Mapping sub-tidal habitats in the Eastern Port of Port Stephens

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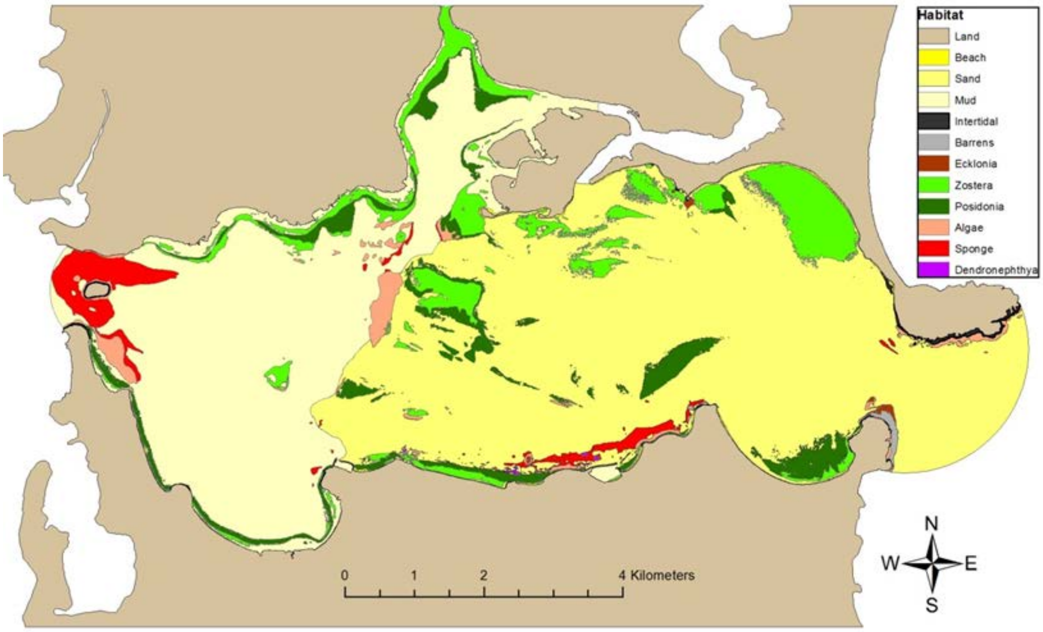

Final report to the Hunter Local Land Services

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Executive Summary

The Port Stephens estuary is an important location for commercial and recreational fishing, and for marine tourism especially dolphin watching and scuba diving. Within the estuary, sub-tidal habitats at depths of more than ten metres had not previously been fully described and a broad scale assessment of estuarine habitats in the Eastern Port of Port Stephens was therefore conducted. The assessment was based on aerial photography, and over 130km of towed video transects, covering an area exceeding 50 km^2.

The study identified nine distinct habitats occurring within the Eastern Port of Port Stephens with: two habitats dominated by seagrass species; two habitats dominated by filter feeders; three habitats dominated by macroalgae; and two habitats with minimal benthic cover. Maps of the geographical extent of these habitats were generated containing details of extensive newly identified areas of macroalgal and filter feeder dominated habitats. Valuable information on changes in the distribution of the *Dendronephthya australis* soft coral habitat was also obtained, along with details of changes to the distributions of seagrass species within the Eastern Port. In addition to the mapping of Port Stephens, some initial mapping was undertaken in Wallis Lake, Forster, to determine the viability of this mapping method being applied in another estuarine environment.

This study provides important new data on habitats occurring within Port Stephens and their extent, which can be used to help inform future zoning reviews of the Port Stephens-Great Lakes Marine Park. Improved zoning will ensure a better level of protection for all habitats occurring within the Eastern Port of Port Stephens, and thereby help to preserve biodiversity of marine species that occur within, and rely upon, those habitats for food and shelter.

1 Introduction

1.1 Habitat mapping in New South Wales

In New South Wales (NSW) the state government is currently implementing a new approach to managing the NSW Marine Estate (NSWDPI, 2013), and mapping marine habitats is increasingly being used in this process, with maps showing the extent, structure and distribution of marine habitats consequently required (Dixon-Bridges *et al.*, 2013). Previously the majority of habitat-mapping effort in NSW has focused on fully marine habitats (Jordan *et al.*, 2010b), and shallow (<10 m deep) aquatic vegetated habitats in estuaries (mangroves, seagrass and saltmarsh) (Creese *et al.*, 2009). Shallow estuarine habitats were mapped using aerial photography, with the primary objective of mapping seagrass which in most NSW estuaries is rarely below 5m (Creese *et al.*, 2009), however the type and extent of deeper habitats in estuaries (i.e. at depths >10 m) remain largely unquantified.

1.2 Habitat mapping in Port Stephens

The Port Stephens estuary is classified as a tide-dominated drowned river valley (Roy *et al.*, 2001) and the entire estuary is contained within the Port Stephens-Great Lakes Marine Park (PSGLMP) which is the largest marine park in NSW, covering approximately 98,000 hectares. The PSGLMP has multiple zoning categories, with different activities permitted within each category, and about 18% of the park is currently classified as sanctuary zone where all extractive activities are prohibited (NSWMPA, 2010a).

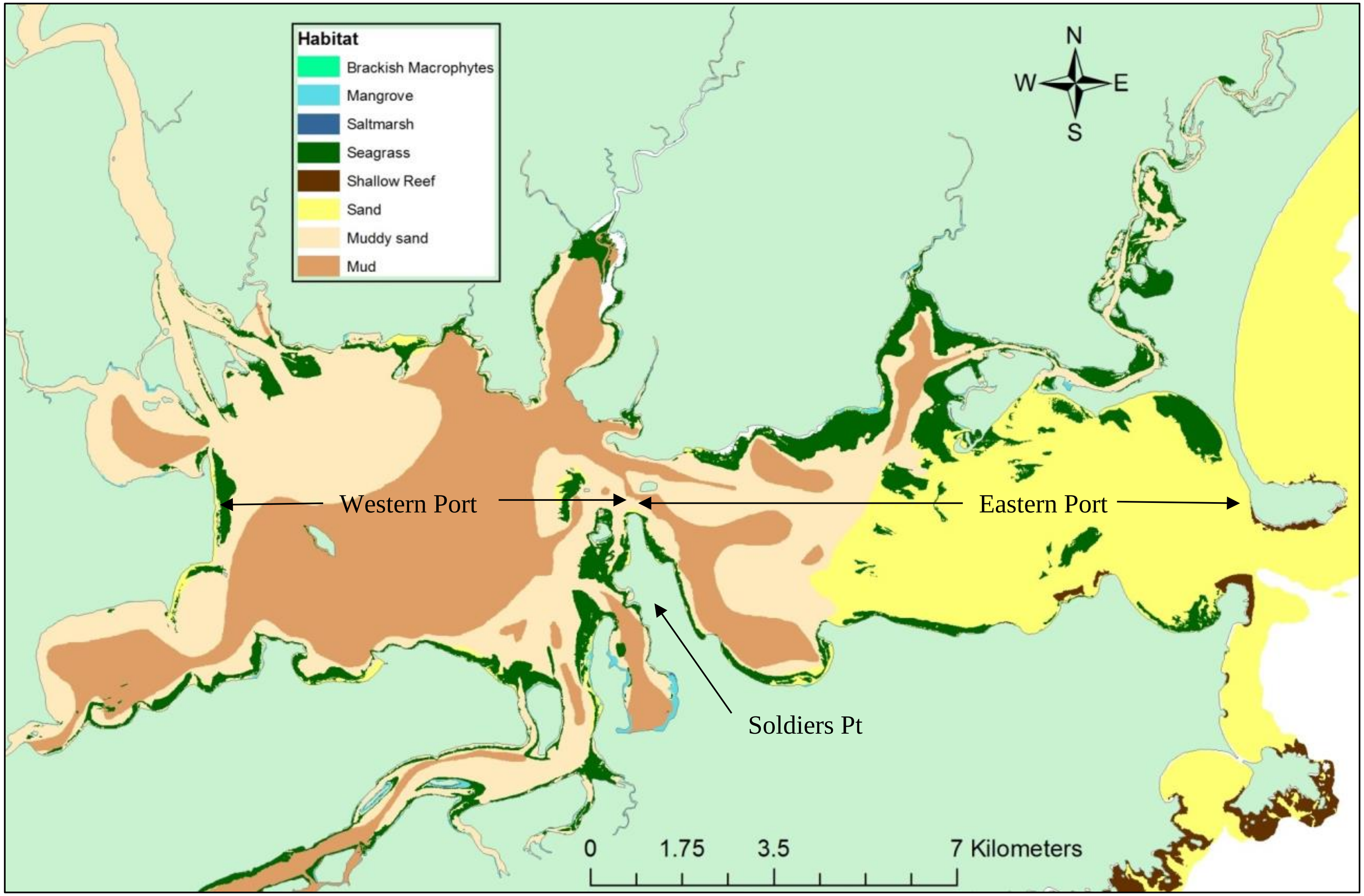
The estuary is divided into Eastern and Western Ports by Soldiers Pt (Figure 1), and this study has focussed primarily on classifying and mapping sub-tidal habitats within the Eastern Port as this section of the estuary contains the majority of the known areas of deep water marine habitats (i.e. sponge gardens and *Dendronephthya australis* soft corals (Poulos *et al.*, 2013)). The Eastern Port is approximately 12 km in length and 5 km wide with an area exceeding 50 km^2 and contains areas of deep water (i.e. depths of up to forty metres) (DPWS, 1998). Large tidal flows ensure that salinity levels within the Eastern Port are essentially marine (i.e. 35 to 35.5 psu) (DPWS, 1998), and the port can therefore be classified as a marine tidal delta (Roy *et al.*, 2001). The Eastern Port is known to support a high diversity of biota (Smith *et al.*, 2010), and to contain a range of habitats, some of which are thought to be unique (Carraro and Gladstone, 2006; Poulos *et al.*, 2013). Information on aquatic vegetated habitats (Creese *et al.*, 2009), and sediment types (Roy and Matthei, 1996; Roy *et al.*, 2001) is available, but knowledge of benthic habitats occurring in deeper sections of the estuary is limited (Figure 1). Mapping the extent of the soft coral *D. australis* and adjacent areas of sponge habitat has been conducted along the southern shoreline of the Eastern Port (Poulos, 2011; Poulos *et al.*, 2015), but deeper areas in the remainder of the estuary have not been examined. In addition existing habitat maps are no longer current as they were developed between 1996 and 2011, and substantial changes have occurred in the estuarine system over this period, particularly due to sand movement (Austin *et al.*, 2009; Vila-Concejo *et al.*, 2011; Wainwright, 2011).

1.3 Project objectives

The Port Stephens estuary is an important location for commercial and recreational fisheries (NSWMPA, 2010a), and for marine tourism, especially dolphin watching (Allen *et al.*, 2007), and scuba diving (NSWMPA, 2010a). There is therefore a clear need to develop a better understanding of deeper benthic habitats within the estuary, so that they can be adequately protected within the PSGLMP. Of particular interest is the extent of the soft-coral (*Dendronephthya australis*) habitat that is only believed to occur in large abundance within the Hunter region, particularly in Port Stephens (Poulos *et al.*, 2013) and is a recognised habitat for protected species (Harasti *et al.*, 2012; Harasti *et al.*, 2014). The soft-coral habitat is considered to be under threat from anthropogenic impacts (anchor damage, fishing line entanglement) (Harasti *et al.*, 2014) and from increasing sedimentation and potentially poor water quality (Poulos, 2011).

The main objectives of this project were: to identify major sub-tidal habitats within the Eastern Port of the Port Stephens estuary; and to generate a Geographic Information Systems (GIS) map showing the extent of the identified habitats within the Eastern Port.

Figure 1: Pre-existing habitat map for the Port Stephens Estuary showing Eastern and Western Ports (GIS data from NSW DPI)



2 Habitat classification for the Eastern Port

Implementing protection of representative areas of marine ecosystems requires information about the diversity of types of habitats, and their extent (Cicin-Sain and Belfiore, 2005). This information-gathering process typically makes use of a Habitat Classification System (HCS) that divides the continuously varying marine environment into categories based on dominant characteristics (Diaz *et al.*, 2004; Last *et al.*, 2010; Malcolm *et al.*, 2011). Ideally a HCS should be exhaustive, describing all habitats within a region, and should use categories that are easily identifiable, mutually exclusive, and which provide sufficient detail for effective management (Ball *et al.*, 2006).

HCSs are strongly dependent on the size of the area being assessed and, at a local level, variation in biological assemblages over relatively small distances become important, particularly when habitats contain protected or threatened species (Last *et al.*, 2010). For example, the distribution of the protected sea horse species *Hippocampus whitei*, within the Port Stephens estuary, is closely linked to the distribution of sponge and soft coral habitats (Harasti *et al.*, 2014). The term "benthic habitat" has been defined as the place where a plant or animal is ordinarily found (Diaz et al. 2004), and when conservation of biodiversity is a primary objective, HCSs should ideally be based on benthic habitats, incorporating both the physical structure of the seabed, and the biological assemblages that dwell there (Last *et al.*, 2010; Bianchi *et al.*, 2012).

NSW marine HCSs have focusing primarily on substrate type (i.e. reef or unconsolidated substrate), and depth (Malcolm *et al.*, 2010; Malcolm *et al.*, 2011) due to the difficulties associated with determining benthic habitats using swath acoustics, which has been the primary tool for marine habitat mapping within NSW (Jordan *et al.*, 2010b; NSWMPA, 2010b). NSW estuarine HCSs have focussed primarily on shallow aquatic vegetated habitats (i.e. mangroves, seagrass and saltmarsh) due to the difficulties associated with distinguishing deeper habitats within estuaries using aerial photography, which has been the primary tool for estuarine habitat mapping within NSW (Creese *et al.*, 2009). As the Eastern Port contains a mixture of both marine and estuarine habitats (Creese *et al.*, 2009; Poulos *et al.*, 2013), and these habitats occur in both shallow and deep waters, it was necessary to develop a new HCS to fully describe benthic habitats occurring within the estuary.

2.1 Development of a new estuarine Habitat Classification System

Within Australia, the Interim Australian National Aquatic Ecosystem (ANAE) Classification Framework has been established with the objective of ensuring national consistency in classifying marine habitats (AETG, 2012). The Interim ANAE Classification Framework specifies that the National Intertidal Subtidal Benthic (NISB) HCS (Mount *et al.*, 2007) should be used for classifying benthic habitats, based on coverage of structural macrobiota, where structural macrobiota are 'sessile habitat-forming species that, by their presence, increase spatial complexity and alter local environmental conditions, often facilitating a diversified assemblage of organisms' (Lilley and Schiel, 2006). The NISB HCS uses a hierarchical system with broad habitat classes, which can be subdivided by biotic modifiers where these are required to provide sufficient detail for management (Mount *et al.*, 2007).

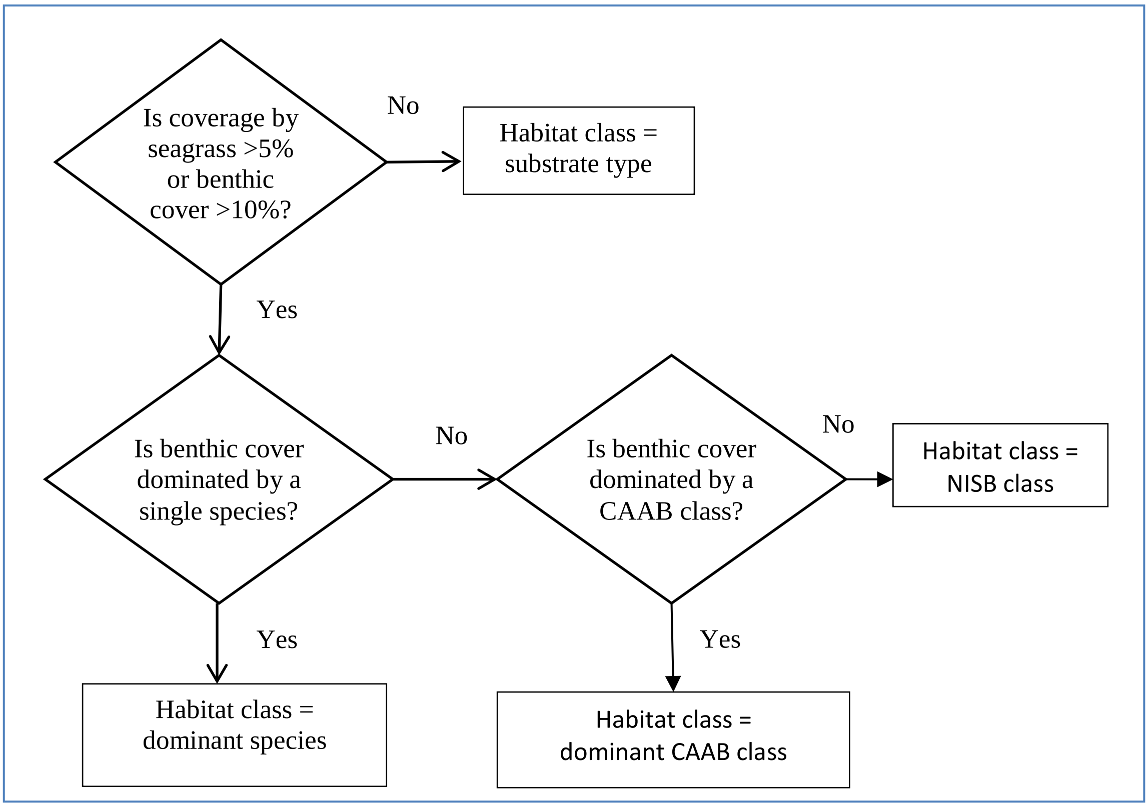
Within Port Stephens the broad structural macrobiota classes contained within the NISB (i.e. seagrass, macroalgae, filter feeders) do not allow discrimination between some of the seagrass and filter feeder habitats known to occur within the Eastern Port (Creese *et al.*, 2009; Poulos *et al.*, 2013), and there was therefore a need to determine suitable modifiers (i.e. benthic habitats classes) to use within the NISB HCS.

2.2 Habitat classification methodology

A preliminary assessment of benthic habitats, conducted in July 2014, identified that differentiation between distinctly different benthic habitats could be made on the basis of dominant species, or dominant groups of species, with species and species groups classified using Codes for Australian Aquatic Biota (CAAB) from the Collaborative and Annotation Tools for Analysis of Marine Imagery and video (CATAMI) classification system (CATAMI, 2013).

Using this differentiation technique a visual habitat classification methodology was developed, based on the NISB HCS framework, with biotic modifiers determined using dominant species and species groups (CAAB classes) (Figure 2). The modified NISB HCS methodology uses a hierarchical system with habitats initially classified by substrate coverage (i.e. covered or uncovered by structural macrobiota), with covered habitats having >5% cover by seagrass, or >10% benthic cover as specified in the NISB HCS (Mount *et al.*, 2007). Covered habitats are then sub-divided on the basis of dominance by species or by CAAB classes, with dominance defined as occurring when a species or class covers the largest proportion of the substrate (Mount *et al.*, 2007).

Figure 2: Visual habitat classification methodology based on the National Intertidal/Subtidal Benthic (NISB) Habitat Classification System with modifiers based on; dominance by individual species; or CATAMI Codes for Australian Aquatic Biota (CAAB) classes



2.3 Habitat Classification System for the Eastern Port

The habitat classification methodology developed for the Eastern Port was applied to all available benthic habitat data, including: existing habitat maps; aerial photographs; preliminary habitat assessment data; and towed video data. This review resulted in the development of a new Eastern Port HCS containing nine distinct benthic habitats;

- "*Posidonia*" habitat, dominated by the seagrass *Posidonia australis* (Figure 3)

- "*Zostera/Halophila"* habitat dominated by the seagrass species *Zostera capricorni* and *Halophila ovalis.* Areas containing these two species were combined into a single habitat within the classification system as: these species were often found in mixed assemblages (e.g. Figure 4); these species grow close to the seabed and are considered to provide less structural habitat than *Posidonia* (Creese *et al.*, 2009); and distinguishing between these species in available aerial photographs was not possible.
- "*Ecklonia*" habitat, dominated by mono-specific stands of the macroalgae *Ecklonia radiata* (i.e. kelp) (Figure 5)
- "Branching algae" habitat, dominated by a mixture of erect coarse branching algae, primarily red algal species, but containing branching brown algae (e.g. *Sargassum* sp.), and green algae (e.g. *Caulerpa* sp.). This habitat may also contain canopy forming algae (e.g *Ecklonia radiata*), fine branching algae, filamentous algae, and filter feeders in lower abundance (Figure 6)
- "Sponge" habitat dominated by sponges in a variety of growth forms (e.g. branching, massive, encrusting), with other classes of filter feeders (i.e. ascidians, hydroids, bryozoans, corals) and macroalgae present in lower abundance (Figure 7)
- "*Dendronephthya"* habitat dominated by mono-specific stands of the soft coral species *Dendronephthya australis,* with other filter feeders and macroalgae present in lower abundance (Figure 8)
- *"Barrens"* habitat with rocky substrate dominated by encrusting calcareous algae, with high abundances of the urchin *Centrostephanus rodgersii* (Figure 9)
- "Sand" habitat dominated by sand with minimal benthic cover (Figure 10)
- "Mud" habitat consisting of bioturbated mud with numerous burrows, but with minimal benthic cover (Figure 11)

Figure 3: Posidonia habitat off Little Beach

Figure 4: *Zostera*/*Halophila* habitat off Dutchies Beach

Figure 5: *Ecklonia* habitat off Nelson Bay

Figure 6: Branching algae habitat off Fly Point

Figure 7: Sponge habitat off Fly Point

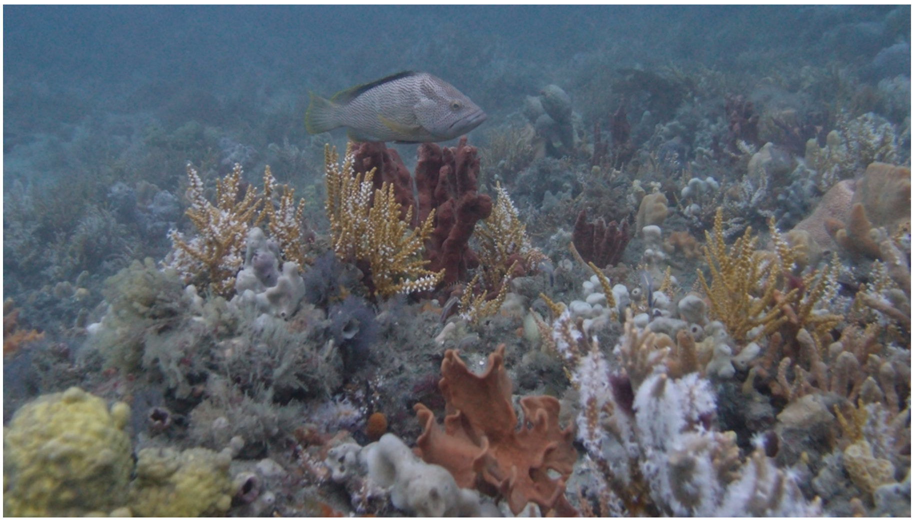
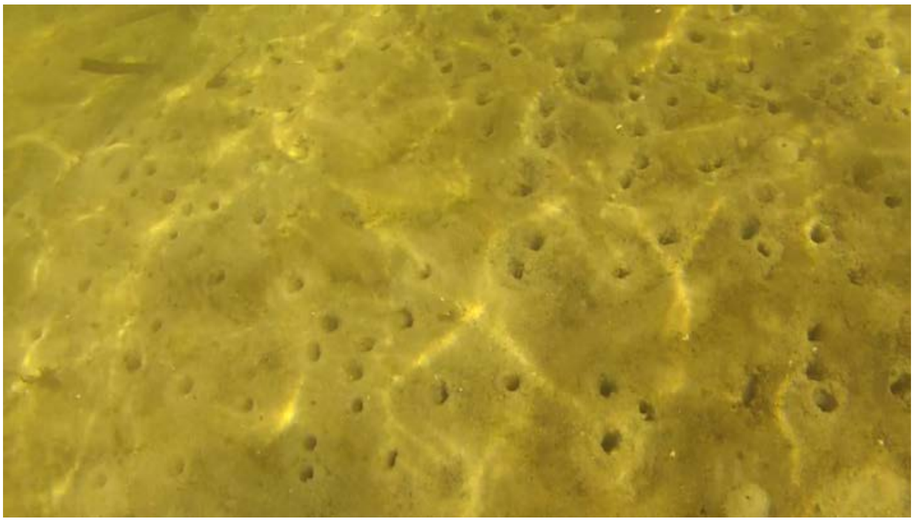


Figure 8: *Dendronephthya australis* habitat off Nelson Bay

Figure 9: Barrens habitat off Tomaree Head

Figure 10: Sand habitat off Nelson Bay

Figure 11: Mud habitat off Salamander Bay



3 Habitat map generation for the Eastern Port

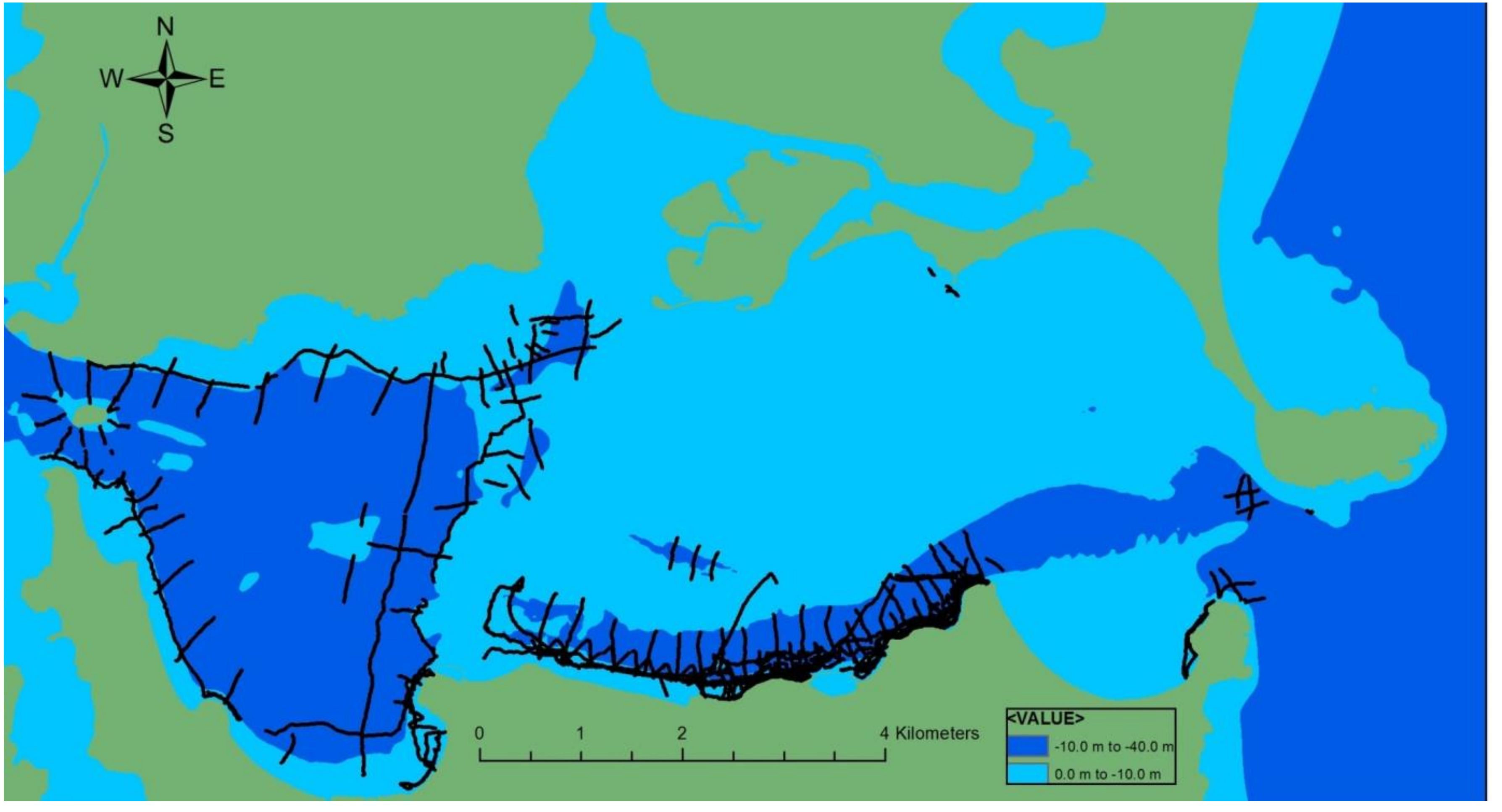
Mapping sub-tidal estuarine habitats can be conducted using a range of methods, with the most appropriate technique dependent on depth, turbidity, and availability of the necessary equipment. The total area of the Eastern Port of the Port Stephens estuary exceeds 50km^2, with approximately 35km^2 covered by relatively shallow water (i.e. <10m depth) and approximately15km^2 having water depths >10m (Figure 12).

3.1 Identifying shallow habitats (<10m deep) using aerial photography

Areas of the Eastern Port covered by relatively shallow water were mapped using high-resolution (7.5cm), georeferenced aerial photographs, for 9 August 2014, from Nearmap Limited (Nearmap, 2014). Habitat boundaries distinguishable in the Nearmap photographs were digitised in ArcMap (ESRI, 2014) at a scale of 1:1500 using the methodology developed for previous mapping of aquatic habitats in the estuary (Creese *et al.*, 2009). The following decision rules were used to map shallow areas of the Eastern Port from the aerial photographs;

1. Where towed video data was available this was used to ground truth habitat type
2. Where towed video data was not available, habitat type was determined from the previous aquatic vegetated habitat map for the estuary (Creese *et al.*, 2009)
3. Habitat boundaries between *Posidonia* and *Zostera/Halophila* habitats were distinguished using the visible colour difference between these habitats in aerial photographs

Figure 12: Map of Port Stephens Eastern Port showing shallow areas in light blue (Depth <10m), and deep areas in dark blue (Depth >10m), black lines = locations of towed video transects conducted for habitat mapping (~130km)

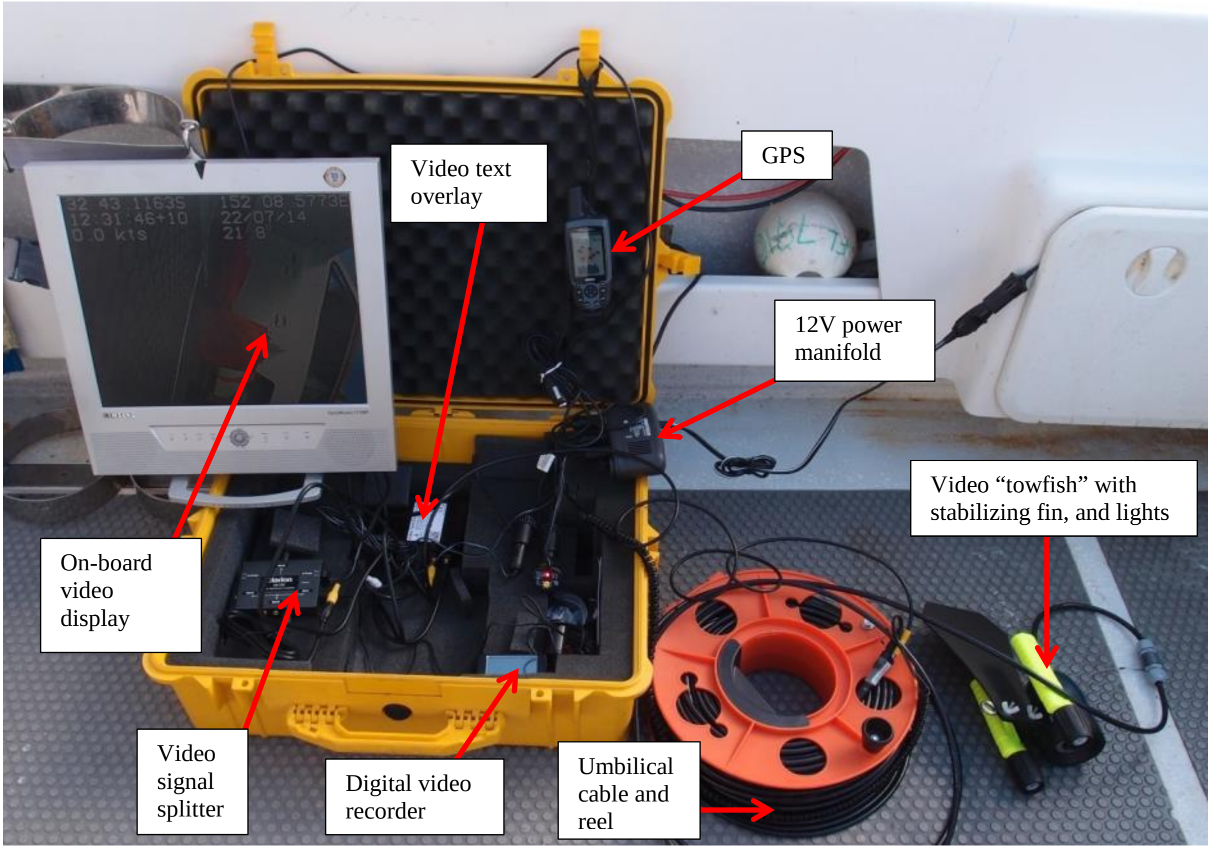


3.2 Identifying deeper habitats (>10m deep) using towed video

Areas of the Eastern Port having water depths >10m could not be mapped using aerial photos, due to depth and water turbidity preventing there being any visible sign of sub-tidal habitats. As the intent of this mapping program was to develop a map detailing the type and extent of benthic habitats, mapping could not be conducted using acoustic techniques, as these techniques have limited ability to distinguish between benthic growth types (Jordan *et al.*, 2010a). Therefore a sub-surface visual technique was required for mapping, and a towed video system deployed by boat was selected as the most appropriate available technology for mapping deeper sections of the estuary.

An initial field trial was conducted using the NSW Department of Primary Industries towed video system (Figure 13). This system consisted of a DeepBlue Splashcam standard definition video camera (towfish) with an umbilical cable connected to a monitor and video overlay unit. The overlay unit overlaid time and Global Positioning System (GPS) coordinates on each frame of the video from a Garmin GPSmap 60C, and output the resulting video to a digital video recorder. The towfish was deployed by hand over the side of a boat while watching the output of the video on a monitor. The video was oriented to point down and forward at an angle of approximately 45 degrees, and was held at a distance of approximately 1m from the seafloor by manually deploying and retrieving the umbilical cable. The field trial identified that habitat mapping could be conducted within the estuary using this system, and helped to determine the most effective approach for mapping the required area.

Figure 13: NSW Department of Primary Industries towed video system



The trial identified that towing was limited to speeds of 2–3 km/hr, as faster speeds made distinguishing habitats from video footage difficult, and increased difficulties associated with maintaining the correct elevation of the towfish above the substrate. The trial demonstrated that a stratified towing plan could be used to achieve good coverage of habitats within the time available. The stratified towing plan developed involved two mapping stages;

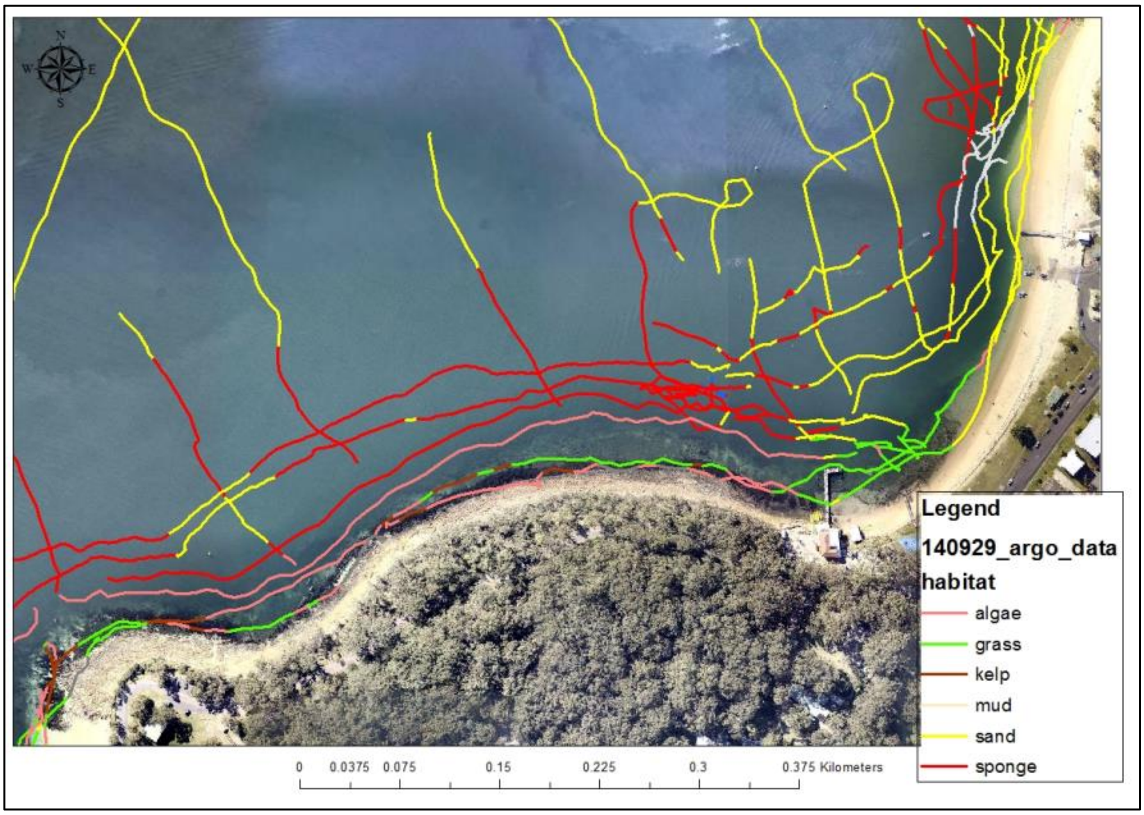
1. Large scale habitat mapping using continuous transects running across all areas deeper than 5m, using video transects spaced at intervals of approximately 500m, to identify regions containing benthic habitats.
2. Detailed habitat mapping, in areas identified as containing benthic habitat, using transects spaced at intervals of 50 m to 100 m, to determine the longitudinal and lateral extent of habitats.

Towed video transects, covering a distance of approximately130km (Figure 12) were conducted between July 2014 and January 2015. Transects were conducted at an average speed of 2.5 km/hr, generating 52 hours of video footage. A total of 44 operational days were required during the 6 month study period as operations were limited by weather, by vessel availability, and by tides, with towed video restricted to 1-2 hours each day at high tide, due to strong tidal currents and low visibility at other times.

3.2.1 Identification and mapping of deeper habitat boundaries

Towed video was assessed on a computer by playing footage back at between one and two times actual speed, and noting habitat types and habitat boundaries as they appeared. Habitats were classified using the habitat classification process developed for this study (i.e. Figure 2). Processing each hour of video footage (~2.5km) required approximately one hour of image analysis to identify habitats and record the location of habitat boundaries. A habitat boundary was defined as any location at which the habitat type visibly changed, and where that change persisted in video footage for a period of at least 10 seconds (i.e. for a distance of approximately 5 m) (Masens, 2009). Video processing generated habitat data in the form of line segments connecting points recorded by the Garmin GPS during towed video operation, with each line segment assigned a habitat type. Line segments were imported into ArcMap allowing visualisation of habitat distributions within the estuary (e.g. Figure 14).

Figure 14: Habitat lines from towed video transects overlaid on an aerial photo of Little Beach



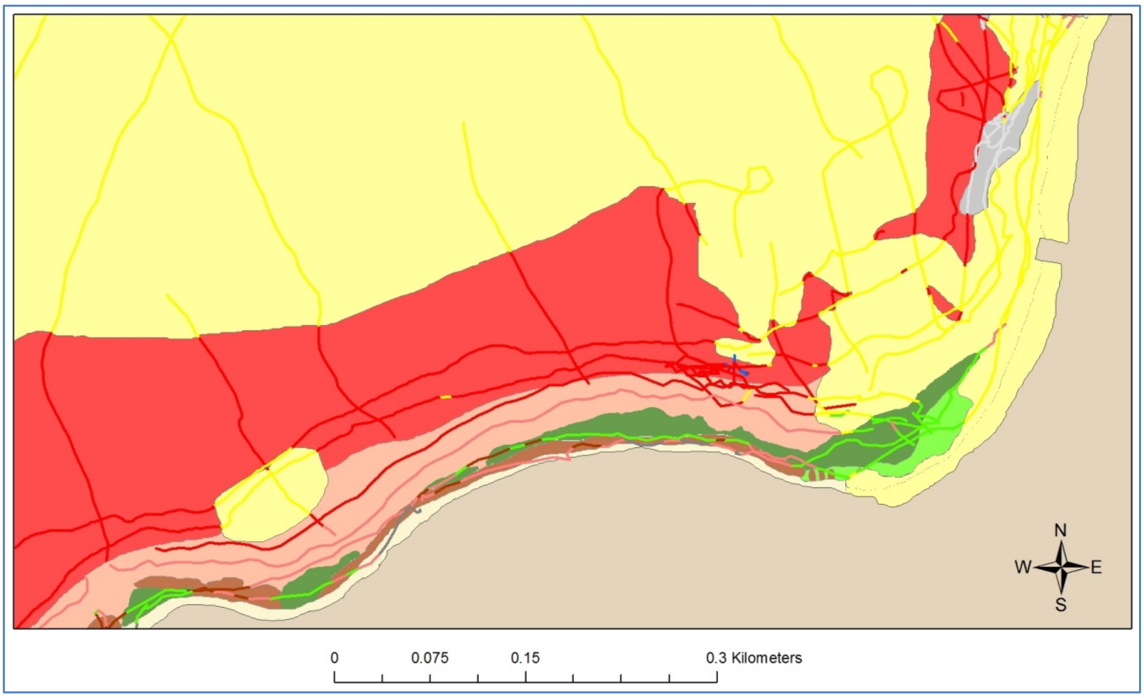
3.2.2 ArcMap GIS map generation for deeper habitats

ArcMap polygons were visually interpolated between habitat lines generated from towed video data (e.g. Figure 15). The following decision rules were applied during map generation for deeper habitats;

1. Polygons were generated by joining adjacent habitat lines displaying the same habitat type.
2. Where visible habitat boundaries could be distinguished from aerial photos these were used to assist with defining polygon boundaries.
3. Where no visible boundaries were present in aerial photos, habitats were assumed to follow the shoreline, with habitat boundaries following depth contours
4. Where intersecting transects were inconsistent (i.e. identified different habitats at a location), the mapped habitat was assigned based on the dominant habitat from other surrounding lines

5. Visual separation of habitats dominated by sponges and branching algae was often difficult due to the complex matrix of species occurring in these assemblages. Therefore, based on the results of the preliminary study, habitats were classified as Branching algae at depths of less than 10m and as Sponge at depths of more than 10m.
6. Small isolated habitat sections (i.e. <5 m long) were not mapped.

Figure 15: Example of habitat polygons generated by interpolation between towed video habitat lines.



4 Sub-tidal habitat maps generated for the Eastern Port

Using the aerial photography and towed video data a sub-tidal habitat map for the Eastern Port was generated covering the Port Stephens estuary from Tomaree Head to Soldiers Pt and to the entrance of the Myall River (Figure 16). The majority of the ~5200 hectares (52km^2) mapped consists of mud and sand with minimal coverage by benthic growth (Table 1).

Table 1: Habitat coverage in the Eastern Port

Habitat Classification	NISB Class	Area (hectares)
Dendronephthya	Filter Feeder	3.2
Ecklonia	Macroalgae	6.8
Barrens	Macroalgae	9.5
Branching algae	Macroalgae	96.2
Sponge	Filter Feeder	132.9
Posidonia	Seagrass	263.4
Zostera/Halophila	Seagrass	420.0
Mud	Uncovered substrate	1640.2
Sand	Uncovered substrate	2631.5
	Total	5203.7

In total 932 hectares of habitat covered by benthic growth was identified, with 683 hectares of seagrass dominated habitats, 136 hectares of filter feeder dominate habitats, and 113 hectares of macroalgae dominated habitats. Barrens habitat was found to be concentrated at Tomaree Head (Figure 17), and at Halifax Point (Figure 18). Beds of *Ecklonia radiata* (kelp) were found scattered along the southern shoreline with a small area of kelp on the northern shore at Jimmys Beach (Figure 19). The majority of the *Dendronephthya australis* (soft coral) habitat was found within close proximity to the southern shore from Nelson Bay to Corlette (Figure 18 and Figure 19). Extensive sponge beds and areas of macroalgae were located in the passage between the Eastern and Western ports (Figure 21).

Figure 16: Habitat map for the Eastern Port of Port Stephens

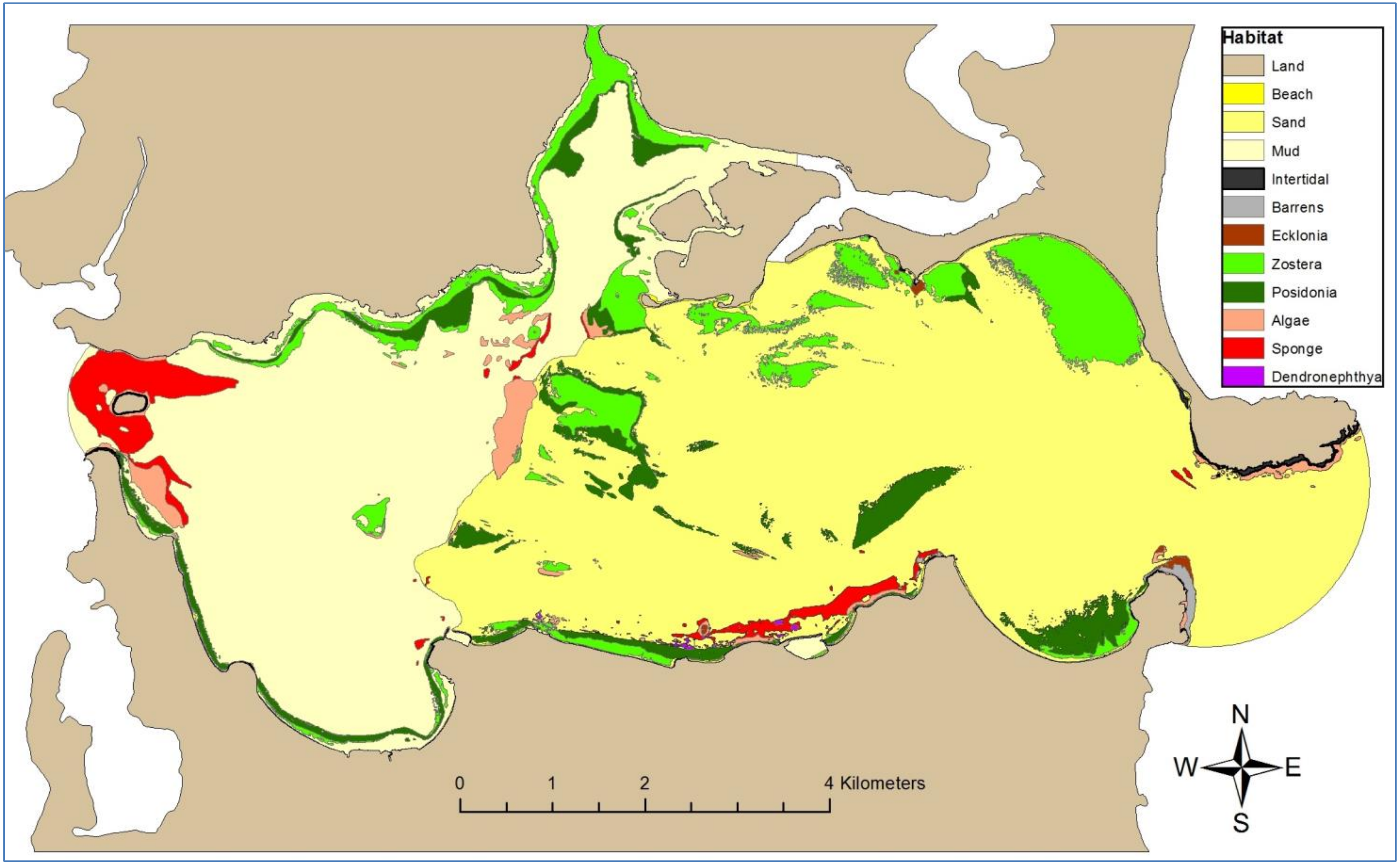


Figure 17: Enlarged habitat map for the Eastern Port entrance and Shoal bay

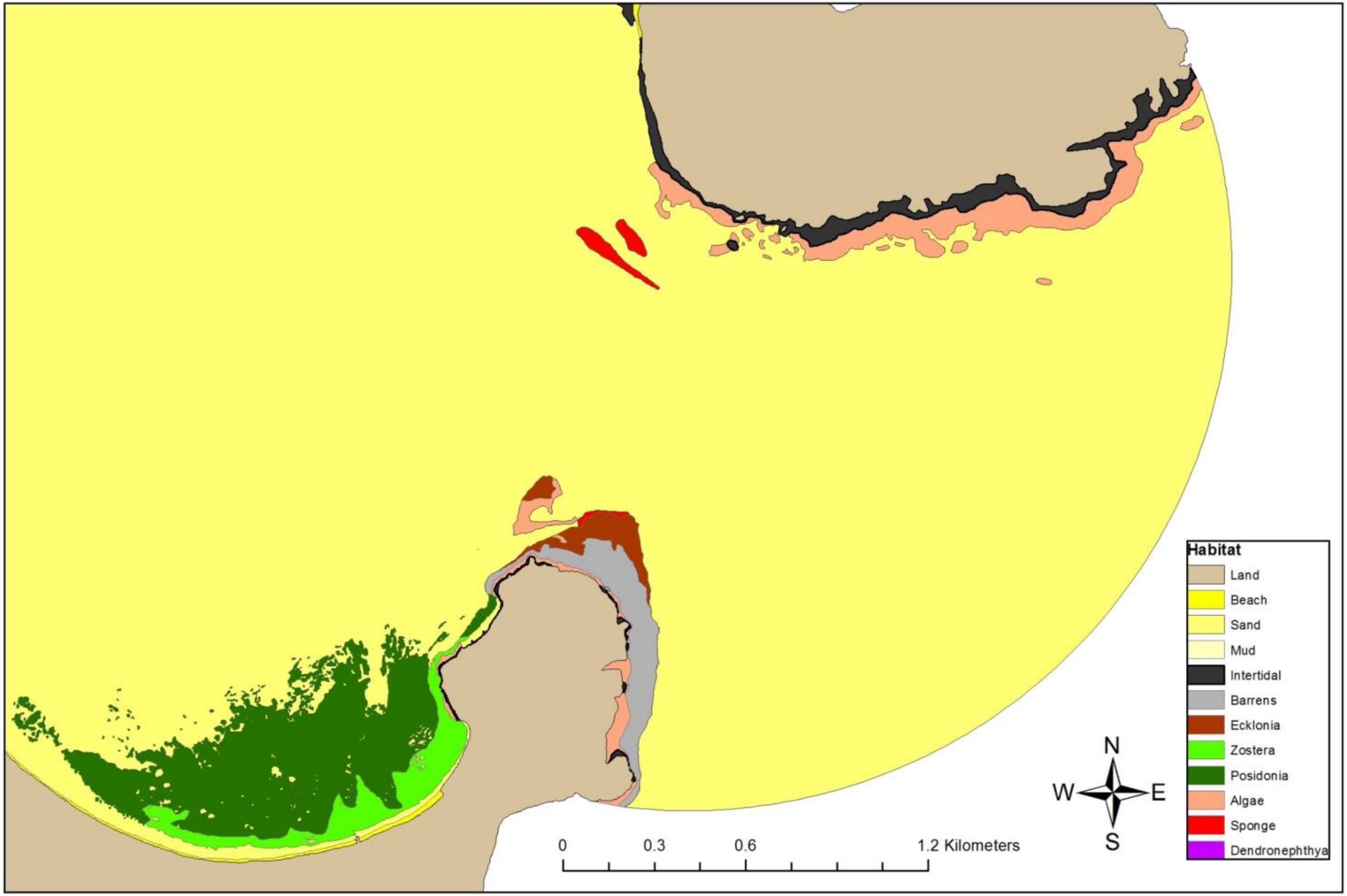


Figure 18: Enlarged habitat map for the Eastern Port southern coast from Halifax Point to Redpatch Point

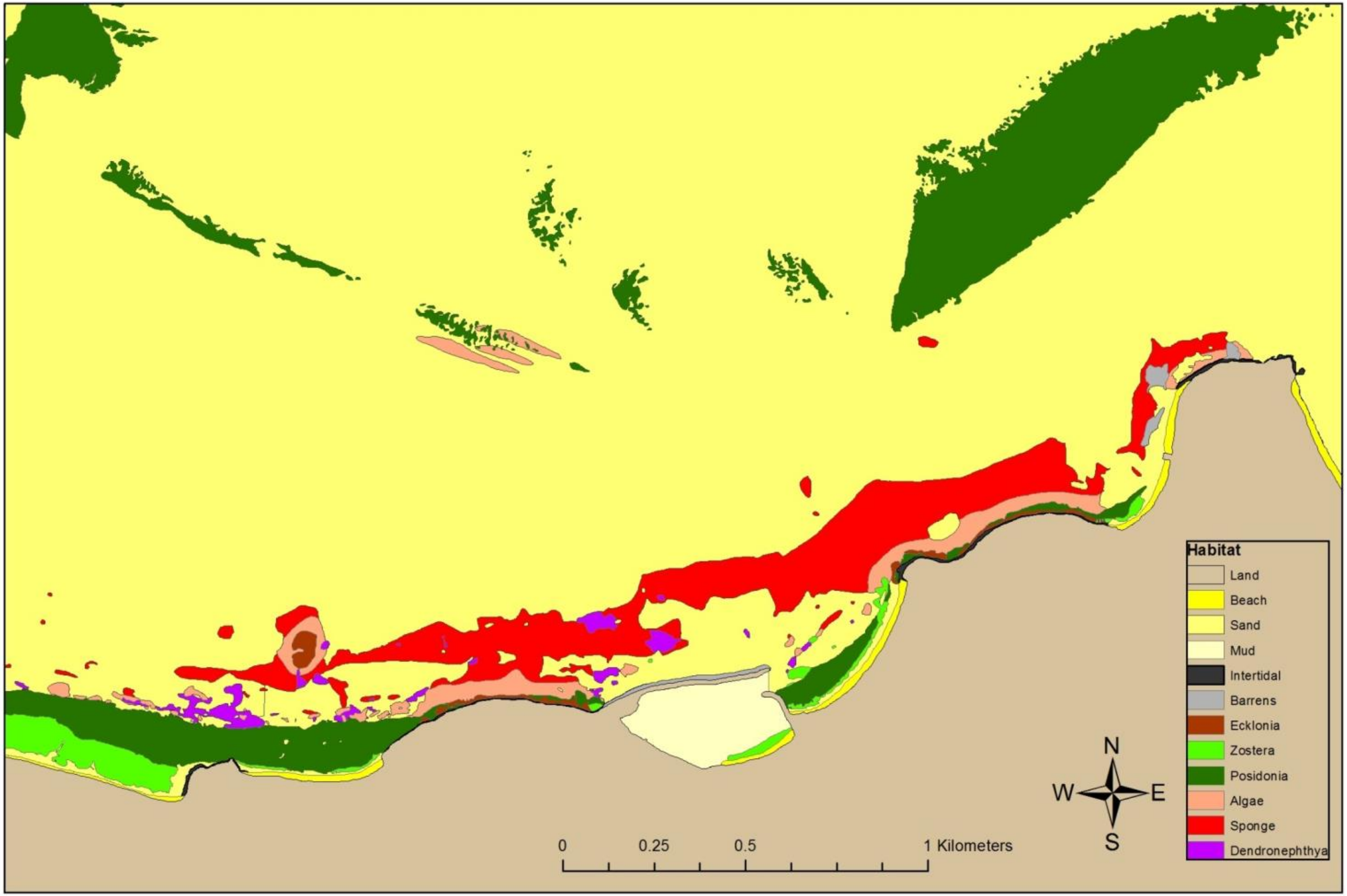


Figure 19: Enlarged habitat map for the Eastern Port southern shoreline from Redpatch Point to Corlette

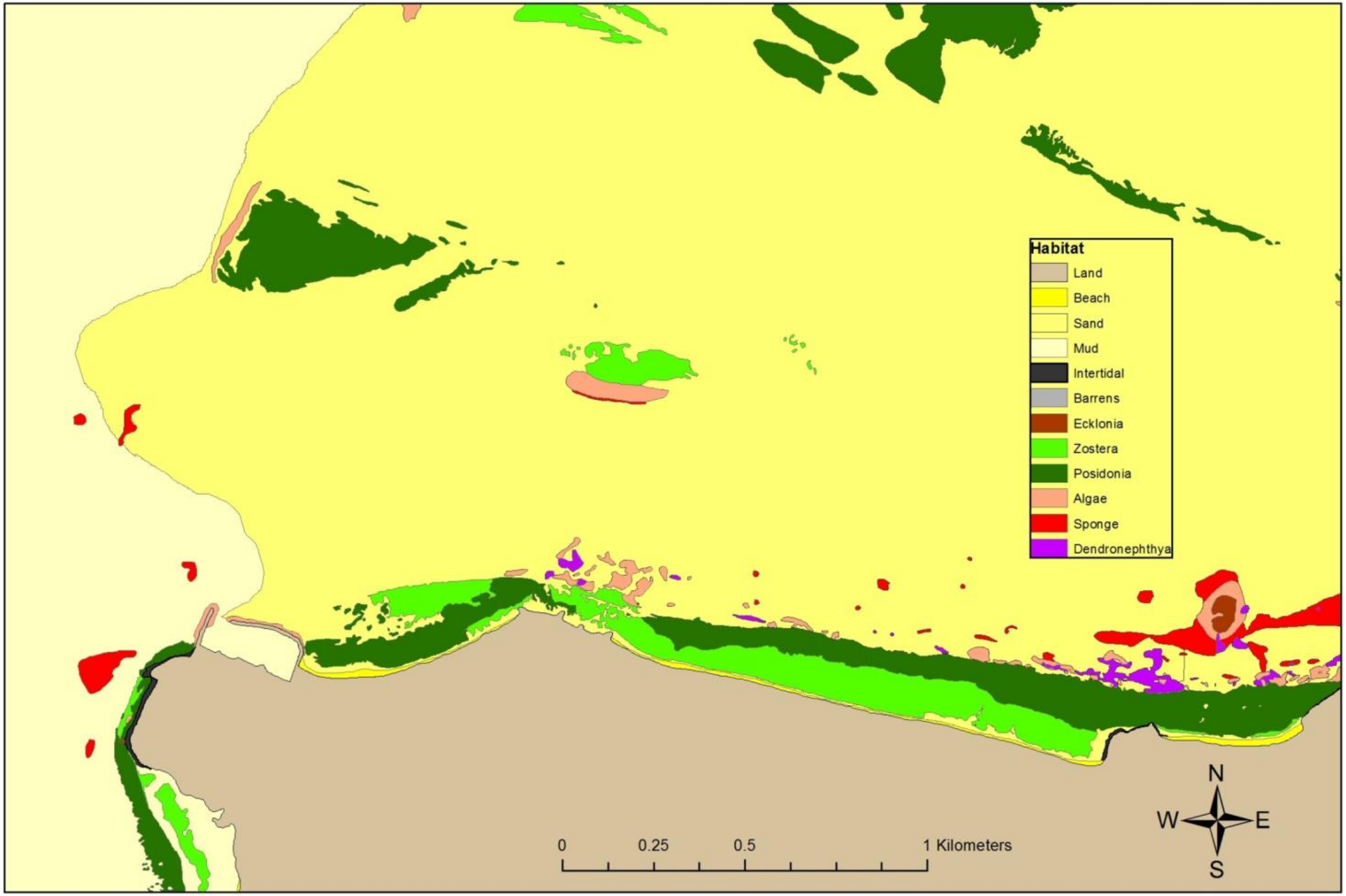


Figure 20: Enlarged habitat map for the Myall River entrance to the Eastern Port

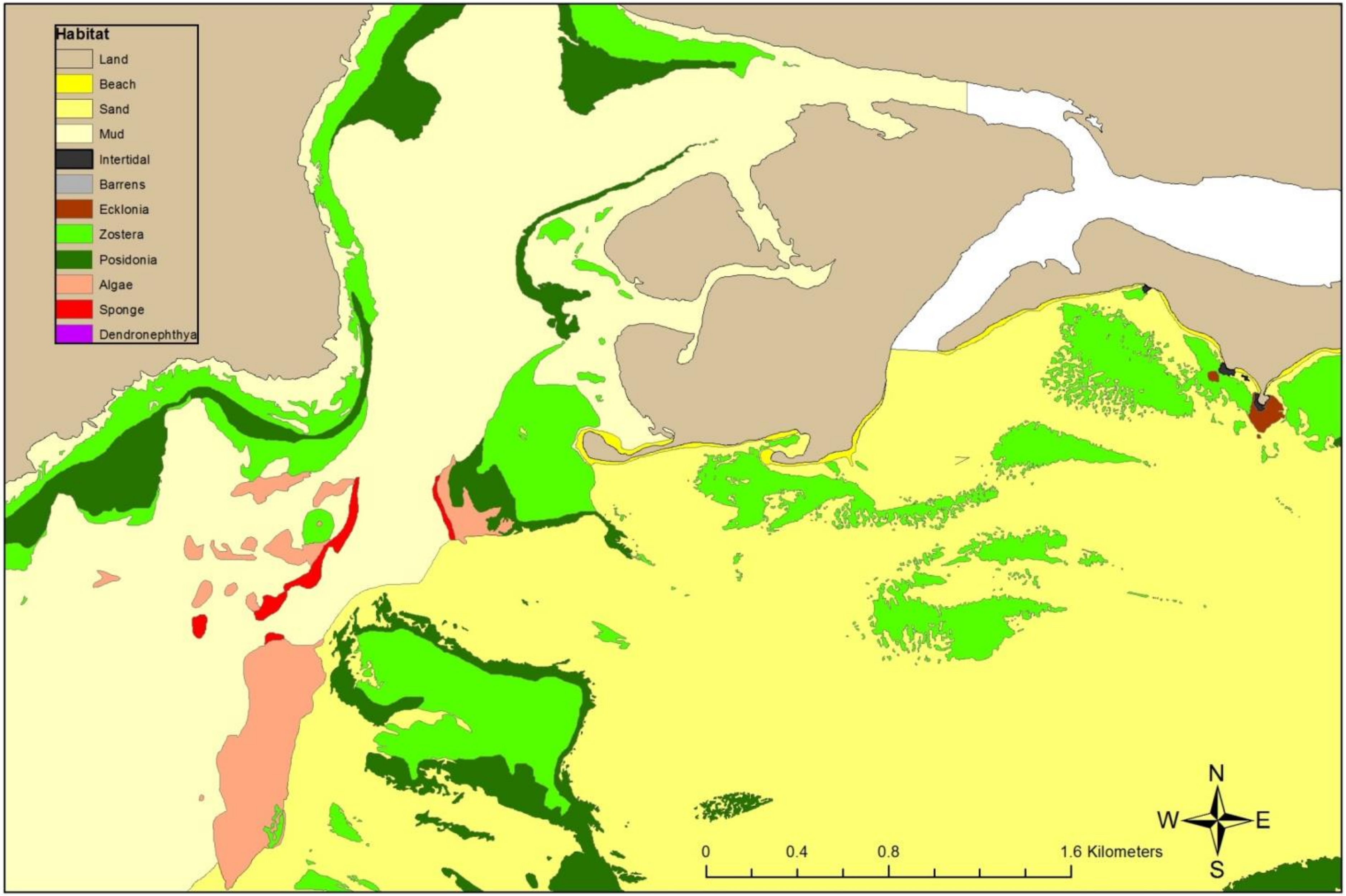
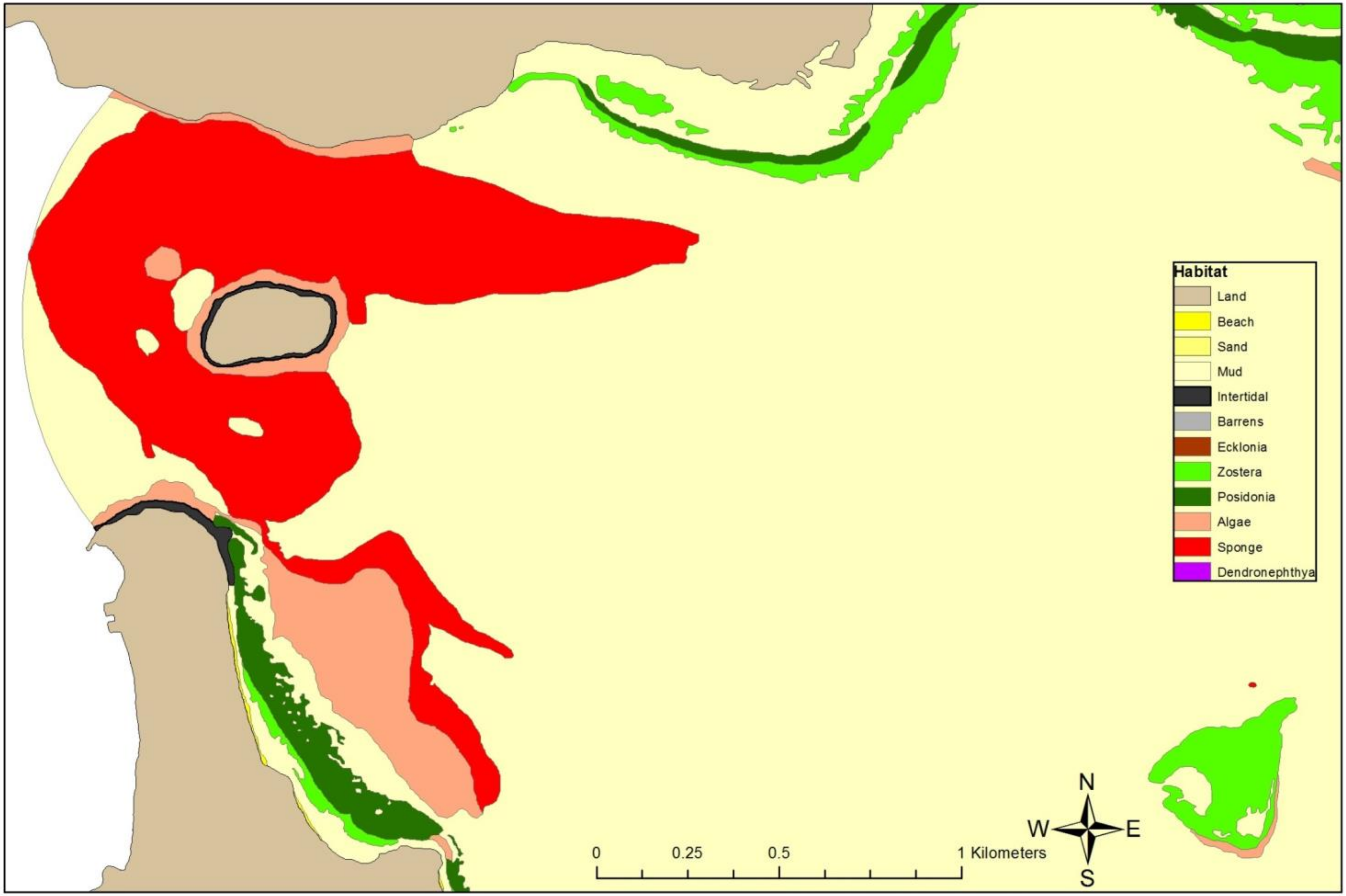


Figure 21: Enlarged habitat map for Soldiers Point and the Western Port entrance



5 Assessment of habitat map accuracy

5.1 Positional accuracy of deep-water habitat boundaries

The positional accuracy of video transects used to define the deep-water habitat boundaries was subject to a number of sources of error including:

- Accuracy of the GPS unit (specified as ±5m for Garmin GPSmap 60C)
- The layback of the towfish behind the boat due to variations in boat speed, current speed, and current direction. Layback was observed to vary from nearly vertical to approximately 45 degrees behind the boat, giving a positional error along transects approximately equal to the water depth.
- Lateral separation between the towfish and the boat due to lateral current flows. Lateral separation was observed to vary approximately 10 degrees either side of the boat giving a positional error across transects of approximately ±20% of the water depth.

Combining these factors gives a positional accuracy dependent on water depth as detailed in Table 2. In theory compensation could have been made during data analysis to reduce layback and lateral positional errors; however, this compensation would have required knowledge of boat speed, boat heading, current speed, current direction, and water depth for each data point. As this data was not all available, no attempt was made to compensate for positional errors during map generation. This was deemed to be acceptable given the large size of most of the habitat areas relative to the magnitude of potential positional errors in the video data.

Table 2: Maximum estimated error in video position calculated by combining error vectors from GPS accuracy, towfish layback, and towfish lateral separation*

Water Depth (m)	Maximum estimated error (m)
5	±10.0
10	±15.1
20	±25.3
40	±45.7

*Maximum estimated error = $\sqrt{(GPS + layback\ errors)^2 + (Lateral\ error)^2}$

5.2 Overall assessment of map accuracy

Assessment of the overall accuracy of the Port Stephens sub-tidal habitat map was conducted in February 2015, using towed video transects and a clustered stratified sampling design (Stehman and Czaplewski, 1998). Sample locations were stratified on the basis of habitat type, with 10 random locations sampled in each of the nine habitat types in the Eastern Port HCS. The use of a stratified design ensured that sufficient data was obtained in all habitats, including rare habitats, to allow adequate assessment of mapping accuracy. In order to reduce the overall cost of the accuracy assessment, samples were clustered within 15 sample areas, systematically located so that they covered all regions of the Eastern Port and all habitat types. Sample areas were 500 m squares, and were spaced at 2.8km longitudinal separations on the northern shoreline, southern shoreline, and through the central section of the estuary (Figure 22).

Within each sample area, samples were separated by a minimum of 20 m, and were situated at least 5 m from mapped habitat boundaries to reduce the impact of positional errors on accuracy estimates. Validation samples were obtained by towing a video over a distance of at least 20 m at each sample location, and a total of 3.8 km of validation samples were collected across all sample areas and habitats.

Validation samples were classified using the HCS methodology developed in this study (Figure 2), with no specific knowledge of mapped habitat types to avoid observer bias. Habitats identified in each validation sample were compared with the underlying map habitats using the intersection tool in ArcMap, and the resulting data was used to calculate a matrix of errors across habitat types using the methodology outlined by Stehman and Czaplewski (Stehman and Czaplewski, 1998). The proportion (P_{vm}) of each validation sample habitat (v) in each mapped habitat class (m) was calculated. The overall proportion of the map correctly classified (P_c) was estimated using the following equation;

$$P_c = \sum_{h=1}^{N} P_{hh} \,.\, A_h / A_{total}$$

Where;

h = habitat type

N = total number of habitat types

P_{hh} = proportion of validation samples of habitat type h overlaying map locations of habitat type h (i.e. the user's accuracy for habitat type h)

A_h = total mapped area of habitat type h

A_{total} = total area of map

Based on the validation samples collected, the overall accuracy of the Eastern Port map was estimated to be 83%. Typical accuracy targets for mapping terrestrial habitats are; overall accuracy of 85%, and accuracy of individual classes of more than 70% (Foody, 2002). Given the additional difficulties associated with mapping sub-tidal marine habitats, when compared with terrestrial habitats, an overall accuracy for the Eastern Port of 83% was deemed to be acceptable. The user's accuracy for individual classes (i.e. the probability that a randomly selected point on the map will be correctly classified) varied with habitat type, ranging from 67% for Mud to 97% for *Posidonia* (Table 3).

Table 3: Error matrix showing the proportion of validation sample habitat types occurring in each mapped habitat type

		Validation sample habitat type								
		Branching algae	Barrens	*D. australis*	*Ecklonia*	Mud	*Posidonia*	Sand	Sponge	*Zostera/ Halophila*
Mapped habitat type	Branching algae	89%				8%		3%		
	Barrens		88%		9%				3%	
	D. australis	1%		73%				8%	2%	16%
	Ecklonia	5%	8%		76%			5%	6%	
	Mud					67%		12%	21%	
	Posidonia						97%			3%
	Sand	1%						94%	4%	1%
	Sponge			2%		23%		1%	74%	
	Zostera/ Halophila	22%			1%		8%			69%

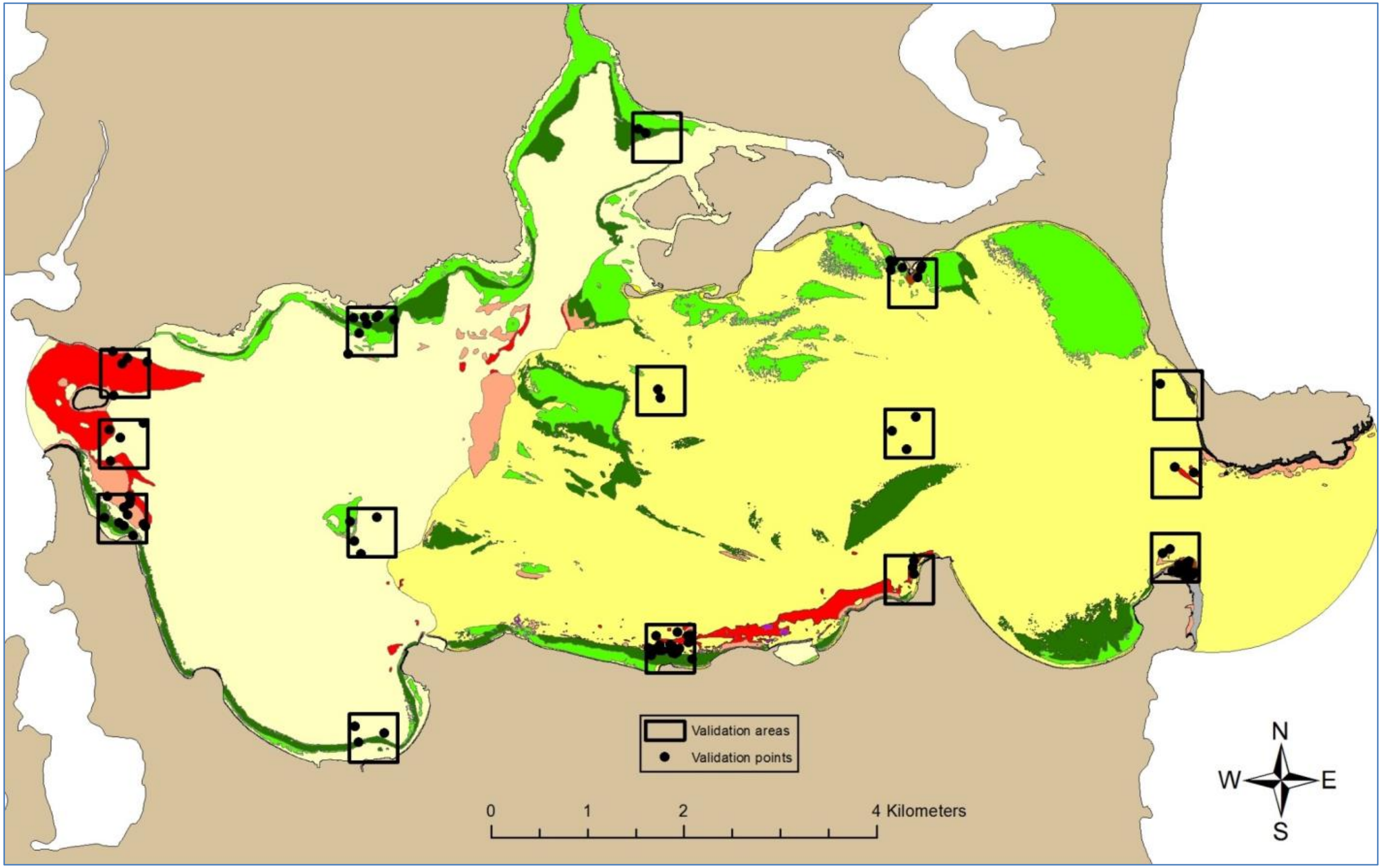
The low user's accuracy for the Mud habitat (67%) was primarily due to high levels of confusion between Mud and Sponge habitats, with 21% of the validation samples on mapped Mud habitat being identified as Sponge, and 23% of the validation samples on mapped Sponge habitat being identified as Mud. The source of this confusion is thought to be mostly due to the depth, turbidity, and low light availability occurring at the boundaries between these two habitats. Increased depth reduces the positional accuracy of the mapped habitat boundaries (see Table 2), while turbidity and low light increase uncertainty in habitat identification at boundaries.

Zostera/Halophila habitat also had a low user's accuracy (69%), and confusion existed between this habitat and Branching algae habitat, with 22% of validation samples on mapped *Zostera/Halophila* habitat being identified as Branching algae. The confusion between these habitats is understandable given that *Zostera/Halophila* and Branching algae were often distinguished from each other using aerial photographs, in combination with an examination of data on seagrass distributions from 2004 (Creese *et al.*, 2009). *Zostera* and *Halophila* are both highly temporally variable and, as the mapping by Creese *et al*. for Port Stephens was done in 2004, it is quite likely that distributions of *Zostera/Halophila* communities will have changed over the intervening period.

5.3 Wallis Lake mapping

In addition to the mapping completed in Port Stephens, baseline mapping was conducted using the same methods, in Wallis Lake, Forster, NSW. Mapping was conducted over 3 days in January 2015 using the towed video system to attempt to identify and reef habitats within Wallis Lake. Habitats were classified using the same habitat classification scheme. Outputs from mapping in Wallis Lake can be seen in Appendix 1a-c.

Figure 22: Eastern Port of Port Stephens, □ = sample areas for map accuracy assessment, ● = random points for accuracy assessment



6 Discussion

Knowledge of the spatial extent of habitats, and of changes that occur in habitat distributions, provides valuable information for management of ecosystems. This study provides new data on the distribution of the *Dendronephthya australis* soft coral habitat within the Eastern Port of Port Stephens, and new data on changes to distributions of seagrass species within the estuary. In addition the study provides baseline data on the spatial extent of a number of previously unclassified habitats within the Eastern Port (i.e. Sponge, Branching algae, Barrens, and *Ecklonia*).

6.1 *Dendronephthya australis* soft coral habitat

A previous study examining the extent of *Dendronephthya australis* habitat within the Eastern Port in 2011, identified a total of 2.9 hectares containing dense patches of *D. australis* (Poulos, 2011). This compares with a total of 3.2 hectares of *D. australis* habitat identified in 2014 during the course of this investigation. However, the survey method used in 2011 differed as it involved a diver video towed GPS system which is considered to be more accurate for mapping the *D. australis* habitat as the diver was able to map the boundaries more accurately (Poulos *et al*., 2015). A statistical comparison between the extents of dense stands of *D. australis* from these two studies is not practical due to the two different survey methods; however, it is obvious from the 2014 mapping there has been a reduction in the extent of this habitat in some areas, particularly in the depth range 5 m to 10m at Nelsons Bay (Figure 23). The observed reduction in cover at Nelson Bay has been offset by an increase in the identified extent of *D. australis* at Dutchies Beach (Figure 24), and Bagnalls Beach (Figure 25).

All *D. australis* habitat identified in this study occurred along a four kilometre stretch of the southern shore of the Eastern Port between Fly Point and Corlette Point. The mapping study did not identify any new regions within the Eastern Port, outside of this area, that contained dense stands of *D. australis*. *Dendronephthya australis* corals are azooxanthellate, feeding primarily on small (i.e. < 20 micron) organic matter, and they are reported to grow best in areas where they are exposed to strong and consistent currents, but are not exposed to wave action (Fabricius and Alderslade, 2001). The areas were soft corals were located within the Eastern Port are consistent with these requirements, as the major tidal flows within the estuary are along the southern shoreline (Jiang *et al*., 2011), and all areas of dense soft corals were found more than four kilometres from the estuary entrance, and therefore were isolated from waves entering the estuary.

Figure 23: Changes in *Dendronephthya australis* habitat at Nelsons Bay from 2011 to 2014

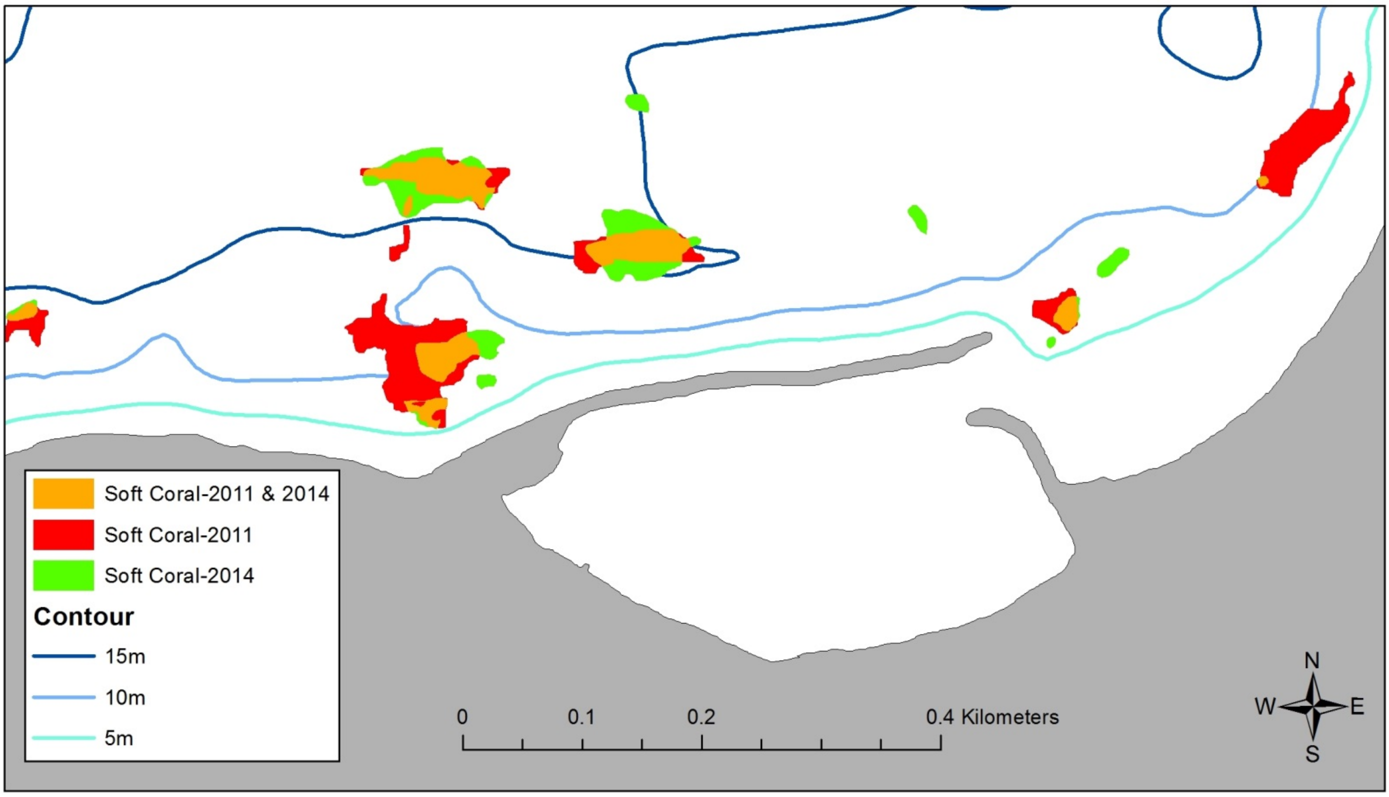


Figure 24: Changes in *Dendronephthya australis* habitat at Dutchies Beach from 2011 to 2014

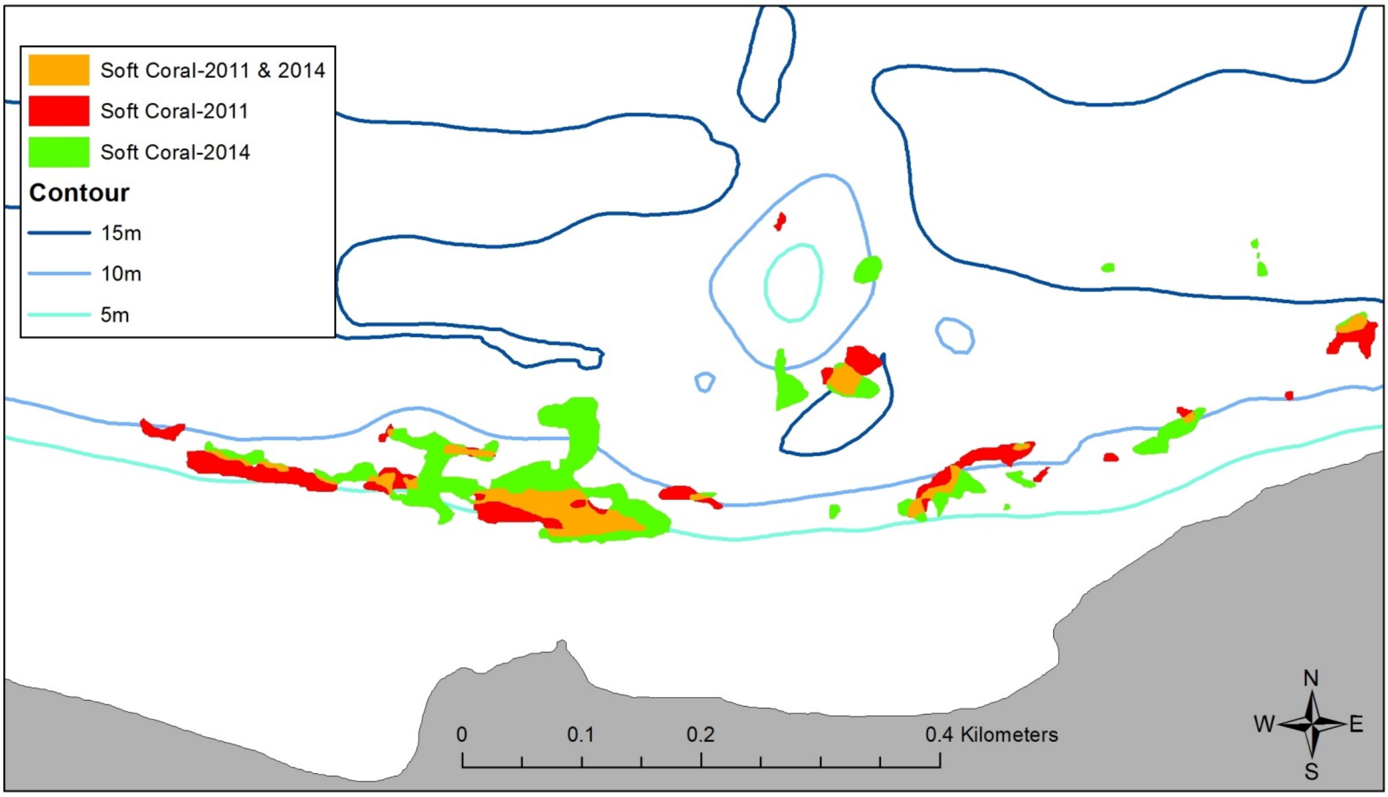
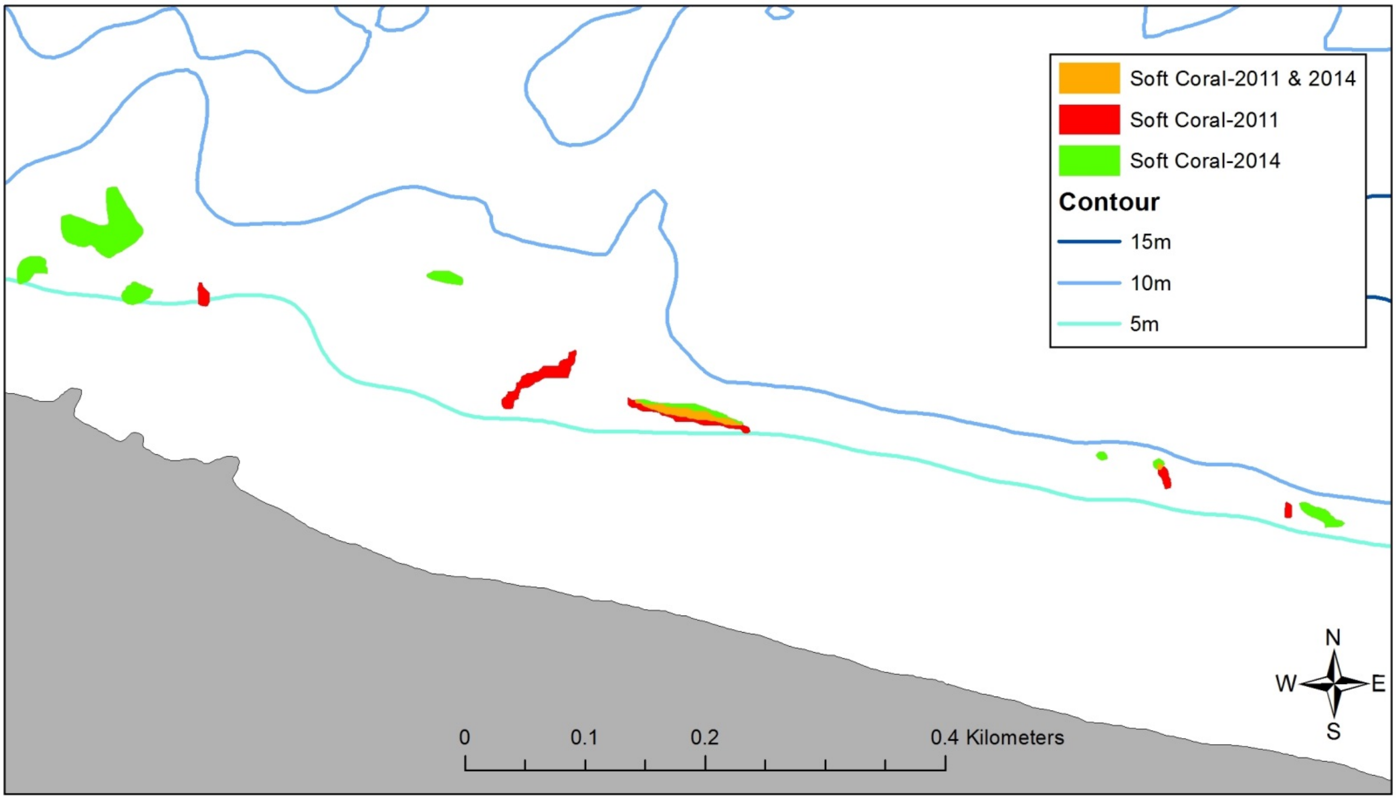


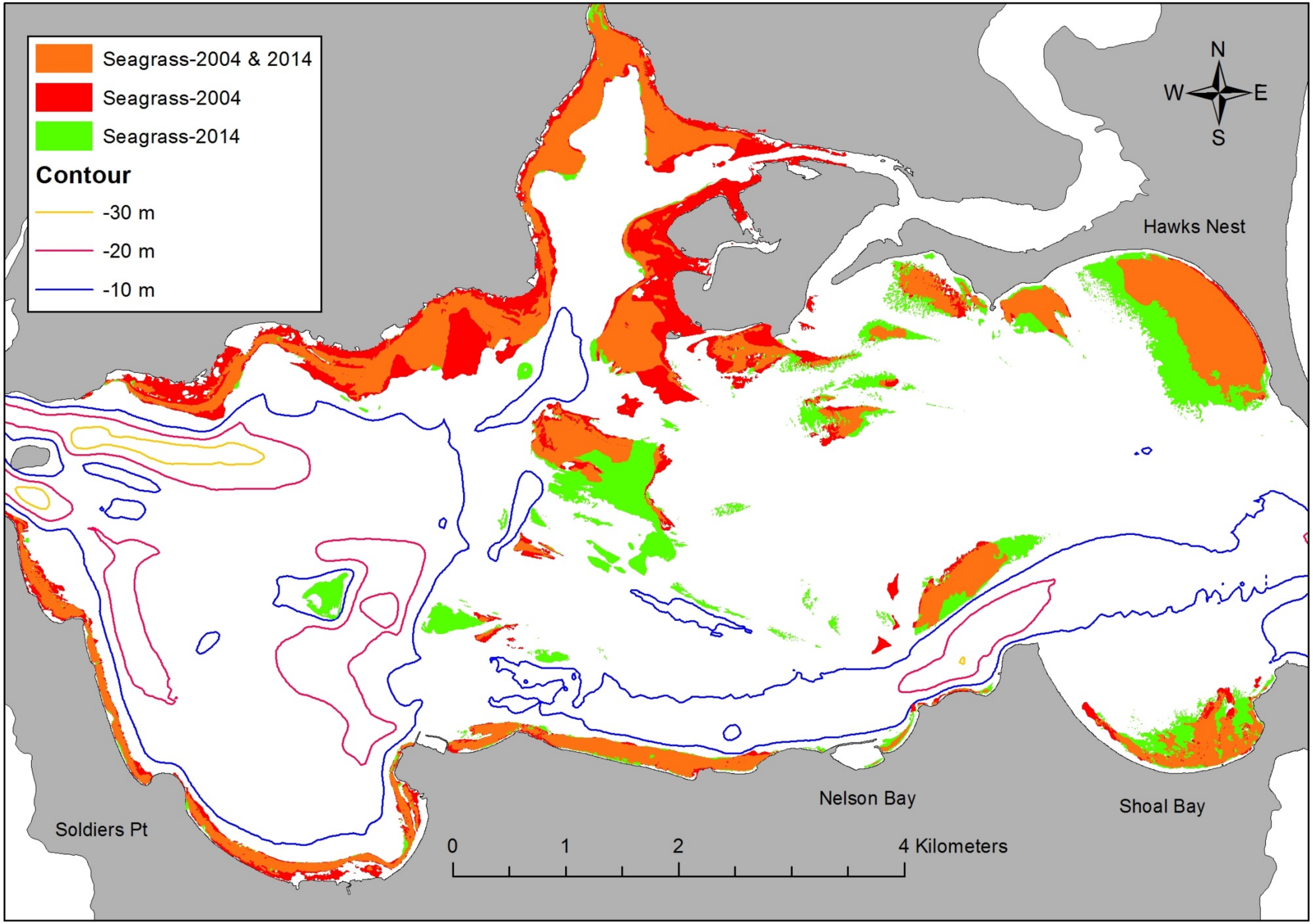
Figure 25: Changes in *Dendronephthya australis* habitat at Bagnalls Beach from 2011 to 2014



6.2 Seagrass habitats

A detailed examination of aquatic vegetated habitats (i.e. mangroves, seagrass and saltmarsh) in NSW estuaries was conducted in 2004 (Creese *et al.*, 2009). A comparison of the GIS data generated during this investigation, with results from the current study identified a small (i.e. 3%) reduction in seagrass cover in the Eastern Port between 2004 (702 hectares) and 2014 (682 hectares). Examination of the comparative distributions of seagrasses from these two studies indicates that the main reduction in seagrass cover has occurred at the entrance to the Myall Lakes, and that this loss has been offset by an increase in seagrass cover at the eastern end, and along the centre, of the Eastern Port (Figure 26). *Zostera* and *Halophila* both have a natural spatial and temporal variability that can be driven by many factors, including seasonal variations in water temperature, sunlight, water quality issues, and sediment movement. There has been a recent decline of *Zostera* in Port Stephens that appears to exceed the natural variability of the species.

Figure 26: Changes in the extent of seagrass habitats from 2004 to 2014



6.3 Baseline habitat data for the Eastern Port

Baseline data on the spatial extent of a number of previously unclassified habitats has been obtained for the Eastern Port. More than 132 hectares of sponge dominated habitat, 96 hectares of branching algae, 9 hectares of urchin barrens, and 6 hectares of the kelp *Ecklonia radiata*, were identified within the Eastern Port. These habitats were primarily concentrated in four regions of the Eastern Port: 1) at the entrance to the estuary; 2) along the southern shoreline between Halifax Point and Corlette Point; 3) in the channels between the Eastern and Western Ports; and 4) in the Schooner Channel leading into the Myall Lakes. The extent and distribution of these deep water habitats has not previously been fully mapped and documented.

6.3.1 Habitats at the Eastern Port entrance

The occurrence of rocky reefs at the entrance to Port Stephens is acknowledged in the previous habitat map for the estuary (i.e. Figure 1), and the current study has identified that these rocky reefs contain a complex matrix of habitats including Barrens, *Ecklonia*, Branching algae, and Sponges, particularly around Tomaree Head. These habitats are similar to the those identified in an extensive study of the NSW coast conducted by Underwood *et al.* (1991), and habitats at the entrance to the Eastern Port are therefore closely aligned with those on the surrounding coast. Habitat diversity has been linked to high species richness, and to biodiversity (Gray, 1997), and the existence of coastal habitats within the Eastern Port will tend to promote higher biodiversity within the port, as the presence of these habitats provides dwelling places for a range of species that are not normally associated with estuarine systems. It is therefore important that any future review of PSGLMP zoning should take into consideration the full range of habitats that have been identified within the estuary and their associated biodiversity values.

6.3.2 Habitats between Halifax Point and Corlette Point

Deep-water habitats have previously been reported along the southern shoreline between Halifax Point and Nelson Bay (Poulos *et al.*, 2013; Poulos *et al.*, 2015). Consequently this area is popular with recreational scuba diving (NSWMPA, 2010a) and its importance has been acknowledged through inclusion of the area in a sanctuary zone within the PSGLMP (NSWMPA, 2007). The current study identified that deep-water habitats within this region (i.e. Sponge, Branching Algae, *Ecklonia*, *Dendronephthya*, Barrens, and Sand) extend well outside the existing sanctuary zone. These deeper habitats are intermingled with seagrass dominated habitats (i.e *Posidonia*, and *Zostera/Halophila*) making the southern shoreline between Halifax Point and Corlette Point the most complex and diverse region for sub-tidal habitats within the estuary. The results from this study indicate that the current sanctuary zone located between Halifax Point and Fly Point has an important role to play in protecting the diverse assemblage of habitats that exists within the port, and any future review of marine park zoning within the estuary should continue to provide the highest level of protection to this section of the shoreline, and potentially look to extend the sanctuary zone so that it protects a larger proportion of this critical region, and includes areas of the *Dendronephthya australis* habitat.

6.3.3 Habitats between the East and West Port and the channel to the Myall Lakes

The previous habitat map for the Port Stephens estuary indicated that the channels between the Eastern and Western ports, and the Schooner Channel to the Myall Lakes, consisted of mud and muddy sand (i.e. Figure 1), however the current study has identified that these regions contain extensive areas of Sponge habitat, and large areas of Branching algae habitat. Strong tidal currents are known to occur in the channels between the Eastern and Western ports, and in the Myall Lakes entrance (DPWS, 1999). These currents, in combination with the flow of nutrients from the shallow Western Port and from the Karuah and Myall Rivers, are thought to provide conditions that support the observed areas of sponges and other filter feeding organisms. The existence of algal beds is perhaps somewhat more surprising, given the high turbidity that generally occurs in these regions (pers. obs.). Large areas of branching algae, especially red algae and *Calerpa cactoides*, were found to occur at depths from 4 m to 8 m. These algal beds occurred immediately adjacent to the shore in rocky areas, and occurred offshore from seagrass beds in areas with a soft sediment substrate. The high turbidity experienced in these regions, during mapping, limited the ability to identify organisms occurring within these habitats, other than at the broadest level (i.e. by growth form). A more detailed examination of these habitats may therefore be warranted, to ensure that they are not significantly different from other sponge and algal habitats occurring within the estuary. In the event that they do contain distinct habitats, this should be taken into consideration in any future review of marine park zoning for the PSGLMP.

6.4 Wallis Lake

The mapping that was conducted in Wallis Lake followed the same methods as those used in Port Stephens and mapping in Wallis Lake was easier to undertake as the lake is very shallow with very few habitat types. The deepest section encountered during the map was approximately 10 metres near the estuary mouth. Unlike Port Stephens, there is very limited complex habitat within Wallis Lake as the lake is dominated by seagrass and sand/mud habitats. Some reef habitat with macro-algal and sparse sponge coverage was found occurring around the northern section of Wallis Island, with the reef found in close proximity to the island shore and occurring down to depths of approximately 3 metres. The other region of Wallis Lake that was found to have some complex habitat was along the breakwall on the Tuncurry side where *Ecklonia radiata* was found to be the most dominant habitat type along the breakwall. Additionally, along the breakwall there were some sparse sponge habitat and also several colonies of an unknown soft coral species from the family Nephtheidae.

During the three days mapping in Wallis Lake, it was discovered that there was limited habitat types occurring and that as the lake is very shallow, it was not suitable for sponge, soft coral and kelp habitats. Even though only three days mapping was undertaken, most of the areas where potentially complex habitats could occur were mapped and there is limited scope to do further towed video mapping in Wallis Lake as most of the lake was assessed.

6.5 Implications of findings

While deeper sub-tidal habitats were previously known to occur within the Eastern Port of the Port Stephens estuary, previous investigations have primarily focussed on the southern shoreline of the Eastern Port (Poulos *et al*., 2015), where these habitats were thought to be concentrated. The results of the current mapping study indicate that while the southern shoreline does contain the most complex array of habitats, the distribution of sub-tidal habitats within the Eastern Port is far more complex and extensive than previously documented. Extensive areas of macroalgae and filter feeder dominated habitats occur in several regions of the port, and each of these regions has the potential to support a diverse and unique assemblage of benthic organisms.

The current PSGLMP zoning plan (NSWMPA, 2007) contains sanctuary zones that provide a high level of protection (i.e. prevent all fishing and extractive activities) for a section of the southern shoreline from Halifax Point to Fly Point and to a number of other smaller areas within the Eastern Port. In addition Habitat Protection Zones provide protection, by prohibiting trawling; at the estuary entrance; to the southern shoreline from Fly Point to Redpatch Pont; and to the channels between the Eastern and Western Ports. Current zoning was implemented prior to there being comprehensive knowledge of the variety and extent of habitats occurring within the Eastern Port, and therefore the current zoning plan may not provide adequate protection for all sub-tidal habitats within the port.

The soft coral *Dendronephthya australis* is particularly noteworthy, as no dense areas of this habitat were found occurring within existing sanctuary zones in the current study. Areas of *D. australis* habitat between Redpatch Point and Fly Point do occur within a Habitat Protection Zone, where they are protected from trawling, but they are not protected from damage caused by entanglement by fishing line and tackle. In addition many of the larger areas of *D. australis* habitat occur in relatively shallow water, off popular beaches, were they are exposed to damage from boat anchoring, and colonies can often be found amongst existing boat moorings (pers. obs.) where they are subject to uprooting by dragging mooring chains (Harasti *et al.*, 2014). The substantial changes that have occurred in the distribution of *D. australis* habitat, between 2011 and 2014, show that rapid losses of *D. australis* habitat can occur, and that the species may be vulnerable to anthropogenic impacts. The reasons underlying the observed losses of this habitat therefore need to be better understood so that any risks to this habitat can be mitigated. There is evidence that *D. australis* is capable of rapid colonisation given the right conditions, and there is potential for rehabilitation using either; habitat modification to encourage improved recruitment, or colony transplantation. Further work is required to gain a better understanding of the ecological requirements of this species, and to determine how *D. australis* can be best protected to ensure its long term conservation.

The results from this study provide valuable new information, which should be used to inform future zoning reviews for the PSGLMP. Improved zoning will ensure a better level of protection for all habitats occurring within the Eastern Port of Port Stephens, and thereby help to preserve biodiversity of marine species that occur within, and rely upon, those habitats for food and shelter. Further work is required to gain a better understanding of the biological associations that exist between the identified habitats and commercially important species occurring within the estuary (e.g. fish and molluscs). This knowledge will help to ensure that: sub-tidal habitats are appropriately protected; commercial interests are guarded; and biodiversity within the estuarine system is conserved.

7 Acknowledgements

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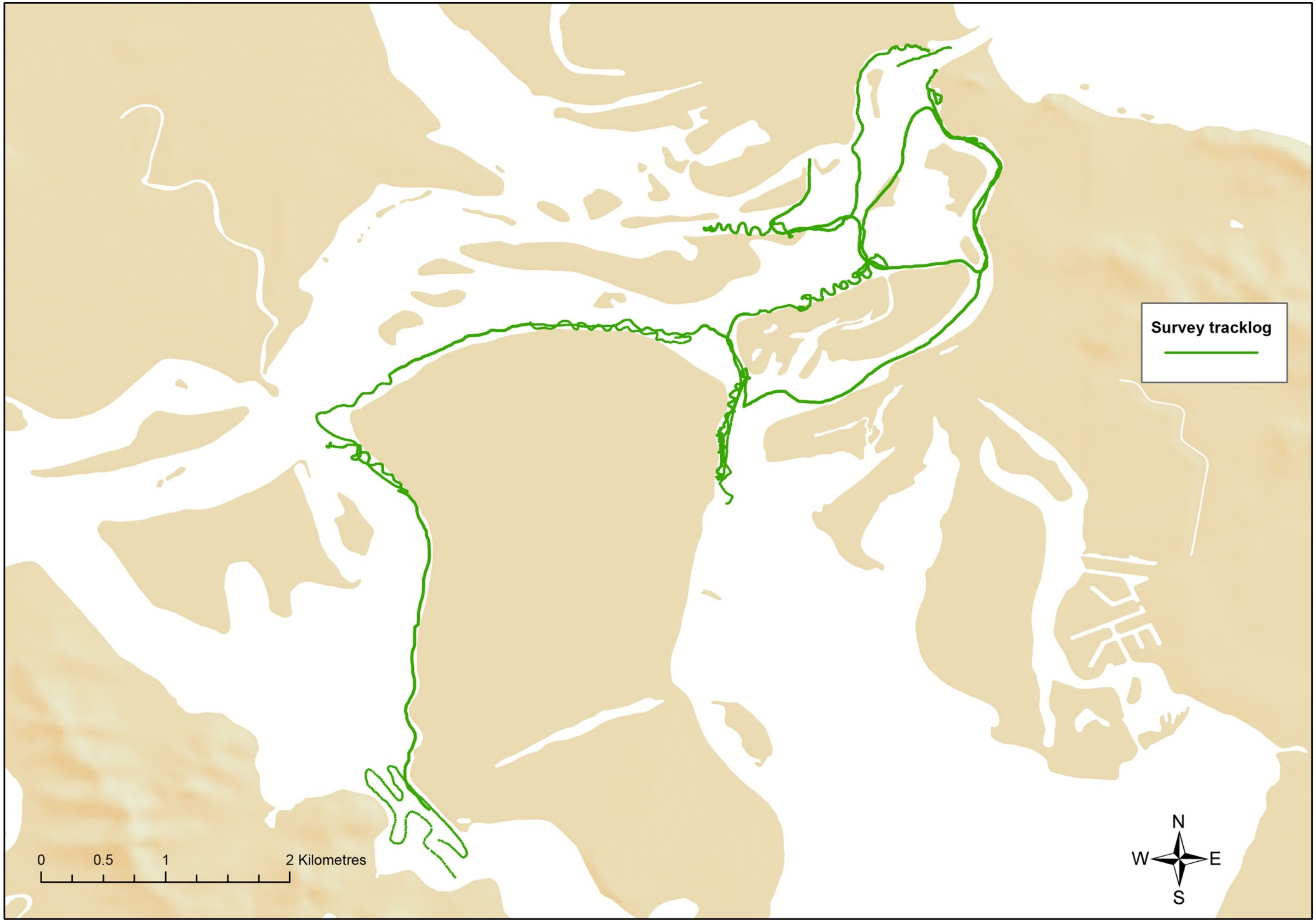
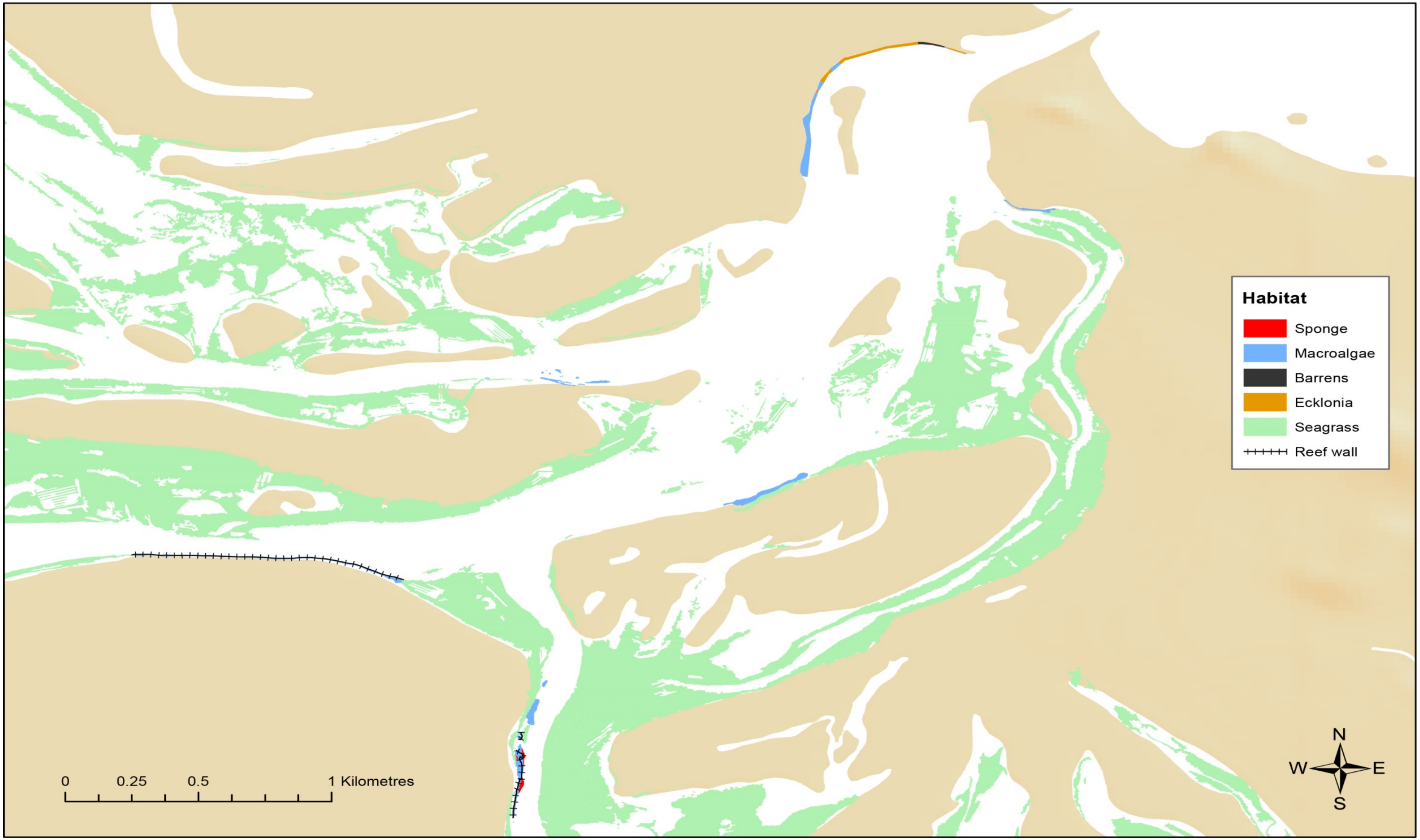
Appendix 1a: Areas surveyed in Wallis Lake in January 2015 using towed video.



Appendix 1b: Habitat map for Wallis Lake entrance and Wallis Island.



Appendix 1c: Enlarged habitat map for northern Wallis Island.