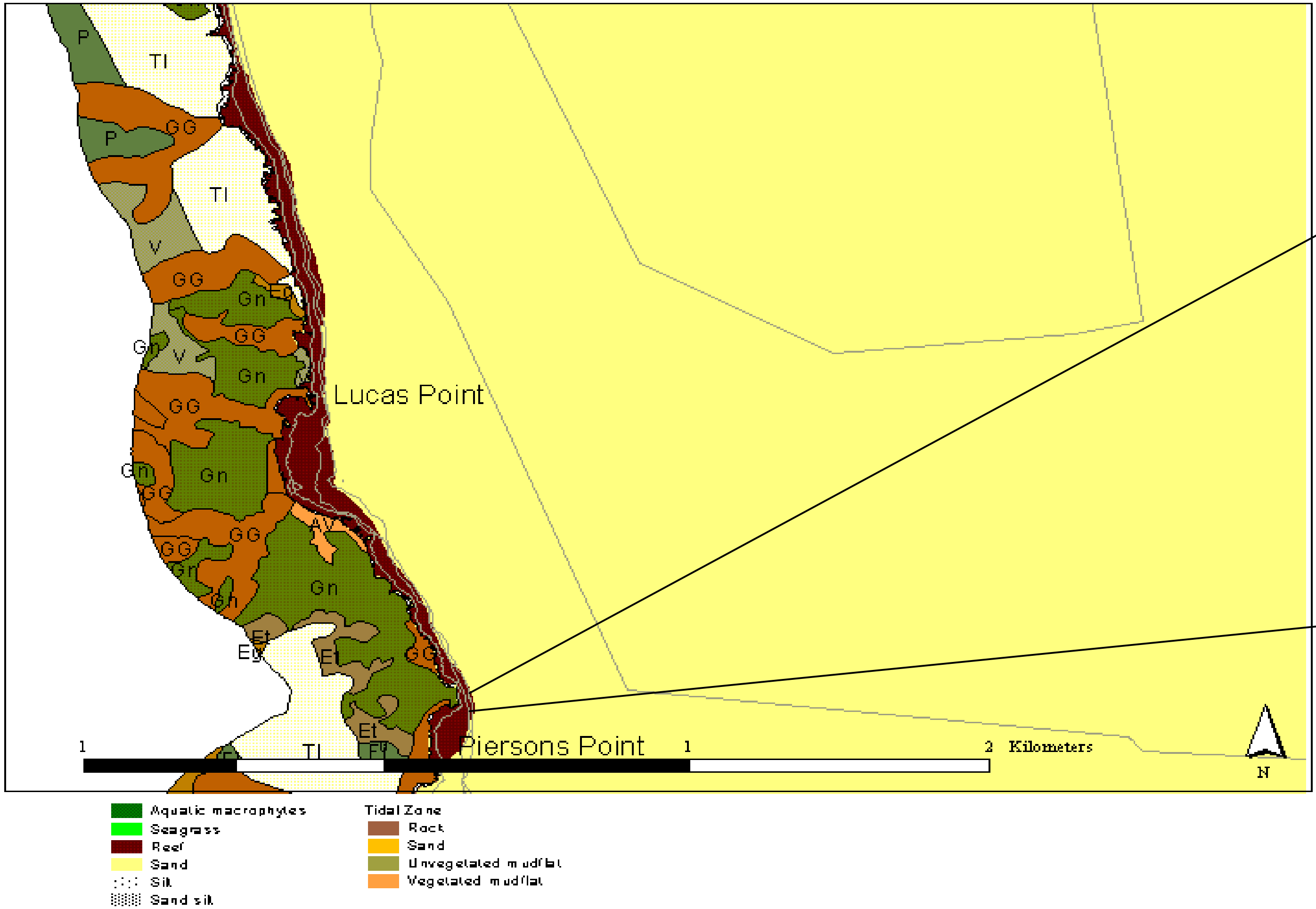
There is also a lack of analysis of uncertainty of seagrass parameters such as cover or biomass. Maps of biomass or cover distribution are often based on interpolation between a small number of sampled points and maps compared between different years to estimate change. This method results in error from both the precision of the mapping and the interpolation process, a process that is problematic when mapping change over time.

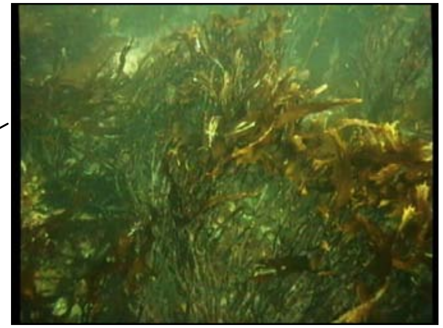
One example of an approach of defining monitoring parameters using conceptual models is the Brisbane River/ Moreton Bay Waste Water Management Study (Dennison *et al.* 1998). This required an understanding of variability and the ability to conduct enough replication to allow impacts to be detected with reasonable statistical power. In the end the parameters monitored were the depth range of seagrass beds and $\delta^{15}N$ measurements on seagrass as an indicator of the extent to which nitrogen from sewage outfalls is biologically available. The seagrass itself is not of primary concern, rather its distribution and $\delta^{15}N$ content is used as an index of ecosystem health.

Given the lack of understanding of spatial-temporal variability in seagrass habitats in Tasmania, it is difficult to be prescriptive in determining the appropriate monitoring protocols for seagrass in the Derwent Estuary. A combination of aerial photograph assessment (when available), ground truthing and fixed sampling may be most appropriate. The use of further techniques will require substantial research and development and the cost-effectiveness of them should be examined. In addition, the further development of conceptual models through the Derwent Estuary Program may help determine the specific range of monitoring parameters required to monitor seagrass and broader estuarine health.

5.2.3 Aquatic macrophytes

In the present study, the aquatic macrophyte beds were mapped entirely from acoustic and physical sampling, as high levels of turbidity in the upper estuary made assessment from aerial photographs impossible. This indicates that ongoing assessment and monitoring of this habitat type will best be achieved through field based mapping and estimates of parameters such as percentage cover, shoot density and biomass. The mapping would be best done over the entire area of aquatic macrophyte habitat in the middle and upper reaches, and the parameter estimates made at a minimum of three sites. The same problem of temporal/spatial variability that is detailed in the above section on seagrass is relevant to monitoring design for aquatic macrophytes.

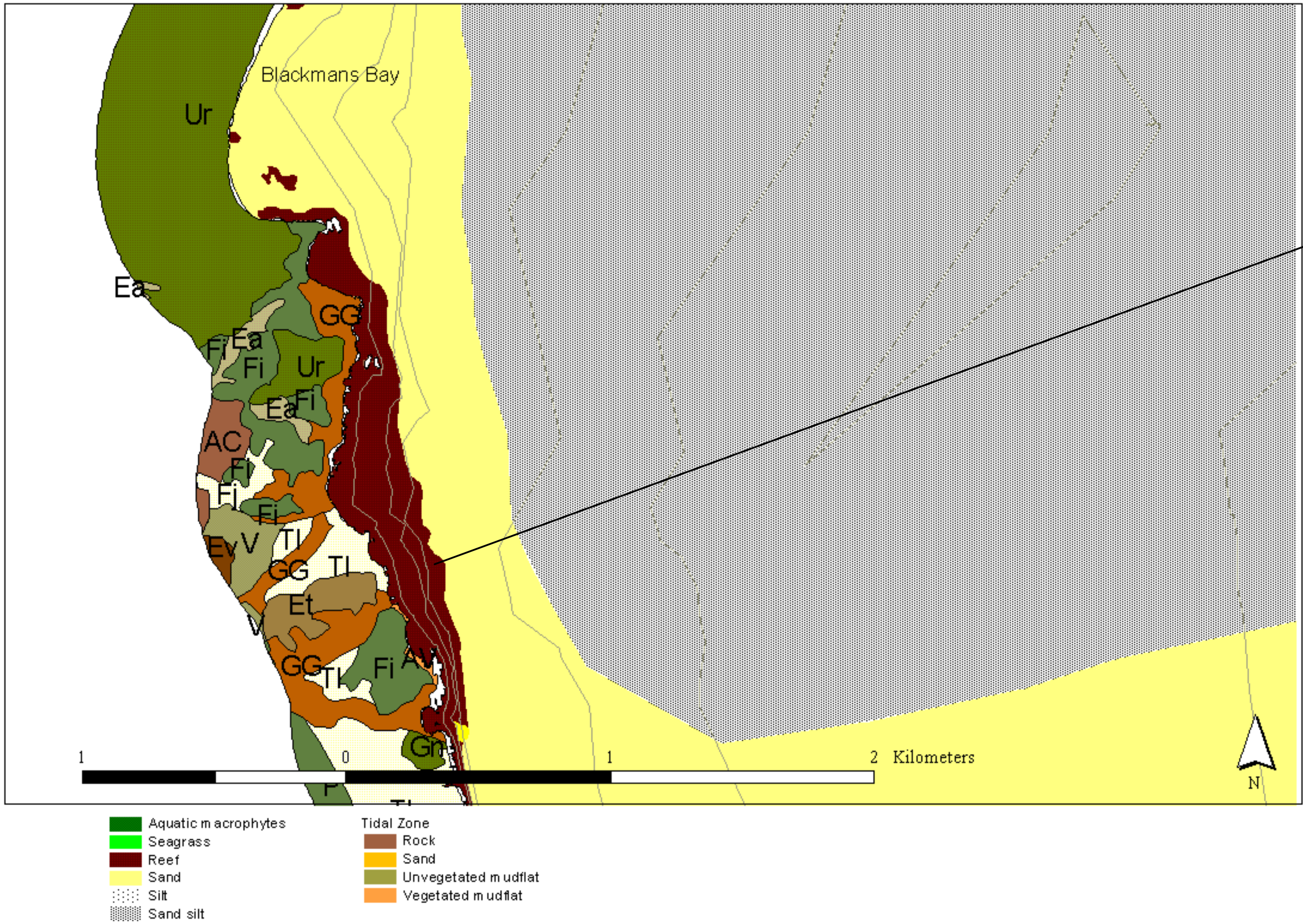




Lessonia dominated reef 3m

Typical reef below 5m

Fig. 5a. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.



Patchy low profile reef in 15m

Fig. 5b. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

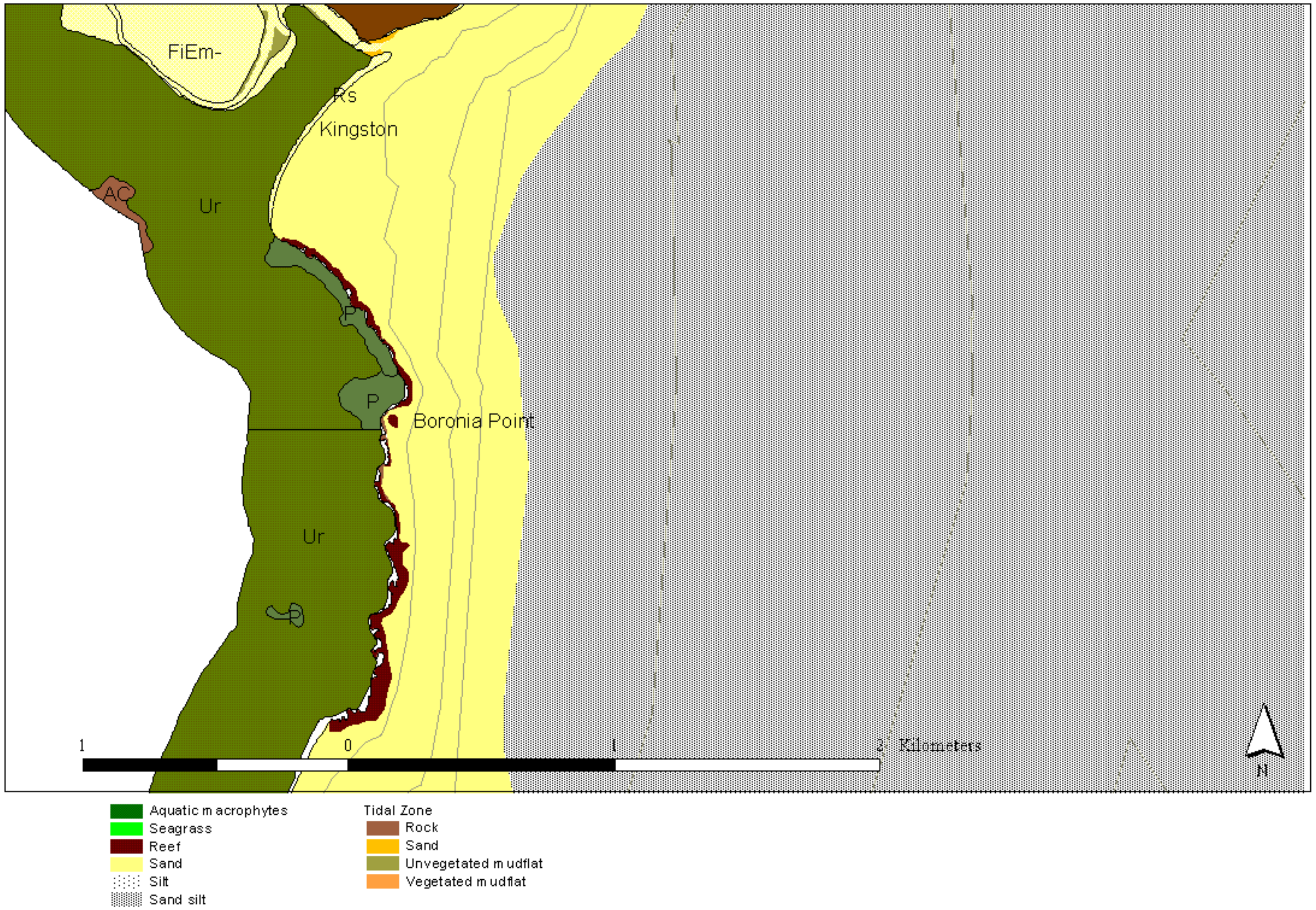


Fig. 5c. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

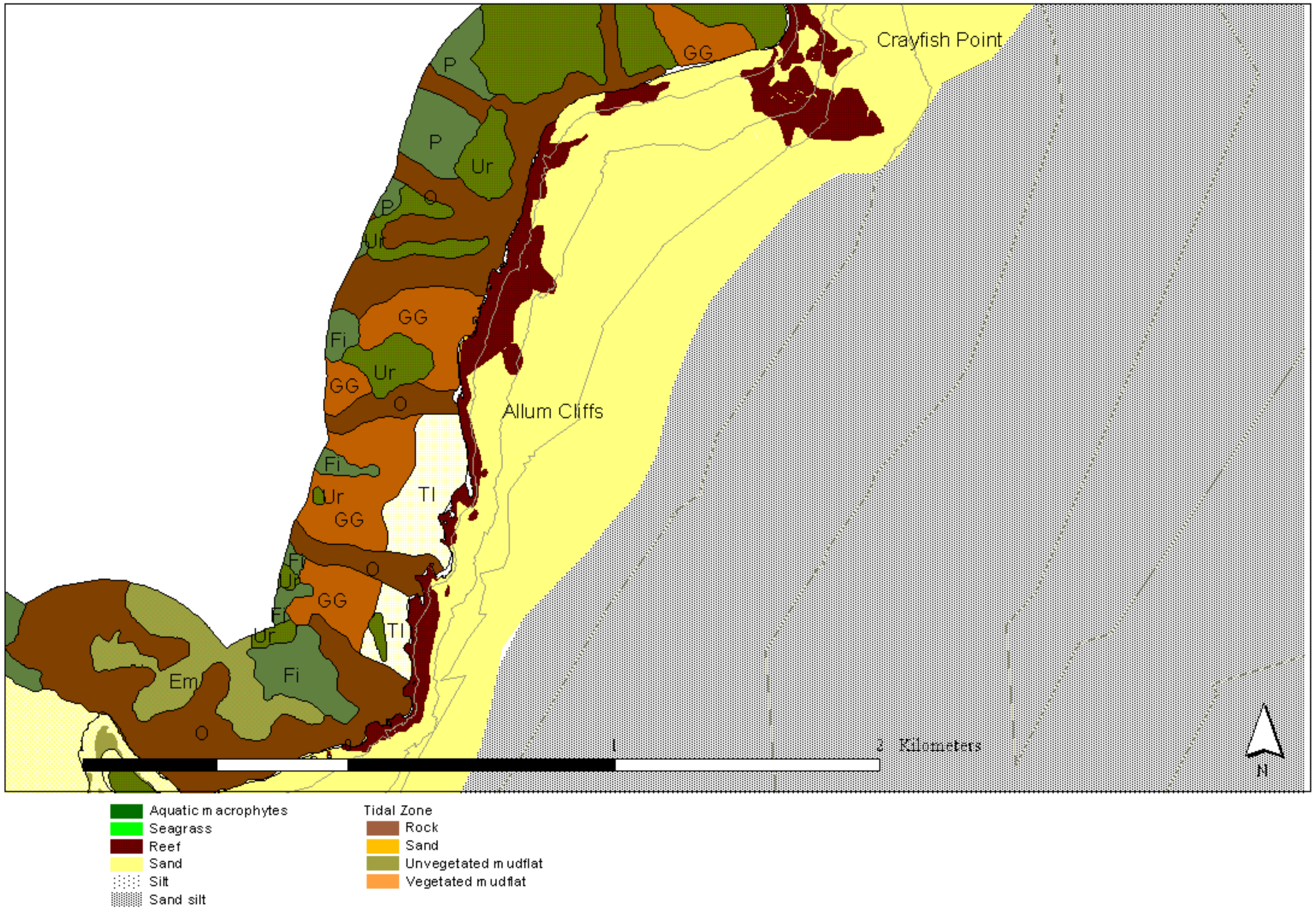


Fig. 5d. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

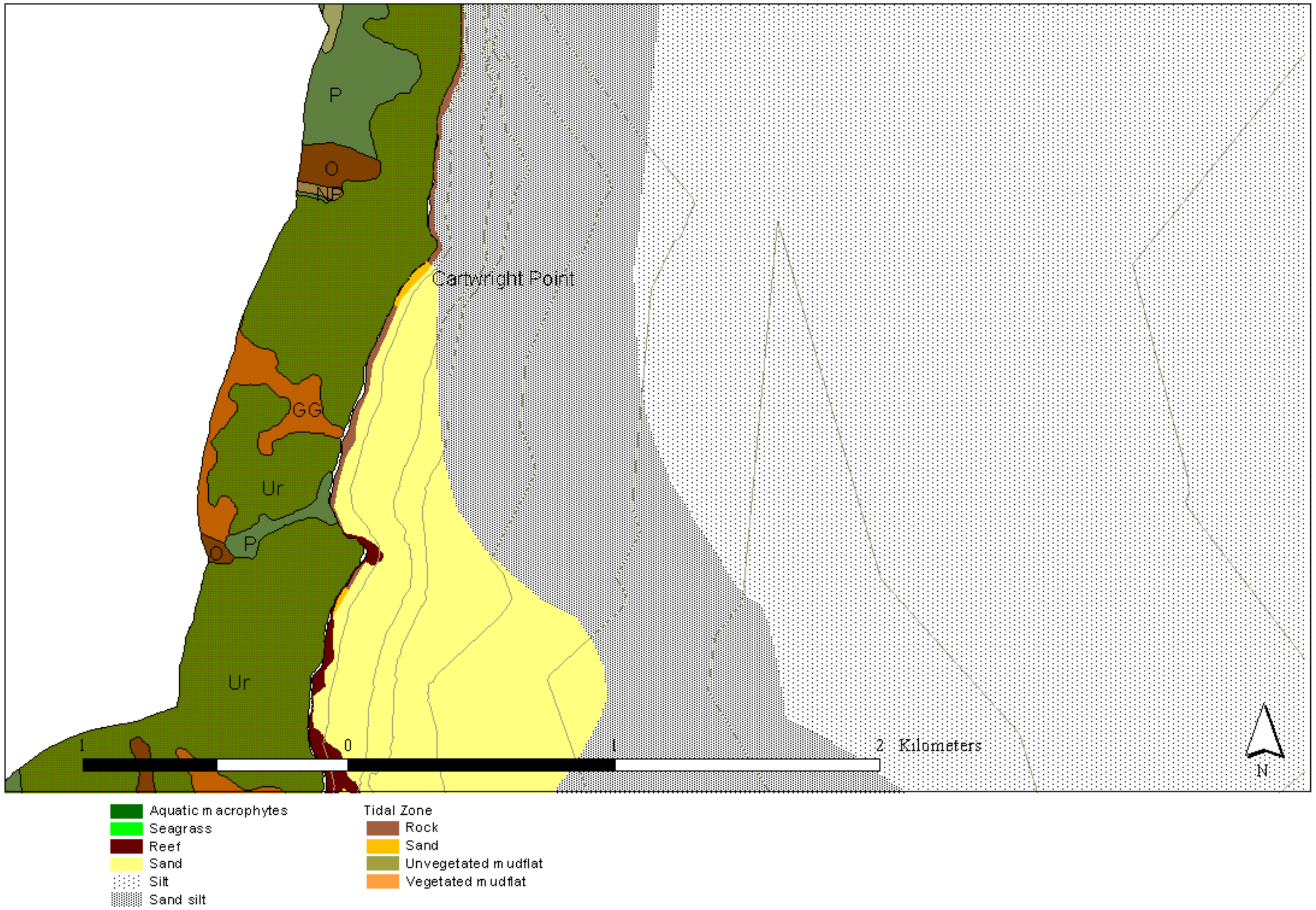


Fig. 5e. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

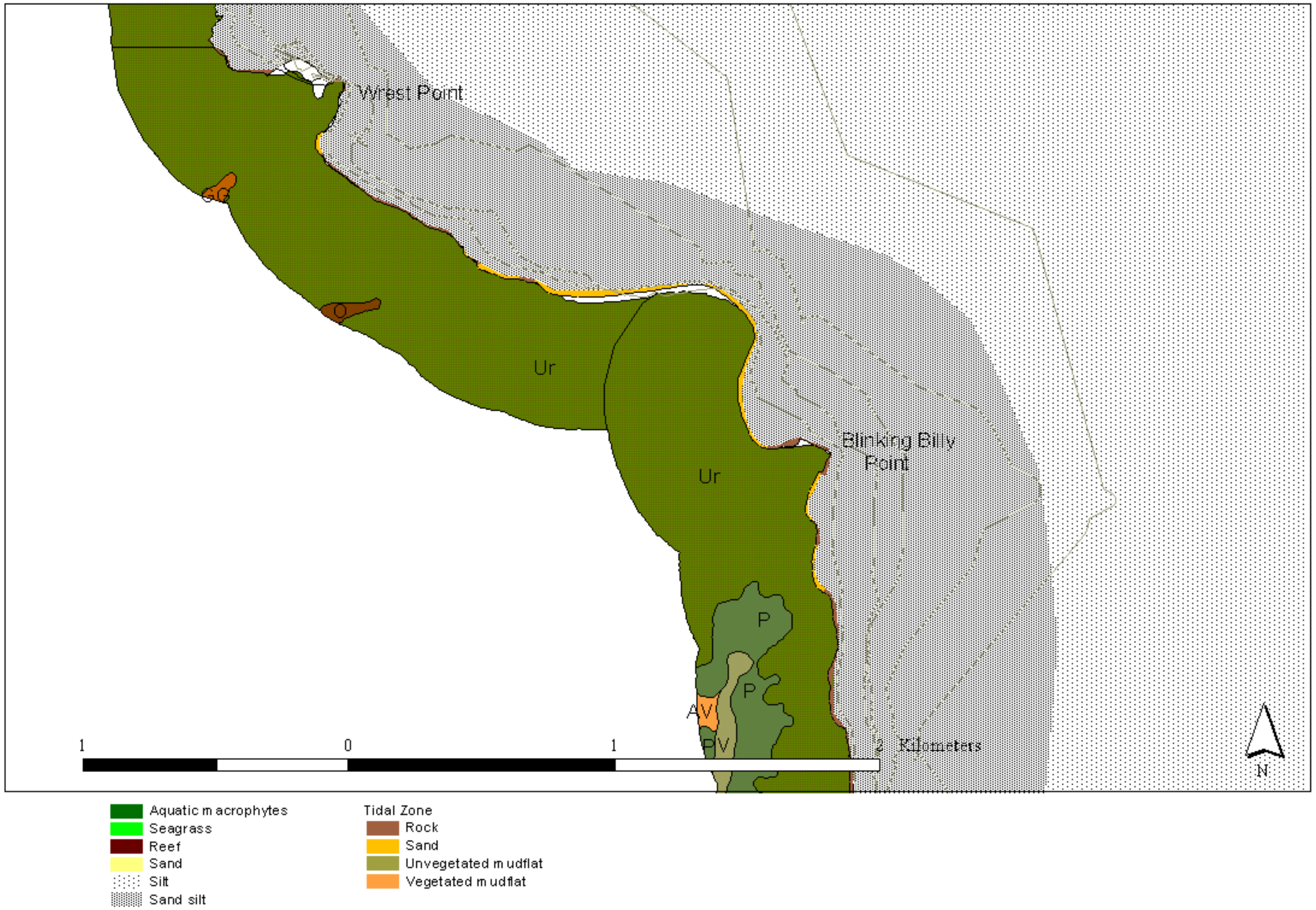


Fig. 5f. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

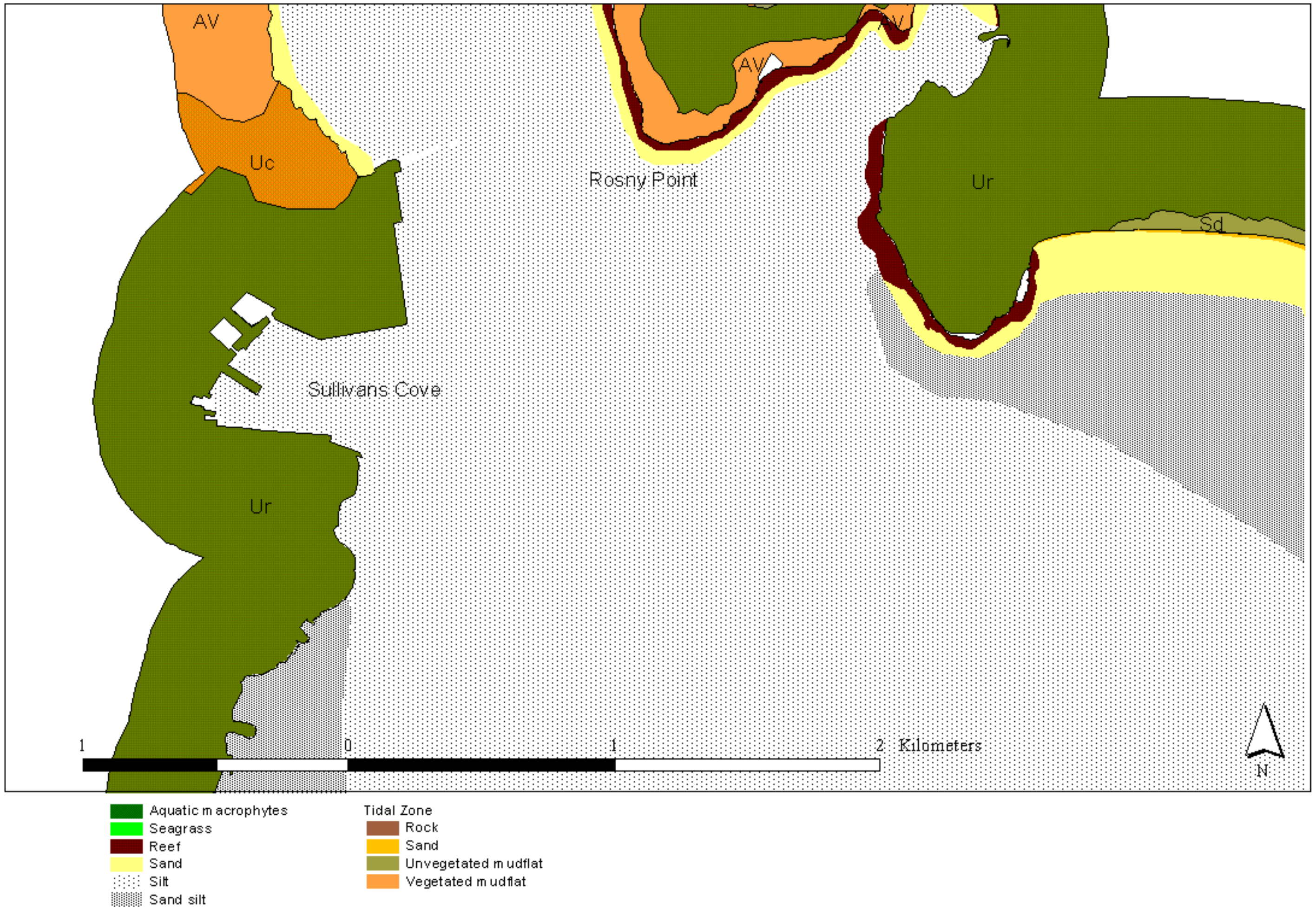
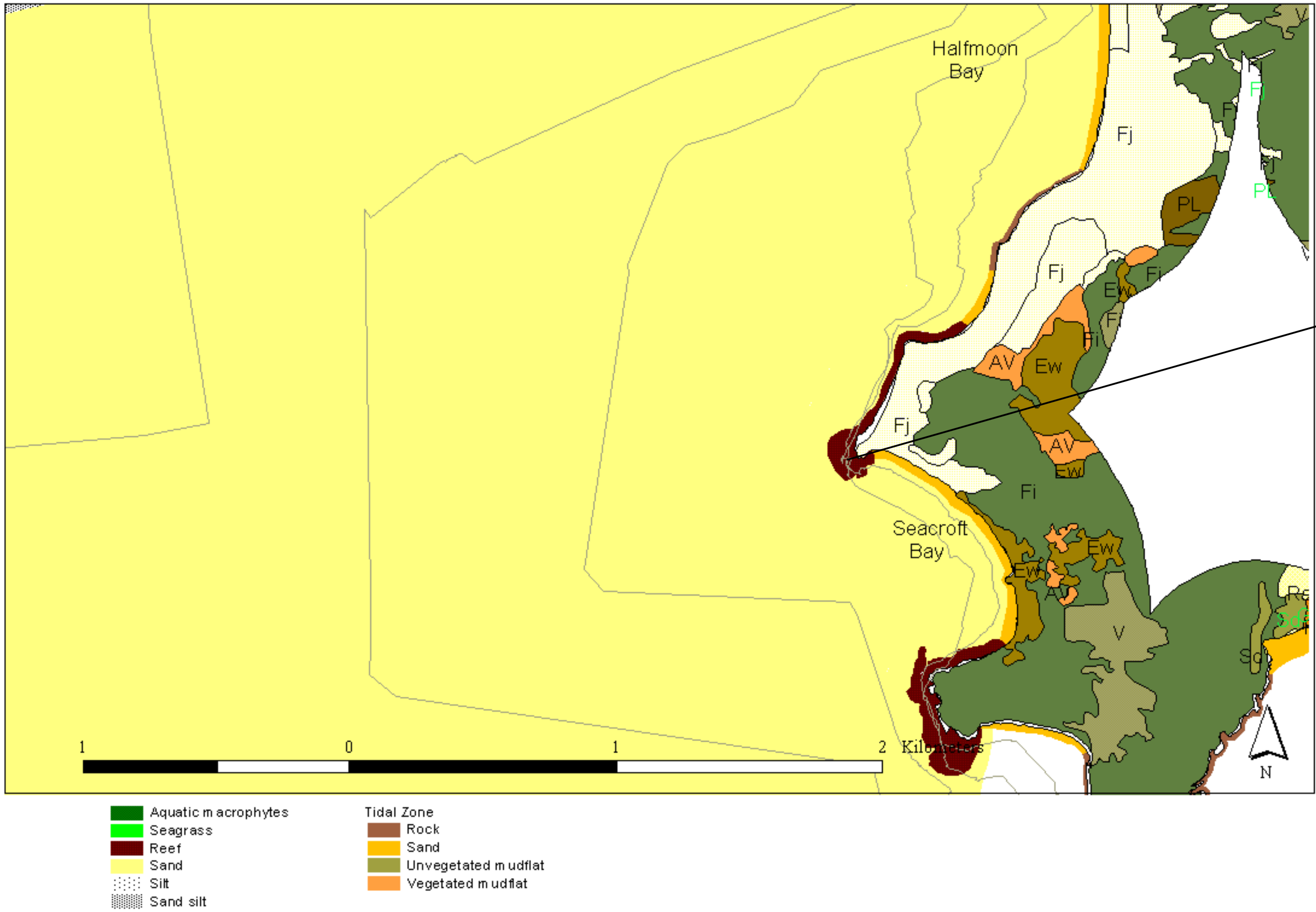
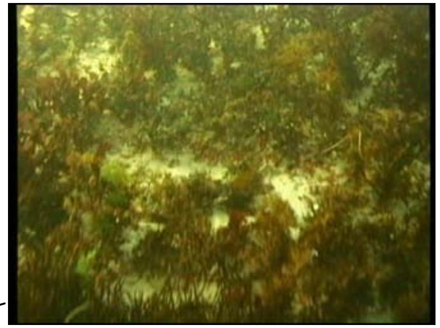


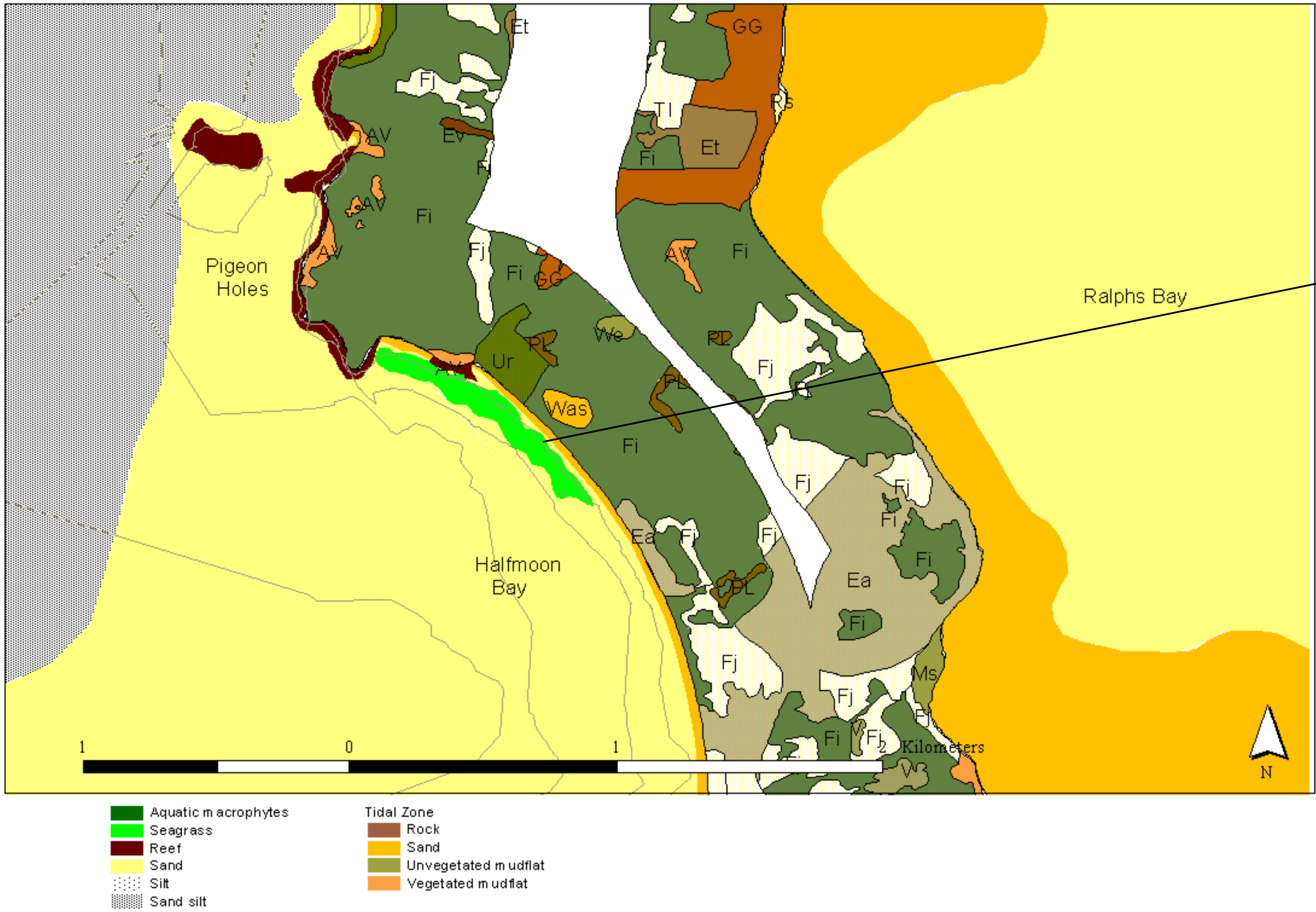
Fig. 5g. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

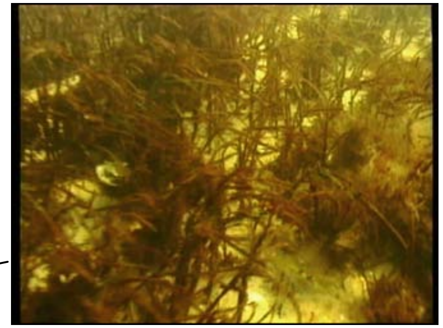




Low profile reef in 2.4m

Fig. 5h. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.





Seagrass bed in 3m

Fig. 5i. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

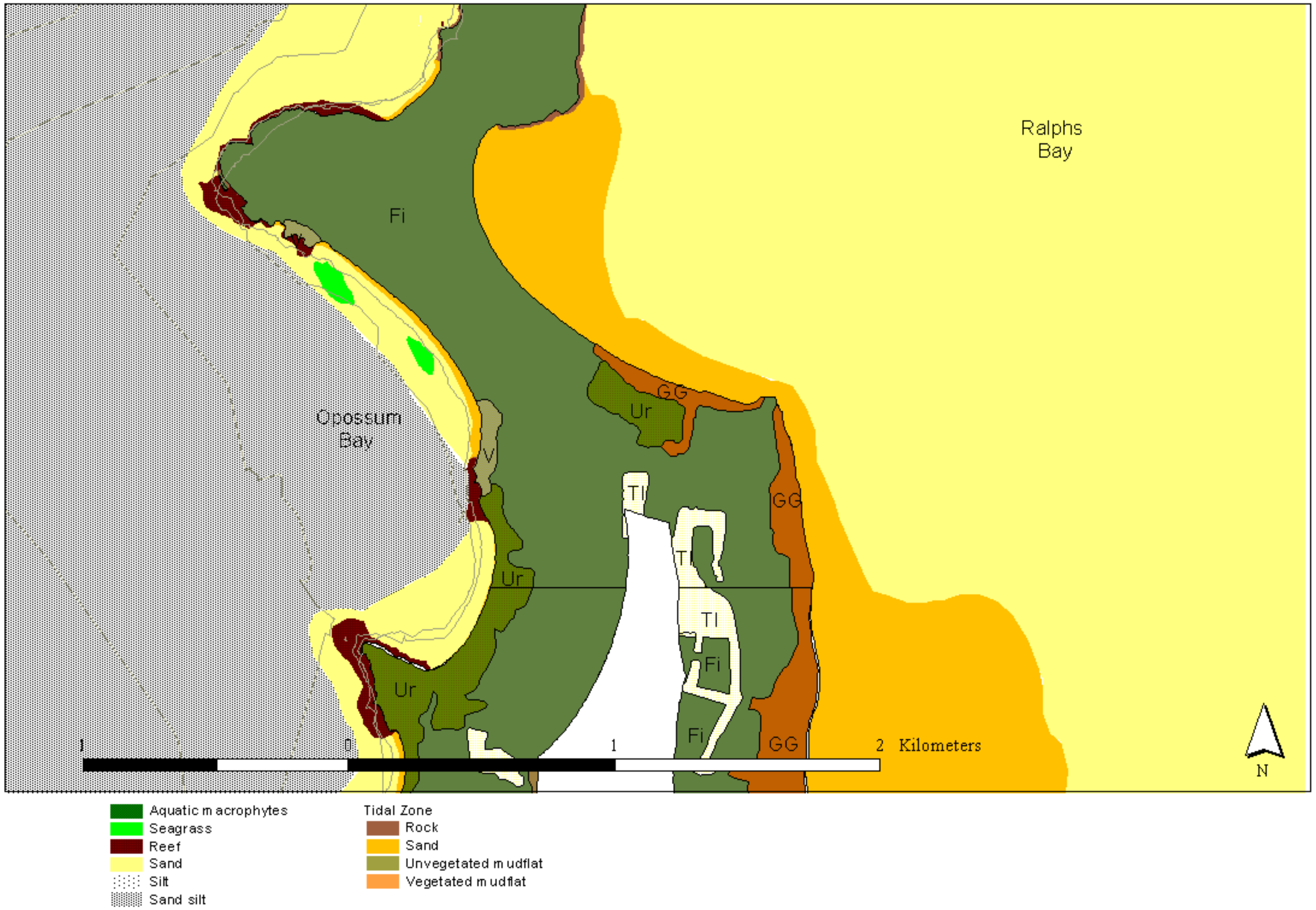


Fig. 5j. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

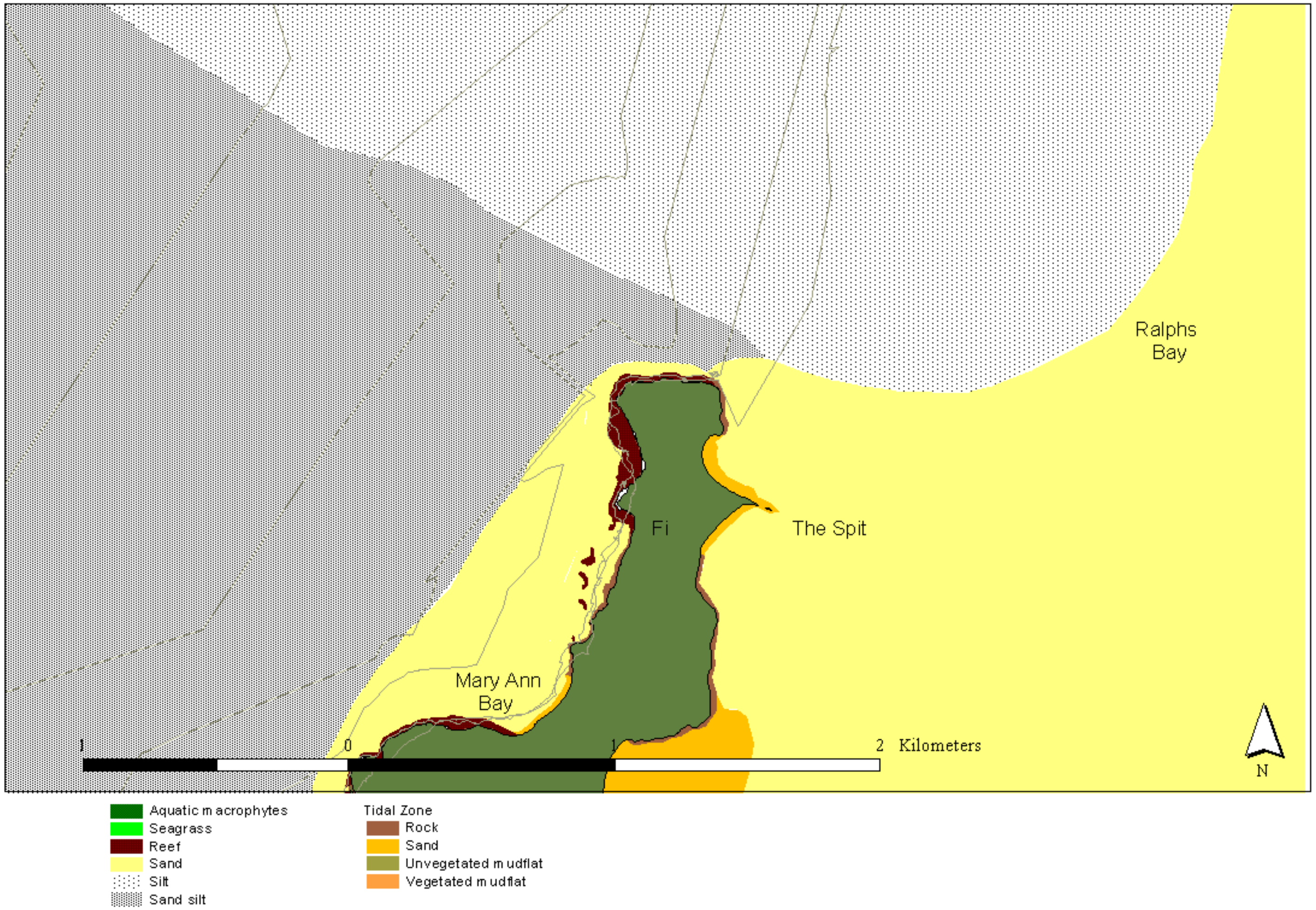


Fig. 5k. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

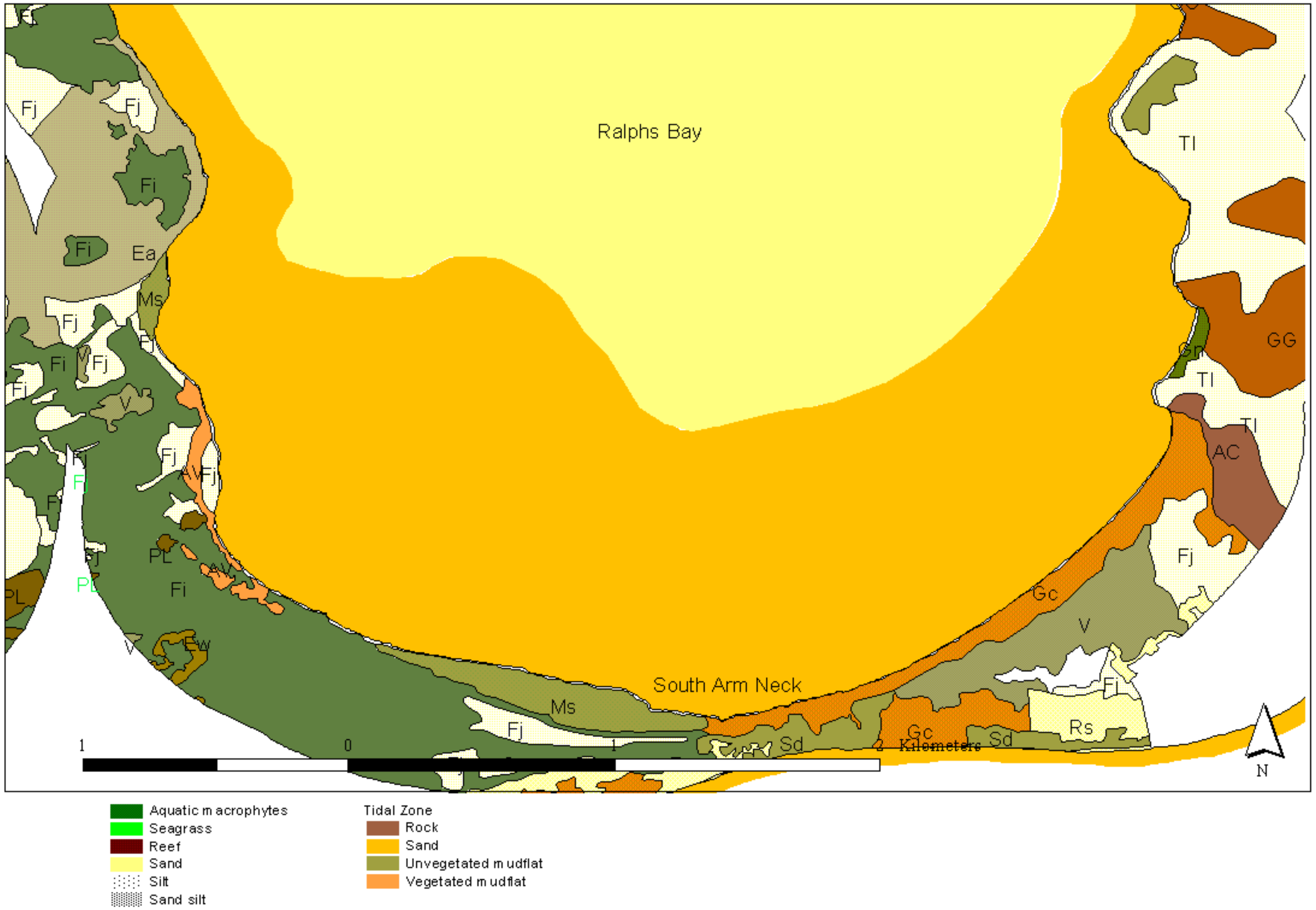


Fig. 5l. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

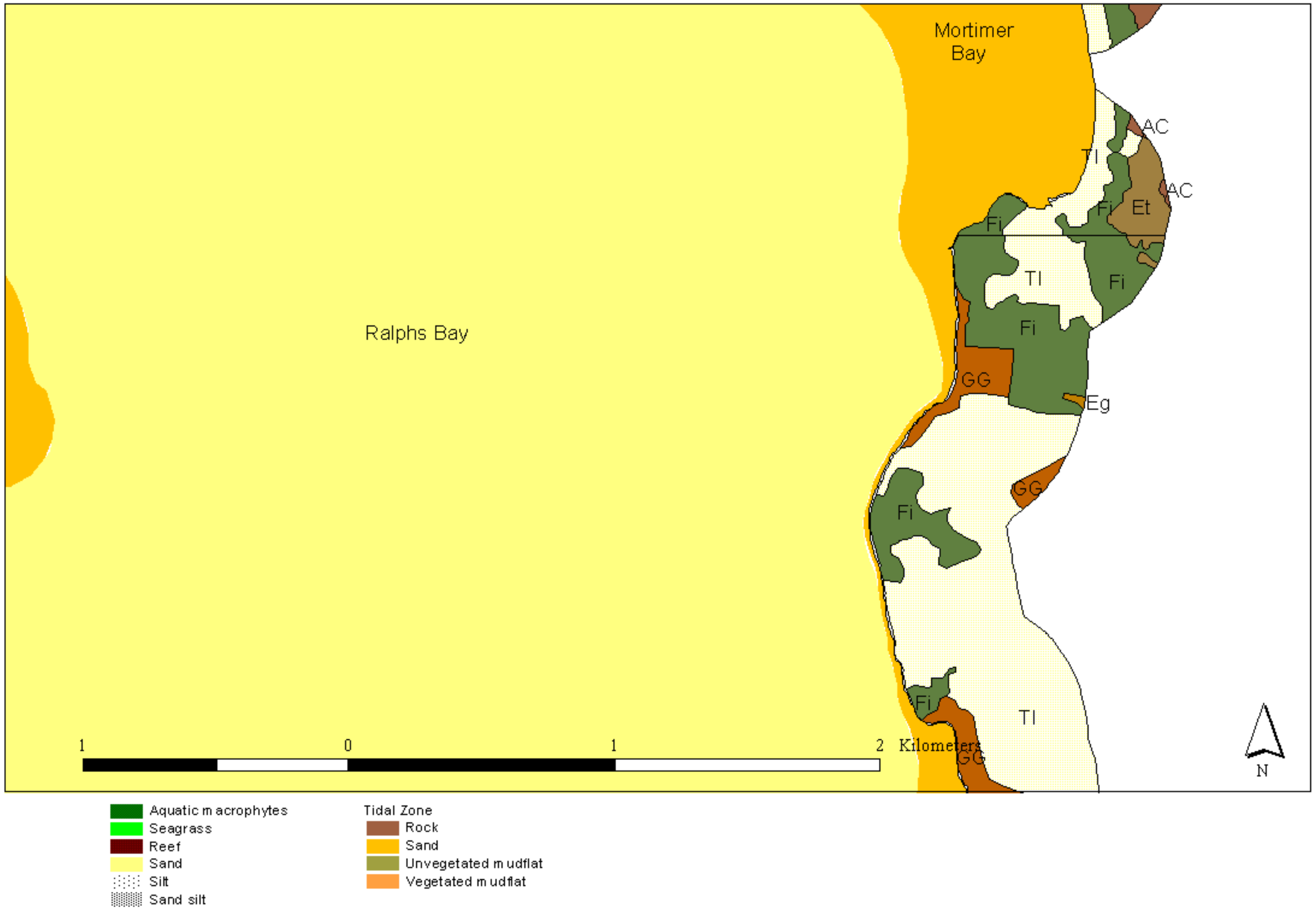


Fig. 5m. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

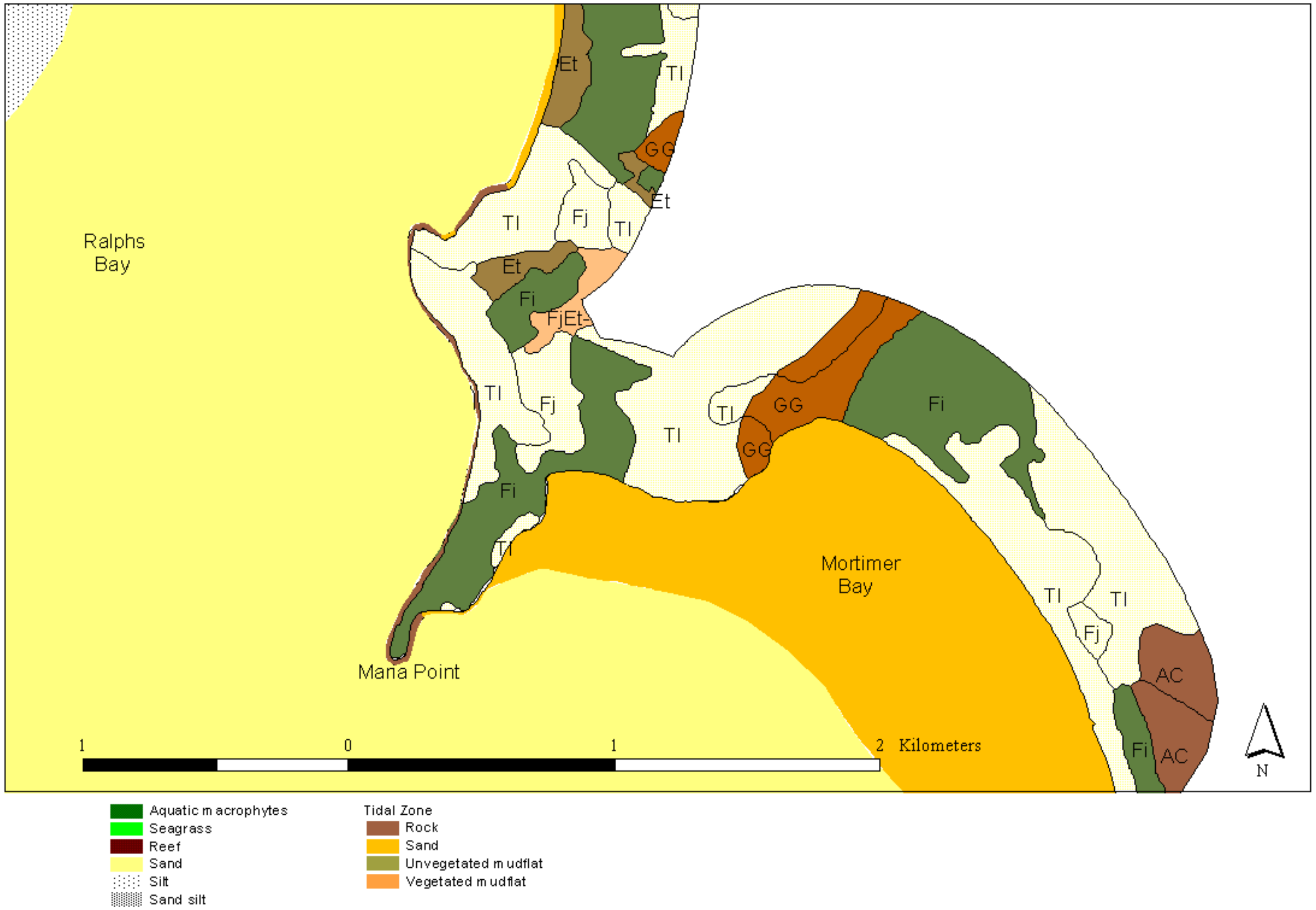


Fig. 5n. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

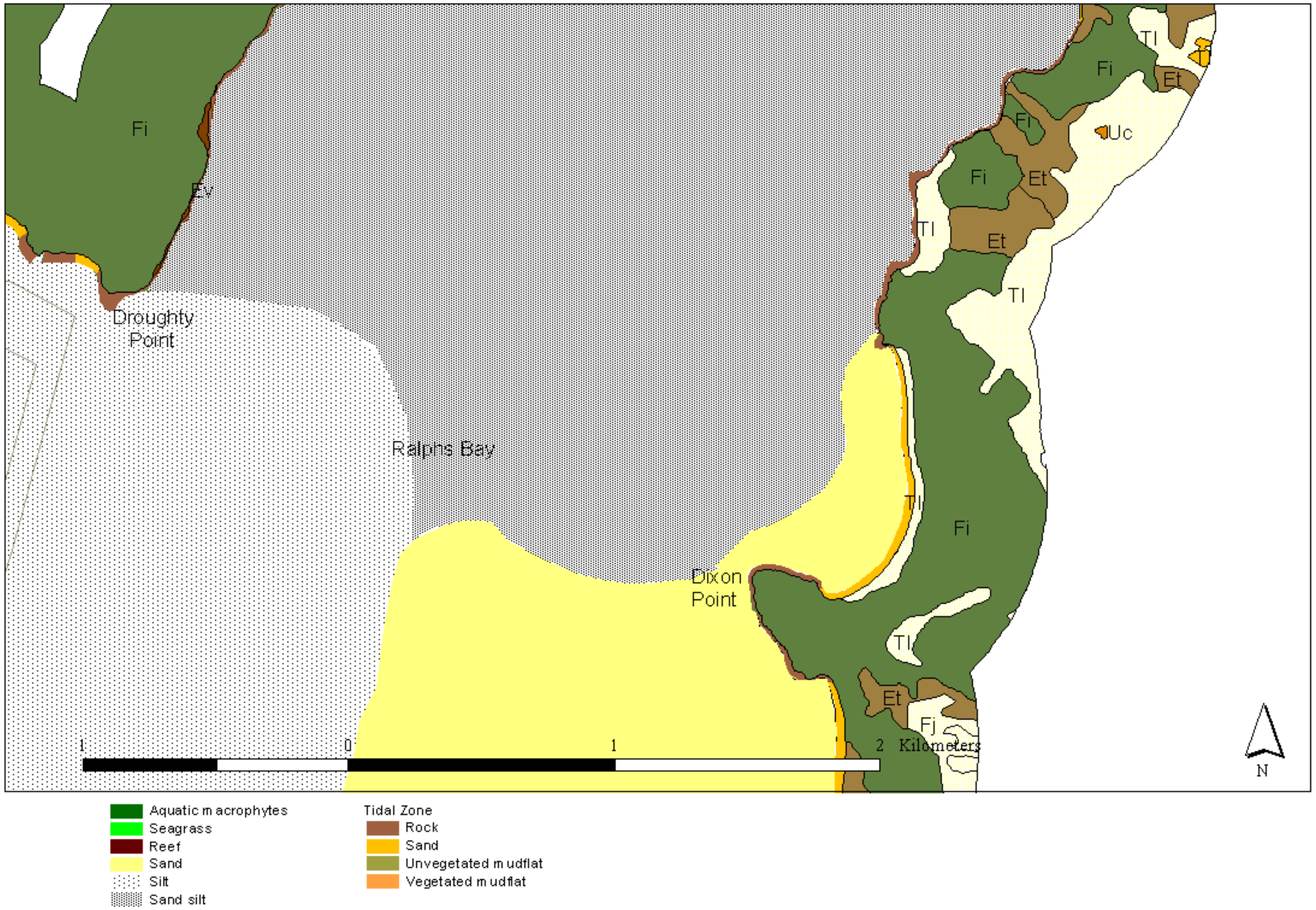


Fig. 5o. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

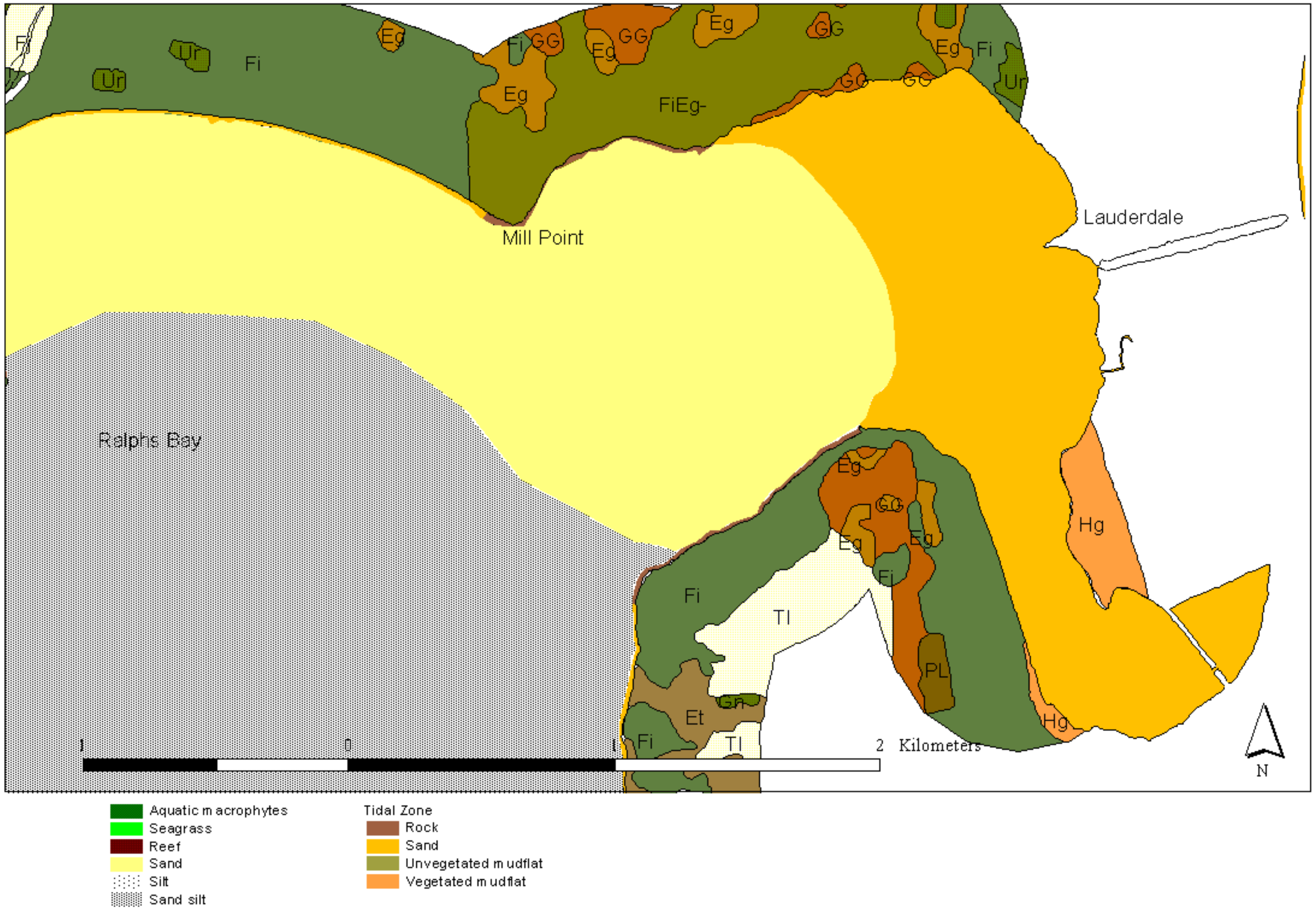
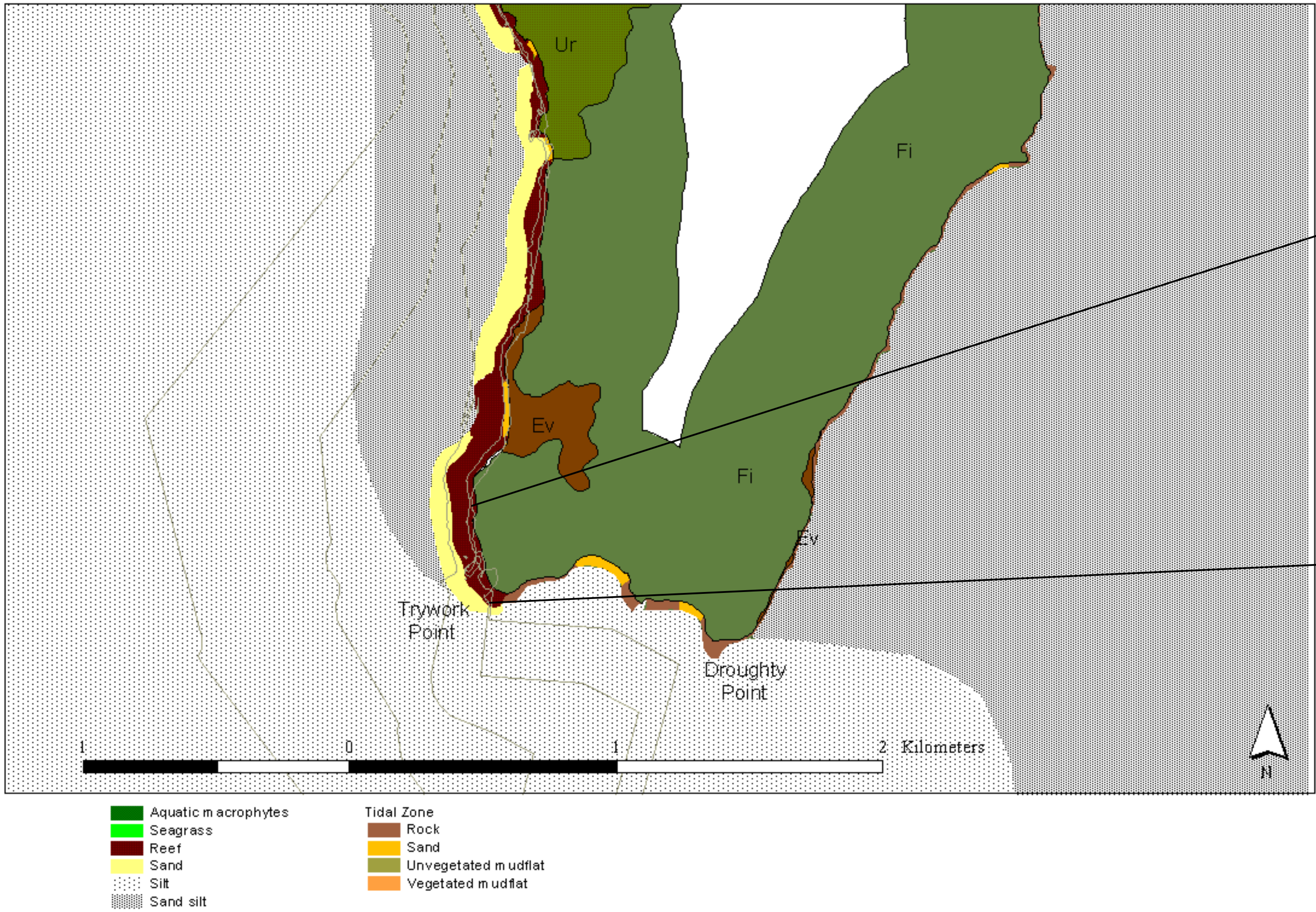
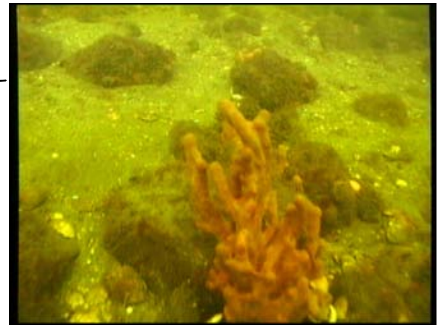


Fig. 5p. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

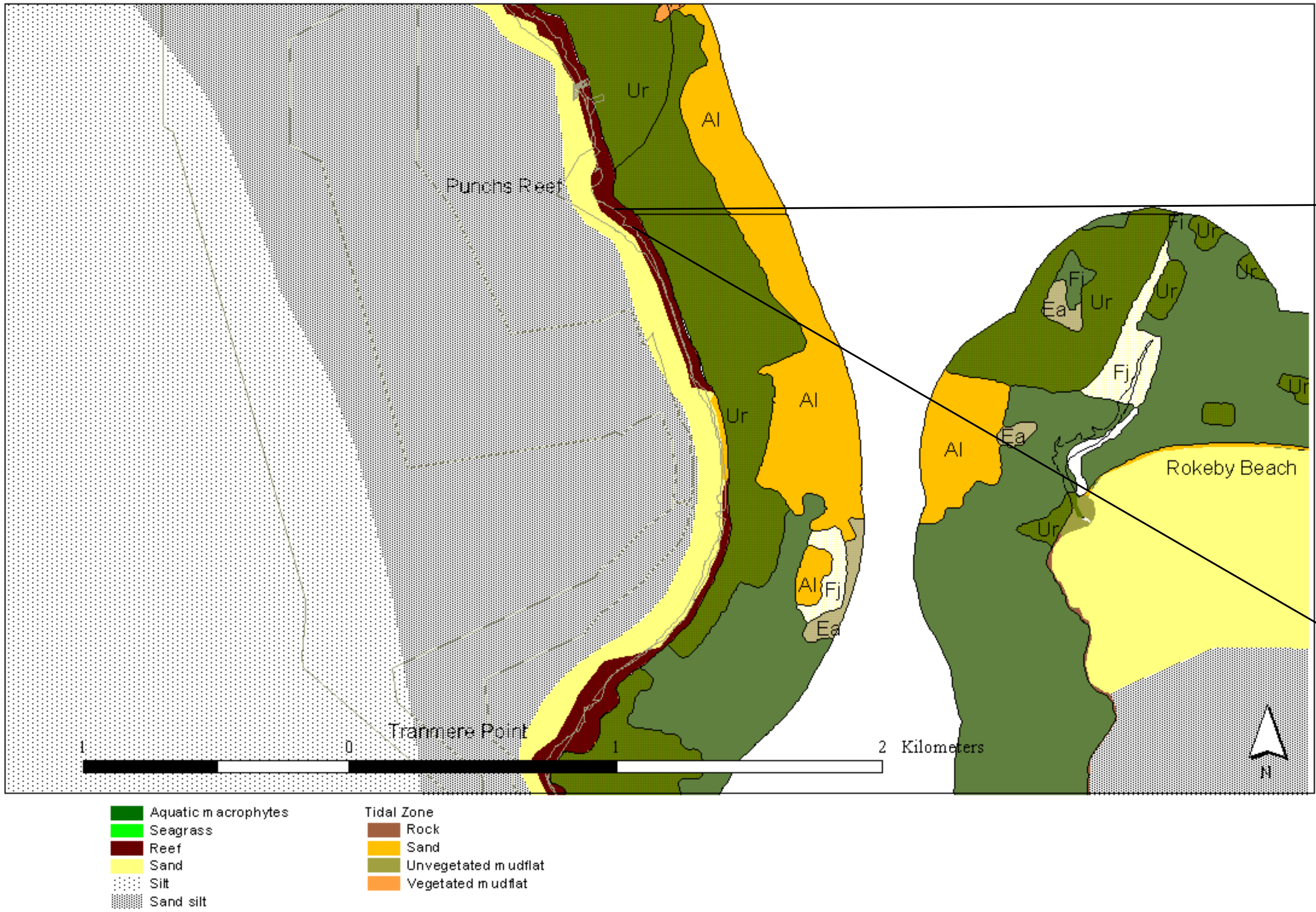


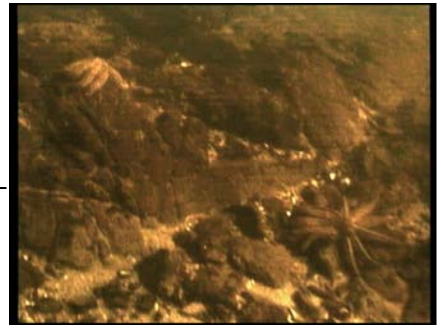
Low profile rubble in 4.2m



Patchy low profile reef in 5.9m

Fig. 5q. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

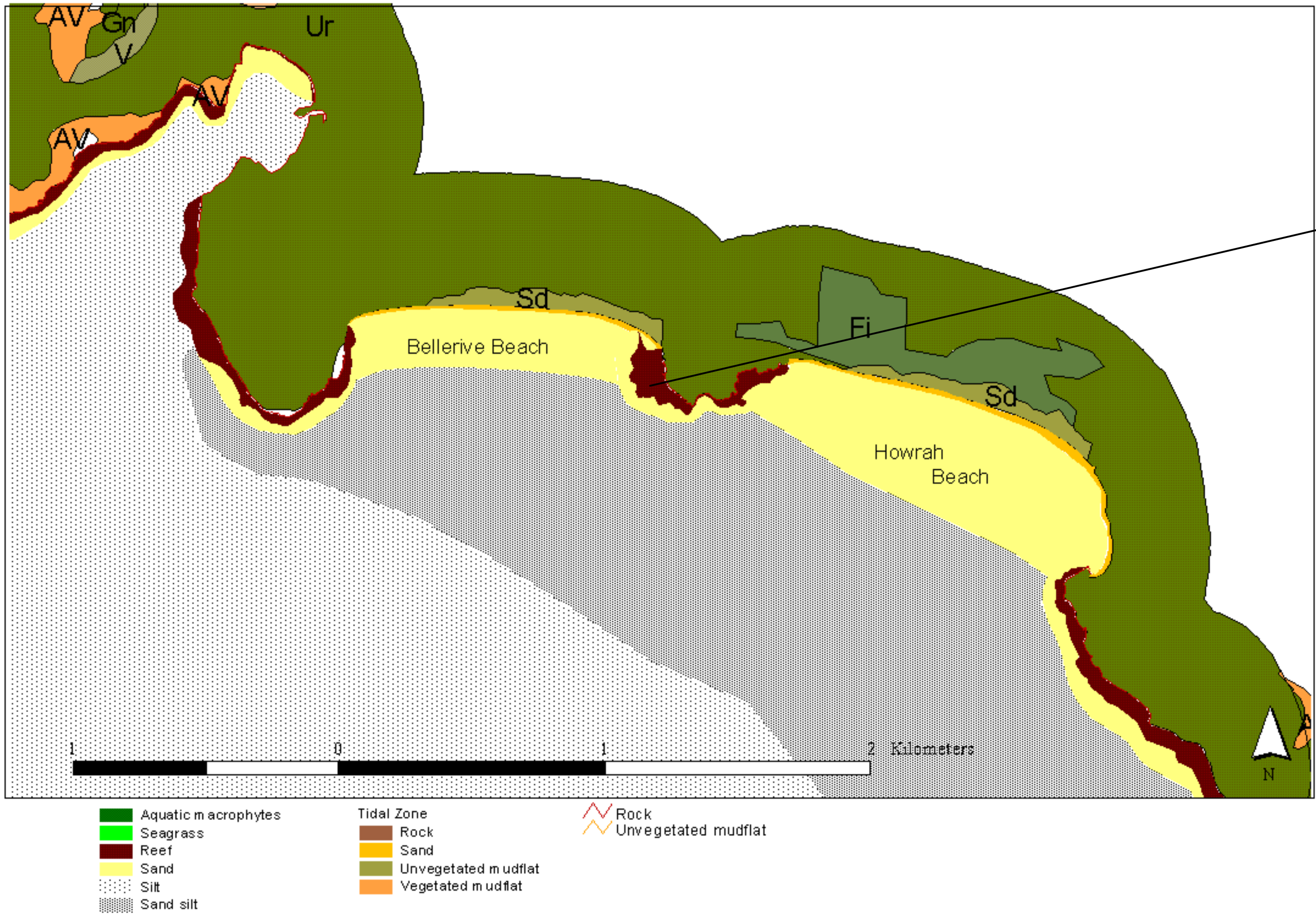




Low profile reef in 1.3m

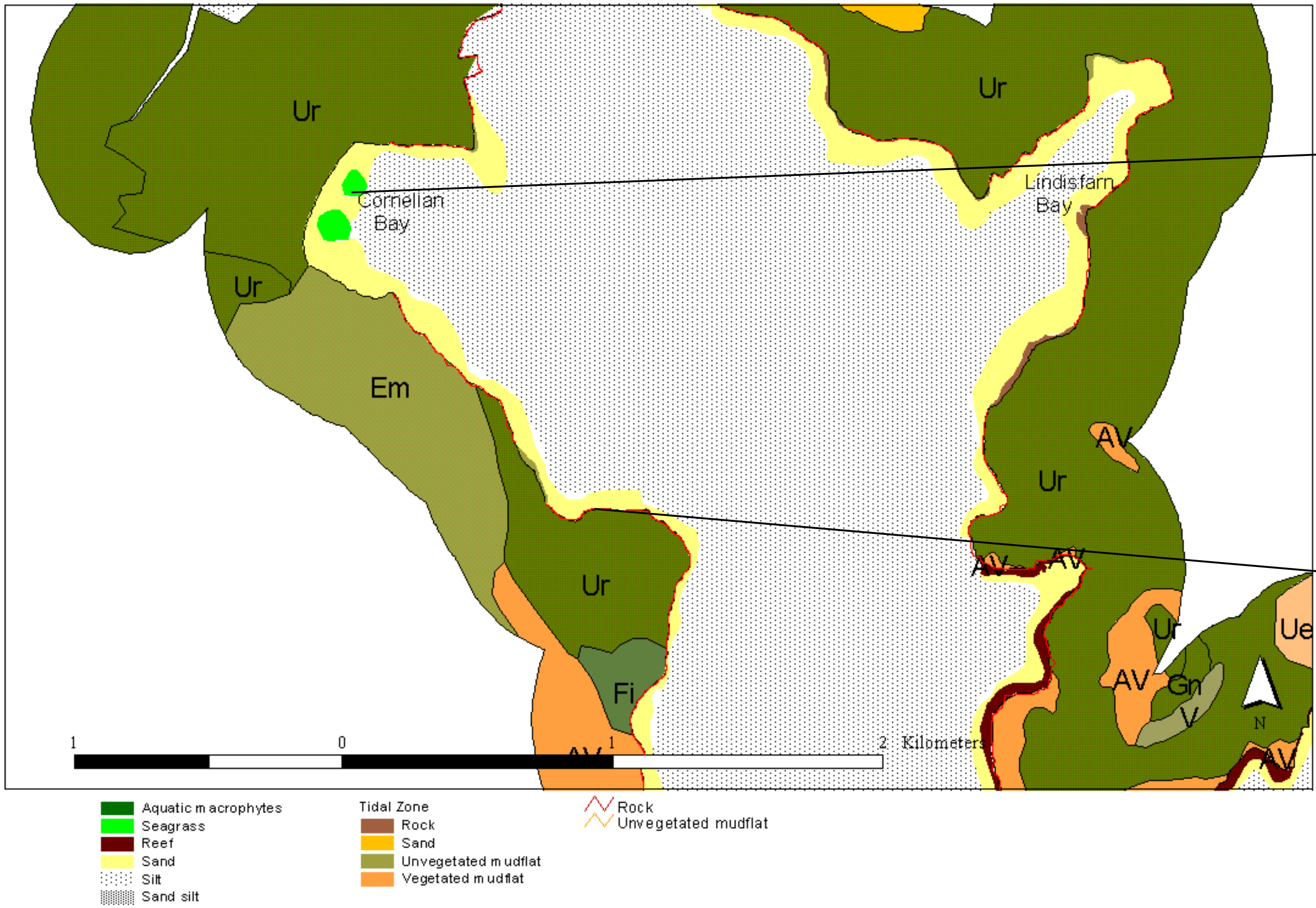
Low profile reef in 0.8m

Fig. 5r. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

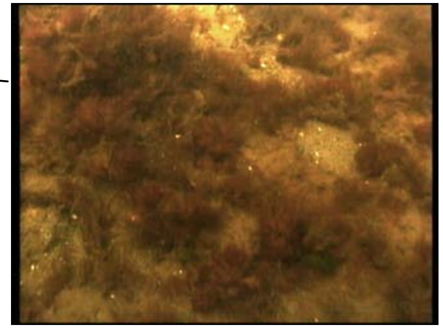


Low profile reef in 3.2m

Fig. 5s. Distribution of habitat types in the lower reaches of the Derwent Estuary at 1:25,000.

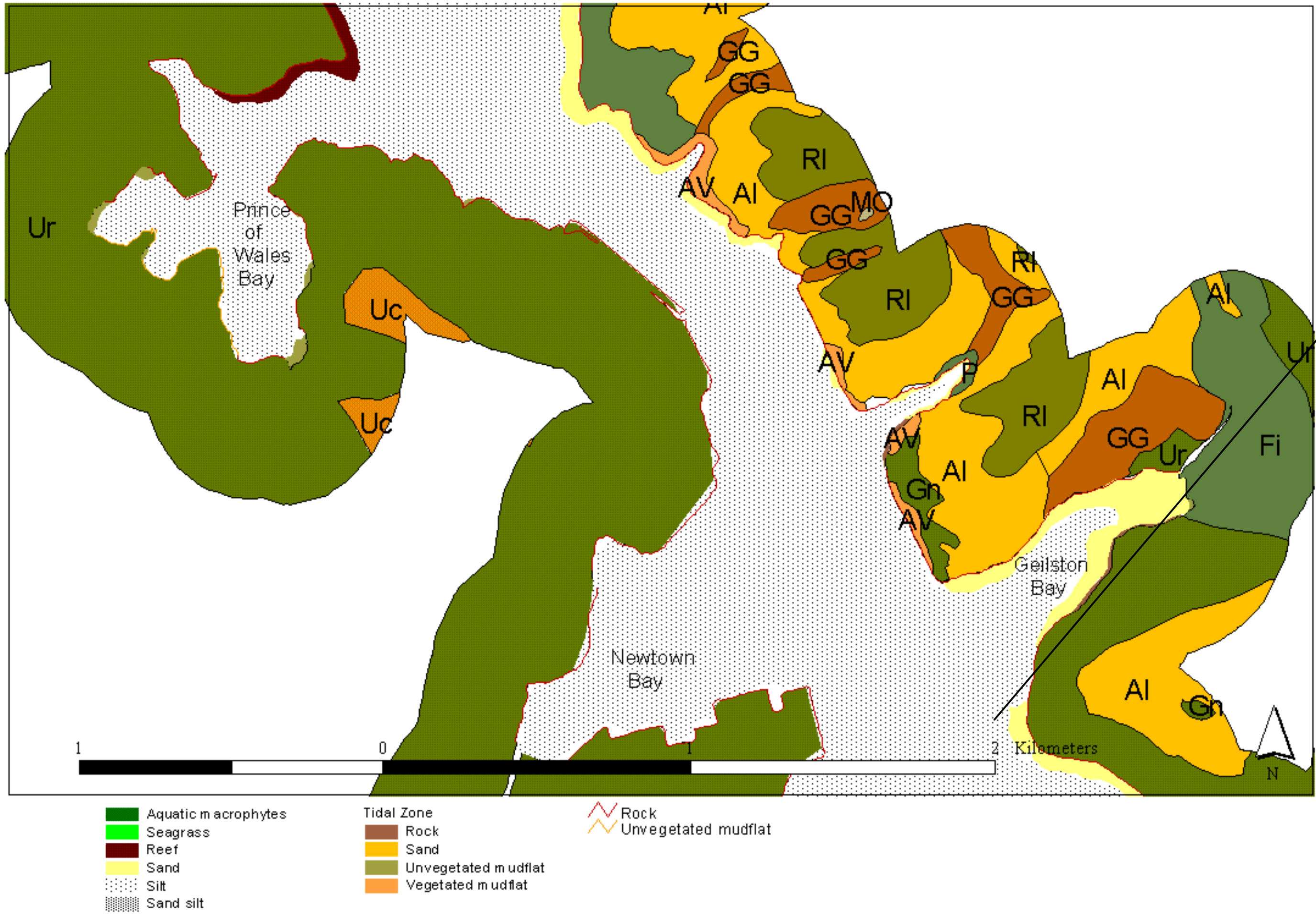


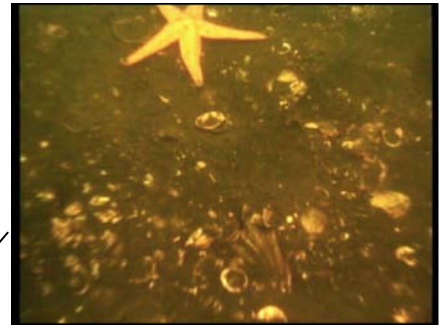
Seagrass in 0.7m



Patchy low profile reef in 1.2m

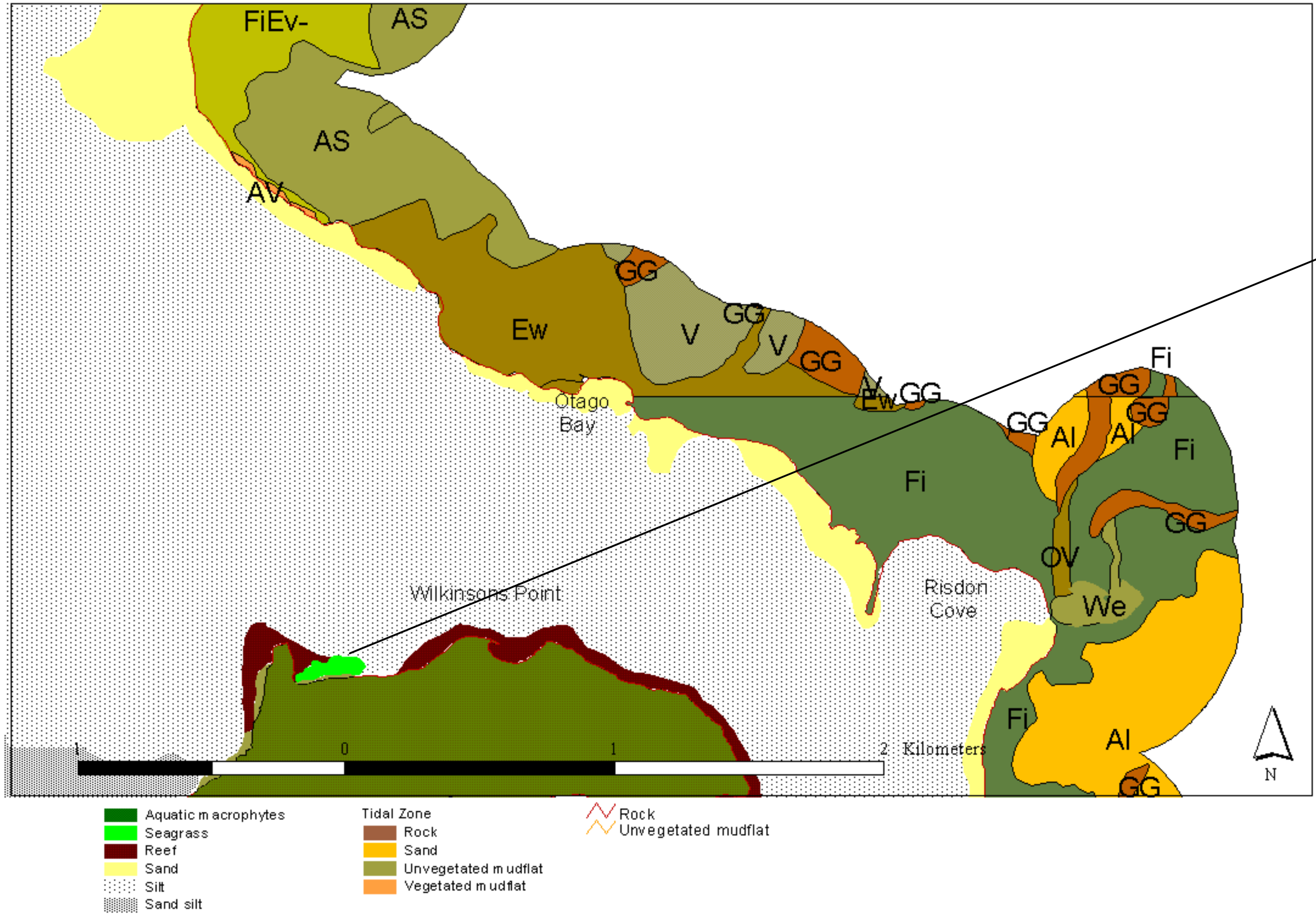
Fig. 6a. Distribution of habitat types in the middle reaches of the Derwent Estuary at 1:25,000.

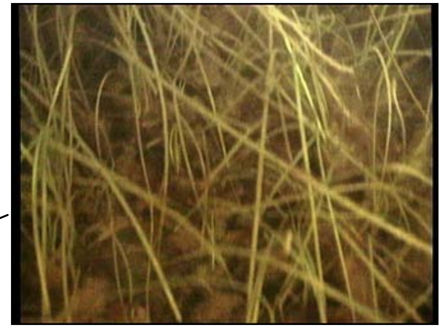




Silt with shells in 6.2m

Fig. 6b. Distribution of habitat types in the middle reaches of the Derwent Estuary at 1:25,000.





Seagrass in 1.7m

Fig. 6c. Distribution of habitat types in the middle reaches of the Derwent Estuary at 1:25,000.

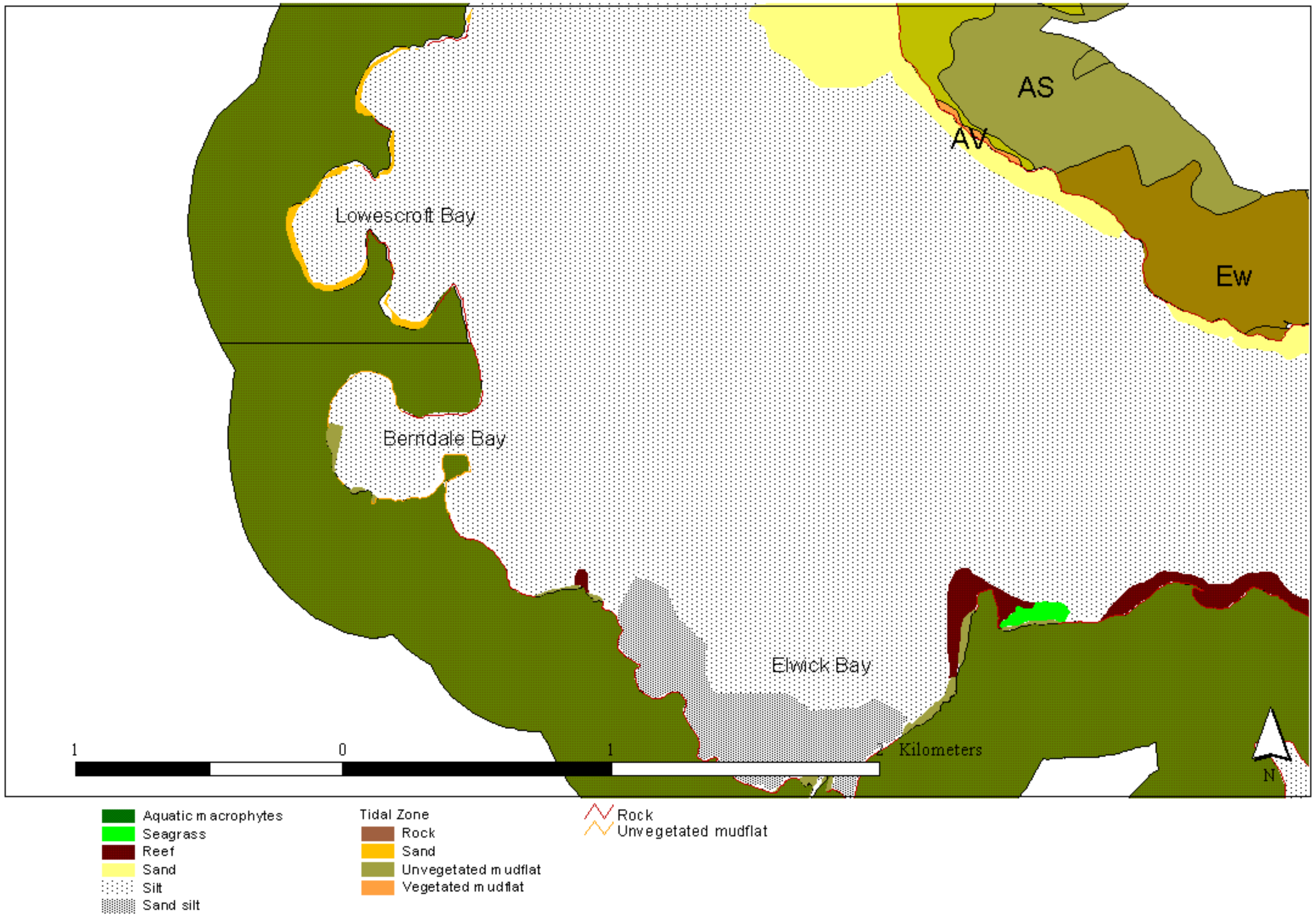
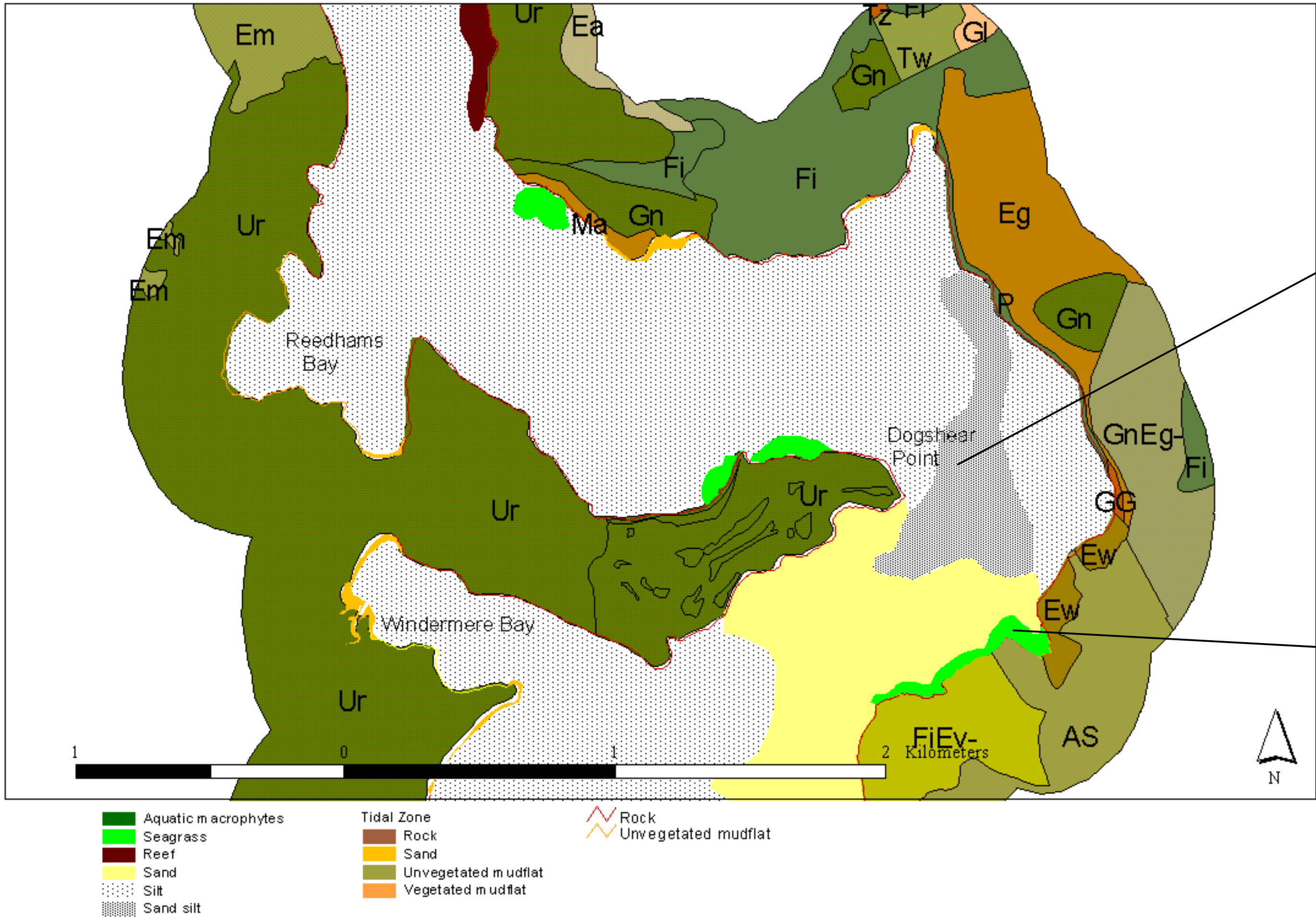
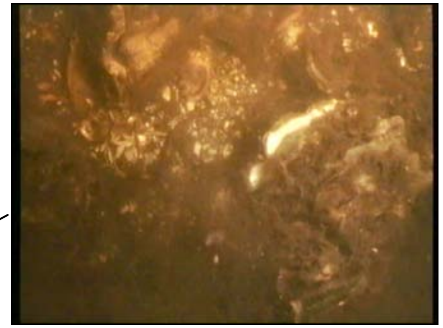
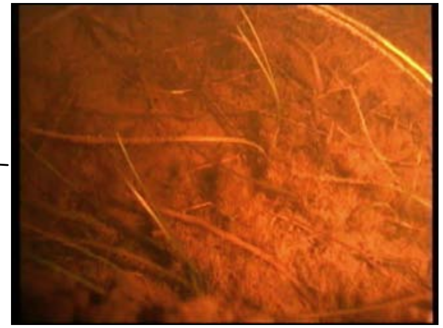


Fig. 6d. Distribution of habitat types in the middle reaches of the Derwent Estuary at 1:25,000.





Oysters on silt in 3m



Silt covered seagrass in 1.7m

Fig. 6e. Distribution of habitat types in the middle reaches of the Derwent Estuary at 1:25,000.

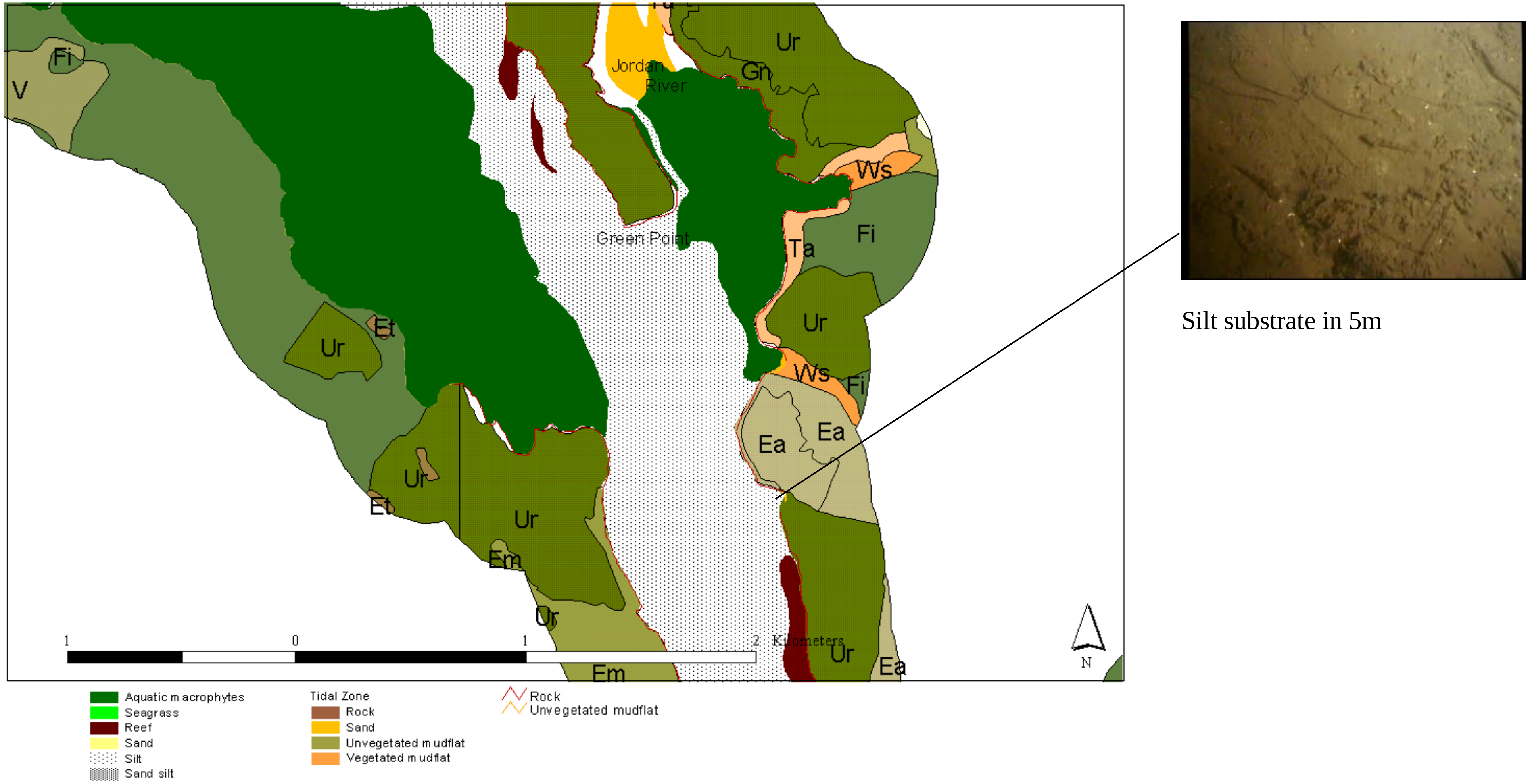


Fig. 6f. Distribution of habitat types in the middle reaches of the Derwent Estuary at 1:25,000.

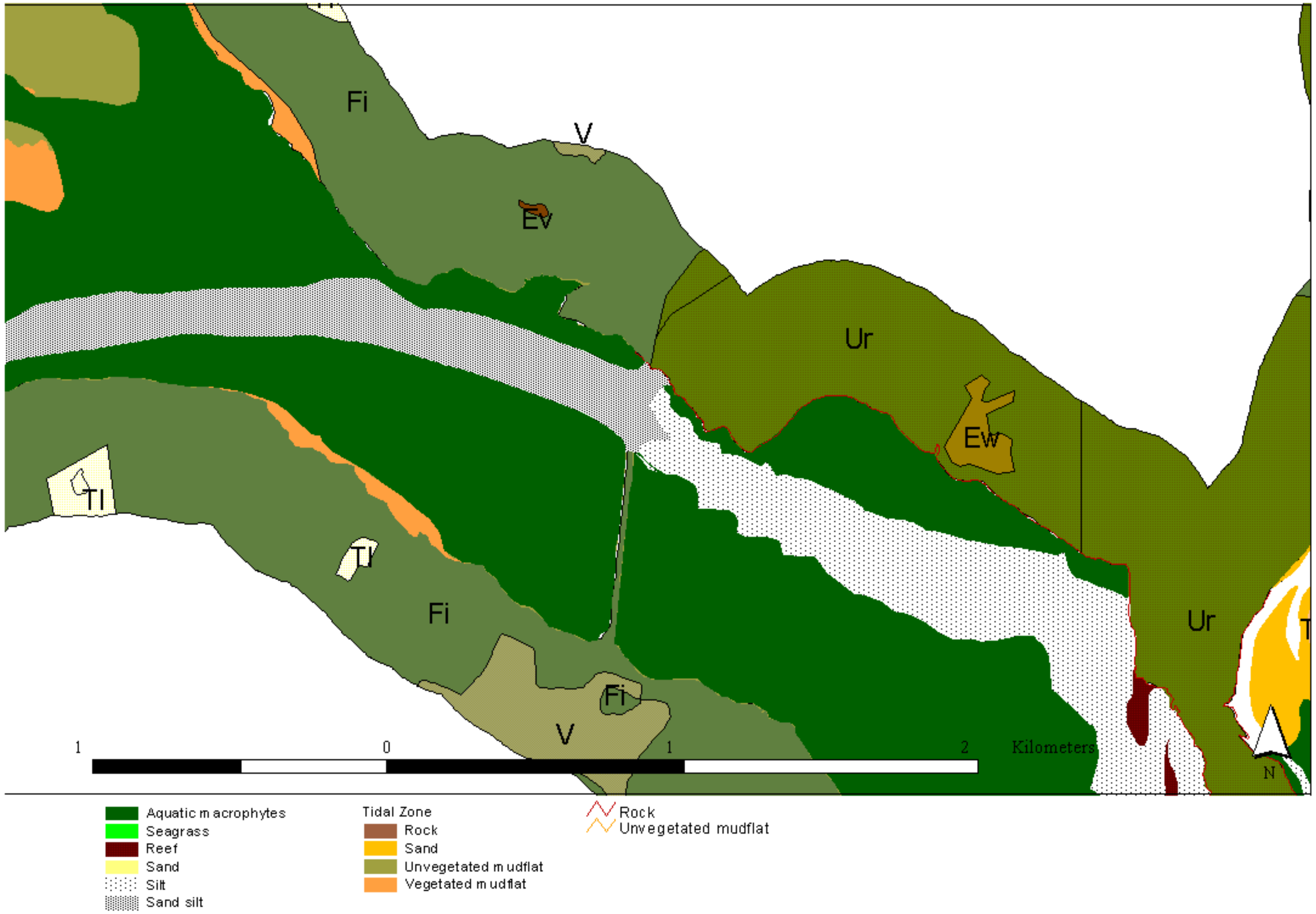


Fig. 6g. Distribution of habitat types in the middle and first part of upper reaches of the Derwent Estuary at 1:25,000.

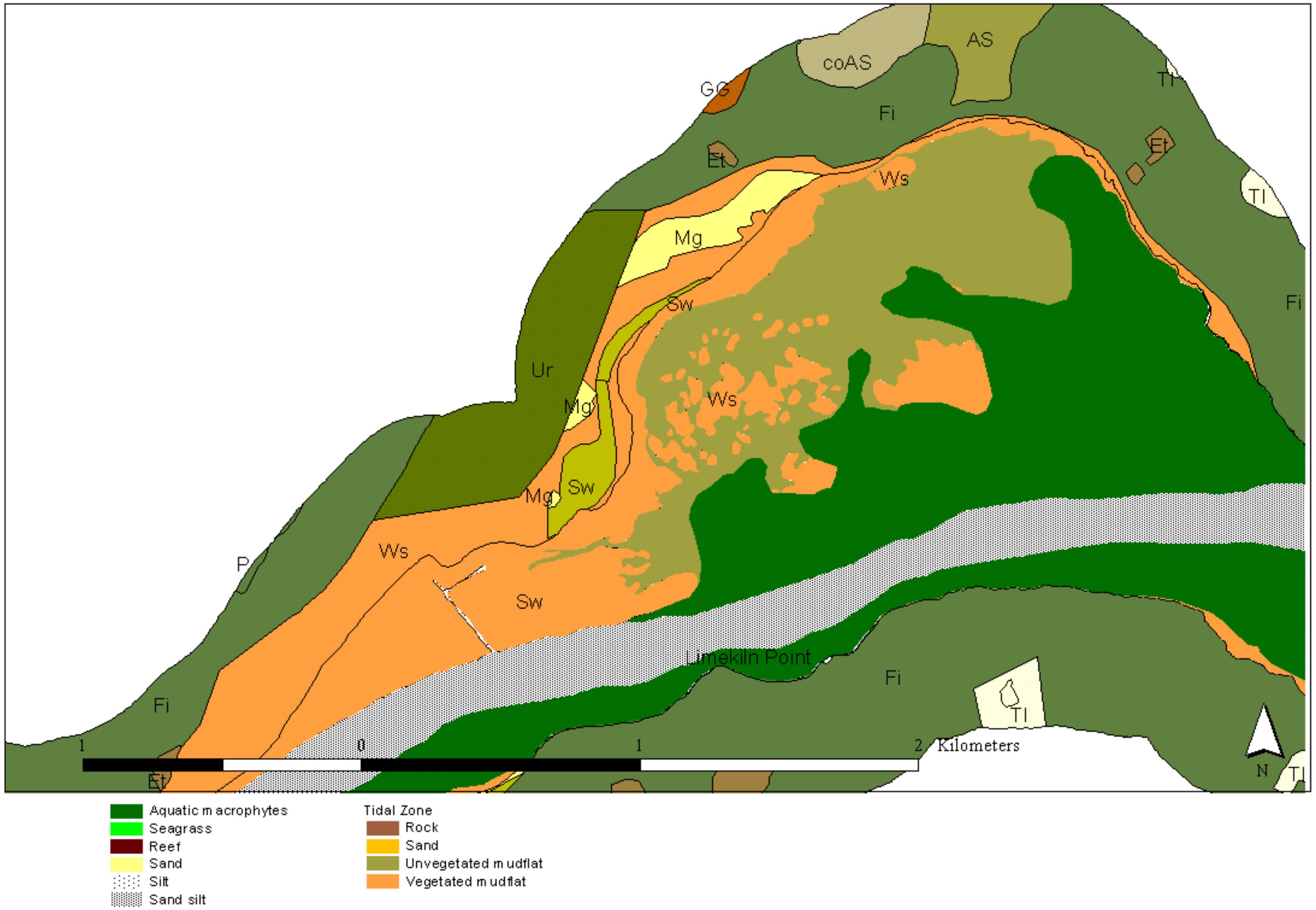


Fig. 7a. Distribution of habitat types in the upper reaches of the Derwent Estuary at 1:25,000.

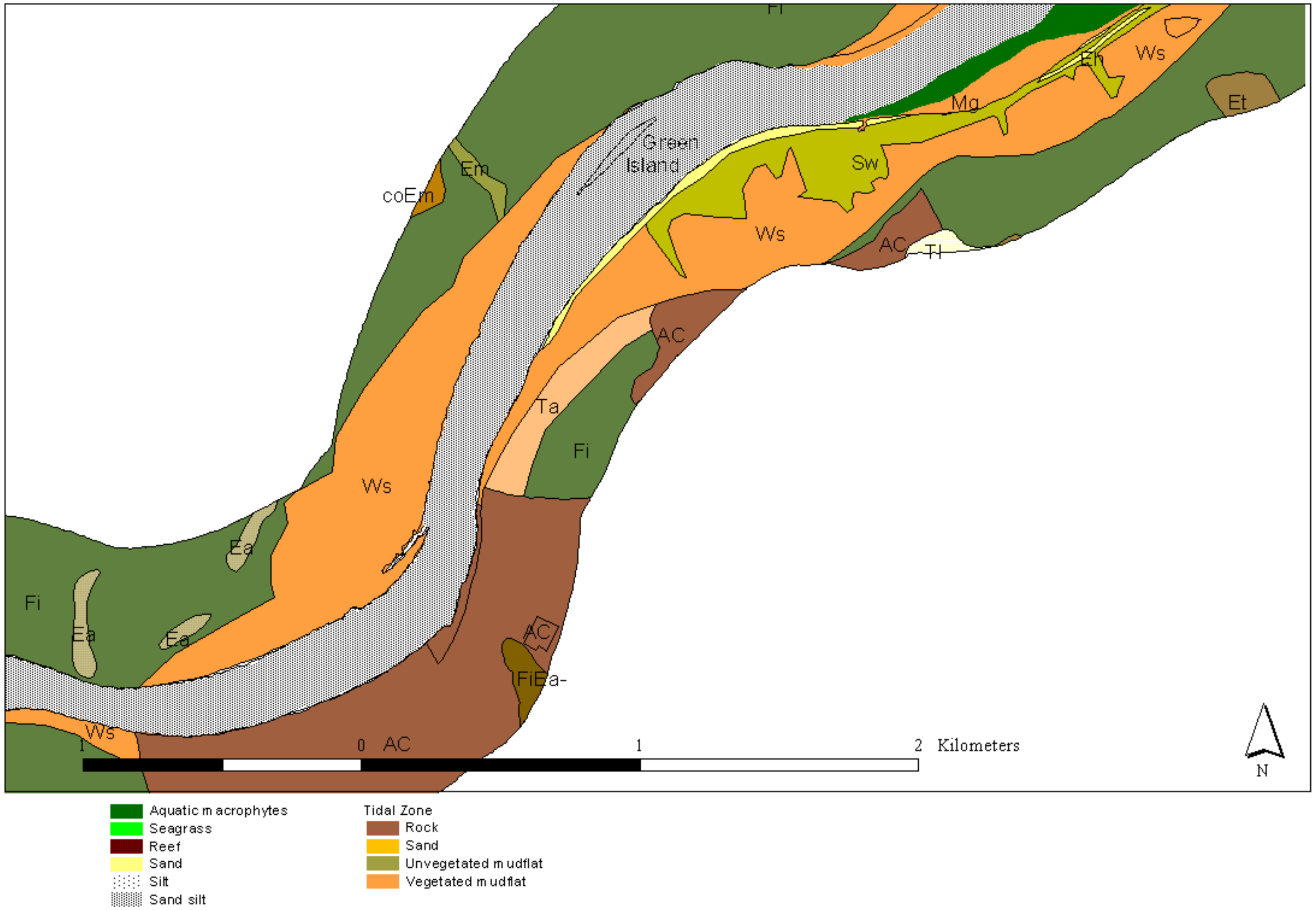


Fig. 7b. Distribution of habitat types in the upper reaches of the Derwent Estuary at 1:25,000.

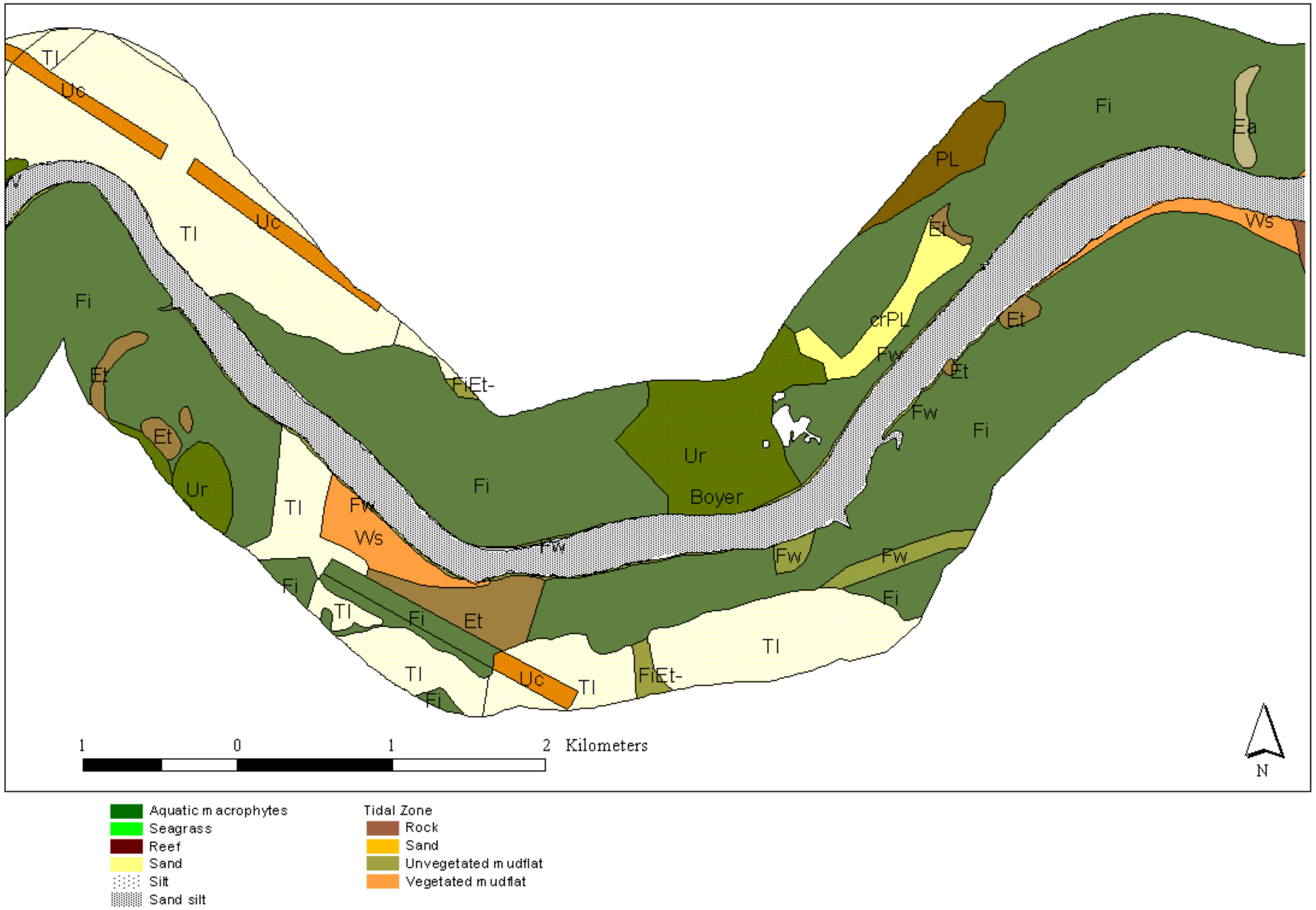


Fig. 7c. Distribution of habitat types in the upper reaches of the Derwent Estuary at 1:25,000.

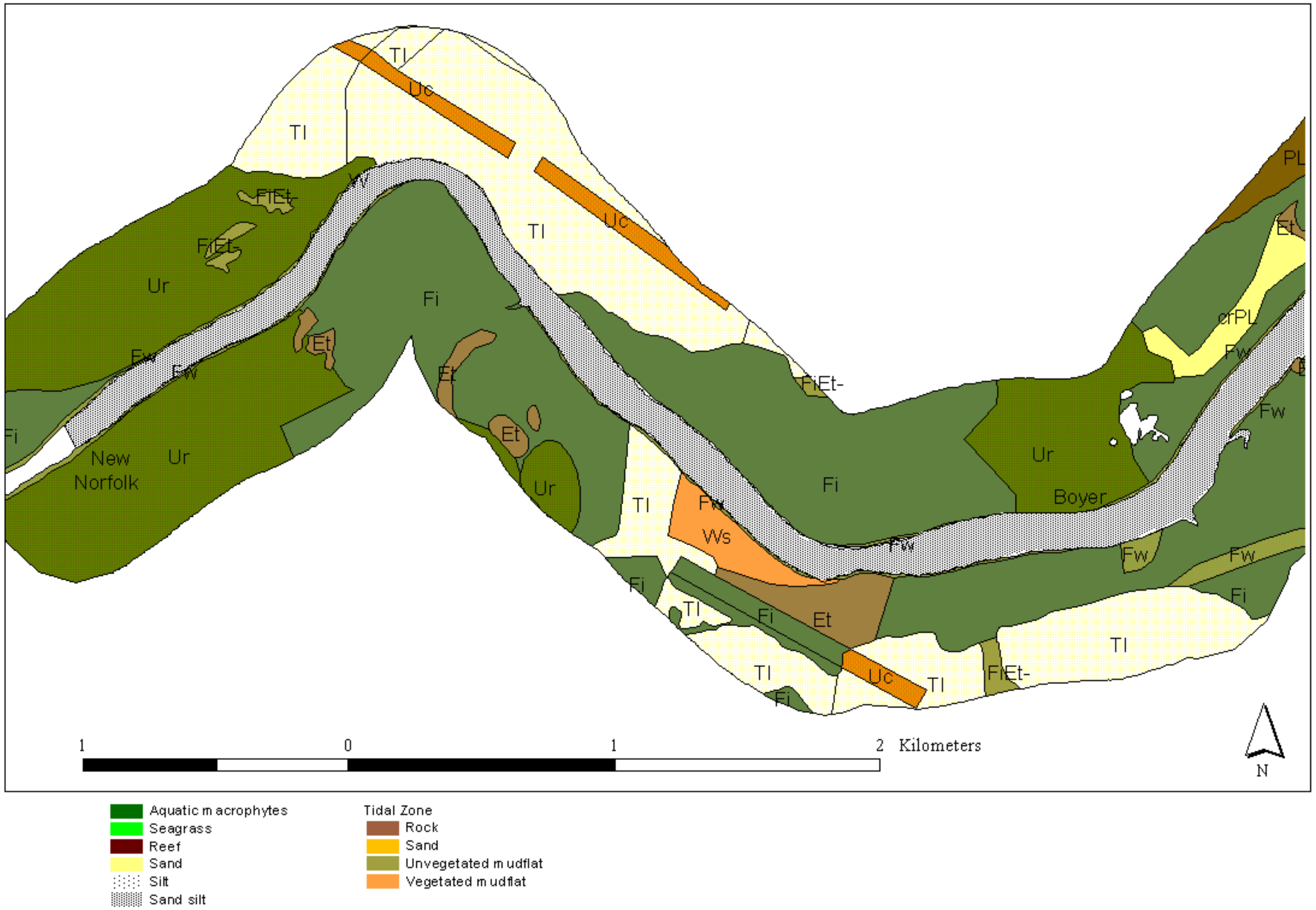


Fig. 7d. Distribution of habitat types in the upper reaches of the Derwent Estuary at 1:25,000.

6. Acknowledgments

We gratefully acknowledge the assistance provided by the crew of FRV Challenger and Robert Connell and Mike Rushton for their assistance in the field. Thanks also to Christine Coughanowr and Colin Buxton for their support of the project. We would also like to thank the Tasmanian Parks and Wildlife Service, Department of Primary Industry Water and Environment for supplying the TASVEG2000 data and the Land Information Services Tasmania (DPIWE) for the tidal zone data.

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Appendix 1. TasVEG 2000 habitat classification codes

AC	coastal *E. amygdalina* |forest
AI	inland *E. amygdalina* |forest
AS	*E. amygdalina* forest|on sandstone
AV	*Allocasuarina verticillata* forest
co	cut over
cr	recently cleared
Ea	*E. amygdalina* |woodland
Eg	*E. globulus* |grassy woodland
Em	*E. pulchella* |grassy woodland
Et	*E. tenuiramis* |woodland on granite
Ev	*E. viminalis* |heathy woodland
Ew	*E. viminalis* |grassy woodland
Fi	improved pasture|& cropland
Fj	regenerating |cleared land
Gc	coastal grass/herbfields
GG	grassy *E. globulus* |forest
Gn	Danthonia/Stipa/|Themeda grassland
Mg	graminoid saltmarsh
Ms	succulent saltmarsh
N	*E. nitida* dry forest
NP	Notelaea &/or |Pomaderris forest
O	*E. obliqua* dry forest
P	*E. pulchella/E globulus/|E viminalis* forest
PL	plantation
RI	*E. risdonii* forest
Ri	riparian
Rs	sand - mud
Sc	tall/windpruned |coastal scrub
Sd	sandune vegetation
Sw	tall wet scrub
T	*E. tenuiramis* forest|on granite
Ta	*Allocasuarina* spp. |(not *A. verticillata*)
TI	inland E. tenuiramis |forest
Tw	*Acacia* spp. (not |*A. melanoxylon*|/*A. dealbata*)
Uc	rural misc.
Ue	permanent easements
Ur	built up areas
V	*E. viminalis* |grassy forest
Was	saline aquatics
We	wetland(gen.)
Ws	sedge/rush wetland

Appendix 2. Site details for sediment sampling sites in the Derwent Estuary

Site No.	X_COORD	Y_COORD	Depth (m)
1	527798.87766	5249924.76864	15
2	529083.66979	5250648.59740	21
3	530312.36821	5251255.94491	21
4	532094.36984	5251947.46504	8
5	529414.00303	5252172.33485	15
6	528420.25343	5251806.27855	21
7	527726.60122	5251922.04725	18
8	529258.78048	5249281.95183	20
9	530246.07260	5249792.27775	24
10	531643.27509	5250354.11319	22
11	532813.78740	5250981.60517	18
12	533482.30960	5248811.13608	19
13	532214.97724	5248358.11773	22
14	530931.71693	5247955.02202	24
15	529703.65946	5247392.20416	21
16	529303.88194	5244856.43769	6
17	530570.63166	5245074.89748	26
18	531869.00643	5245339.17413	23
19	533205.25432	5245821.45883	13
20	531979.39261	5242173.72179	17
21	529234.27136	5242248.94539	22
22	527952.29341	5242176.55812	13
23	532869.26123	5233337.23850	16
24	530421.13173	5233468.84210	16
25	528586.29265	5233545.28070	15
26	527196.58509	5237327.58127	11
27	528484.94618	5237176.30796	25
28	529927.16460	5237207.91037	21
29	532869.69575	5237190.74512	10
30	531700.95251	5238395.61492	
31	529591.39497	5238405.05828	26
32	527036.35657	5238415.62535	12
33	527164.32704	5240165.49747	12
34	529392.71074	5240156.29795	22
35	531954.88819	5240102.06976	12
36	529899.54824	5242083.16467	26
37	528793.55449	5244105.34745	5
38	531349.83940	5244205.18927	26
39	532669.22415	5244626.57595	21
40	532871.99238	5247788.64999	22
41	530612.41097	5246503.59033	25
42	529619.55926	5247817.33159	14
43	530652.96471	5248276.42775	24
44	531463.28183	5251163.82178	20
45	529947.06904	5250174.81897	23
46	527295.19380	5250219.17916	
47	527994.19118	5251456.44711	21
48	529234.78587	5251951.00201	
49	527552.27786	5253253.43935	7
50	527778.27775	5253252.53033	11
51	528001.50063	5253251.62519	17
52	527249.10322	5255753.22444	17
53	523750.33217	5260004.51003	2

Appendix 2. Continued

Site No.	X_COORD	Y_COORD	Depth (m)
54	522157.97831	5260602.02240	1
55	523634.73641	5262727.20523	4
56	522245.56279	5262837.54026	2
57	521097.99735	5263788.69710	1
58	520591.48492	5265848.22895	2
59	519396.88214	5267328.58412	3
60	518785.48022	5267559.46976	3
61	521752.13679	5261547.20625	1
62	521542.66749	5259937.69561	1
63	525502.55483	5258499.11769	8
64	524523.24807	5257955.62698	
65	524657.85387	5259201.22007	4
66	524866.00900	5259500.29422	10
67	525001.58054	5259686.69270	3
68	525732.78488	5258042.18171	8
69	525795.55428	5258084.58780	17
70	525931.11757	5258269.08061	4
71	526453.03133	5257326.79817	6
72	526587.95180	5257344.82018	24
73	526693.03044	5257401.71153	22
74	526199.48554	5256547.62412	5
75	526761.93610	5256545.46094	3
76	527402.03889	5256548.49558	10
77	526939.91456	5255907.43778	15
78	527218.12952	5256008.16896	17
79	527411.88531	5256094.34693	10
80	528288.67460	5253230.12826	36
107	527650.00000	5254831.00000	
108	528563.00000	5255042.00000	
109	527644.00000	5255422.00000	
110	528107.00000	5254110.00000	
111	526767.00000	5255133.00000	
101	523686.00000	5259444.00000	
102	522738.00000	5258775.00000	
103	522100.00000	5259295.00000	
104	523018.00000	5259877.00000	
105	518637.00000	5267062.00000	
106	519234.00000	5266389.00000	
a	538870.00000	5248189.00000	
b	538190.00000	5248520.00000	
c	537433.00000	5218189.00000	
d	536056.00000	5248562.00000	
e	536579.00000	5247100.00000	
f	535256.00000	5245895.00000	
g	536280.00000	5245180.00000	
h	534616.00000	5244059.00000	
i	535352.00000	5242715.00000	
l	538073.00000	5241189.00000	
m	536718.00000	5238063.00000	
n	535831.00000	5236136.00000	
o	537678.00000	5236622.00000	