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Developing a habitat classification typology for subtidal habitats in a temperate estuary in New South Wales, Australia

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Abstract

Effective estuarine management depends on adequate data about the ecology, extent and biodiversity of component habitats. However, these data are often scant as exemplified by the Port Stephens estuary, part of the Port Stephens-Great Lakes Marine Park, NSW, Australia, for which even basic descriptions of habitat types and extent are lacking. Here we present the results of the first quantitative assessment of sub-tidal benthic communities within the estuary, involving 130 km of towed video transects over an area exceeding 50 km^2.

We identified previously undocumented macroalgae-dominated habitat types, and found strong correlations between habitat types and depth. The soft coral *Dendronephthya australis* habitat is of particular interest as this was found to occur exclusively outside current sanctuary (no take) zones. The habitat map of Port Stephens generated during the study provides the basis for more objective representative planning in future iterations of zoning in the estuarine section of the marine park. The study also suggests that depth may be a useful proxy for estuarine habitat types where specific data are lacking. The classification methodology developed during the study was cost-effective, generated robust data, and consequently has potential for wider application in other large estuarine bays.

Additional keywords: conservation management, habitat mapping, marine protected area, Port Stephens, structural macrobiota, towed video

Introduction

Marine ecosystems throughout the world are being subjected to increasing levels of disturbance, suffering from chronic anthropogenic impacts (Crain *et al.* 2009; Halpern *et al.* 2007), and are consequently in severe decline (Jackson 2001; Kennish 2002; Lotze *et al.* 2006). There is global concern that these impacts will lead to further degradation of marine habitats and the continued loss of marine species (Costello *et al.* 2010; Gray 1997; Halpern *et al.* 2008). As part of efforts to preserve biodiversity, there is a need to protect representative marine communities, and the habitats in which they reside (Fernandes *et al.* 2005). Due to the difficulties associated with obtaining quantitative data on marine species, habitats are often used as surrogates for marine communities (Jordan *et al.* 2005; Rees *et al.* 2014; Shokri and Gladstone 2013; Smith 2005; Stevens and Connolly 2004), and protection of representative areas of marine habitats is frequently used as a means of protecting overall biodiversity (Gladstone 2007; Jones and Srinivasan 2007; Malcolm *et al.* 2010).

Implementing protection of representative areas of marine ecosystems requires information about the range of habitat types, 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).

Habitat Classification Systems 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 chemical properties (e.g. salinity, nutrients, pH), the physical structure of the seabed, and the biological assemblages that dwell there (Bianchi *et al.* 2012; Last *et al.* 2010).

In New South Wales (NSW), Australia, the state government is currently implementing a new approach to managing the NSW coastal waters (termed the "Marine Estate") (NSWDPI 2013). Within NSW, a Comprehensive, Adequate, and Representative (CAR) network of multi-use marine parks was previously established with the objective of protecting biodiversity (Beeton *et al.* 2012). Under the new management approach, a CAR system of protected areas is perceived as addressing only some of the problems facing coastal waters, and threat and risk assessment are being promoted as the primary approach for ensuring the long term health of the Marine Estate (NSWDPI 2013). Marine habitat mapping is increasingly being used in this process to show the extent, structure and distribution of marine habitats (Dixon-Bridges *et al.* 2013). Previously, the majority of habitat-mapping effort focused on fully marine habitats (i.e. marine habitats with a low fresh water input) (Jordan *et al.* 2010; Underwood *et al.* 1991), with the existing HCS used in NSW marine parks focusing primarily on substrate type (reef or unconsolidated substrate), and depth (Malcolm *et al.* 2011; Malcolm *et al.* 2010). Substrate type and depth were used due to the difficulties associated with determining benthic habitats using swath acoustics, which has been the primary tool for habitat mapping within NSW (Jordan *et al.* 2010; NSWMPA 2010b). The existing HCS, therefore, does not fully describe benthic habitats, and while a broader typology (i.e. naming convention) for marine benthic habitats in NSW was developed by Underwood et al. (1991), its applicability is constrained to marine rocky reefs in central and southern NSW (Harriott *et al.* 1999). Within NSW estuaries, aquatic vegetated habitats (mangroves, seagrass and saltmarsh) have previously been mapped using a combination of aerial and satellite photography (Creese *et al.* 2009). In addition, work has been conducted in a number of estuaries to describe estuarine habitats in terms of sediment type and infauna (Dixon-Bridges *et al.* 2013; Hastie and Smith 2006; Jones *et al.* 1986; Lindegarth and Hoskin 2001). However, due to limitations imposed by turbidity, the type and extent of deeper benthic habitats (i.e. depths >5 m) remain largely unquantified. The Port Stephens estuary, in particular, is known to contain areas of deep water (i.e. depths of up to forty metres) (DPWS 1998), and is renowned for supporting a high diversity of biota, protected species, and habitats (Carraro and Gladstone 2006; Harasti *et al.* 2012; Smith *et al.* 2010). Information on aquatic vegetated habitats (Creese *et al.* 2009), and sediment types (Roy and Matthei 1996; Roy *et al.* 2001) is available for the estuary, but information on benthic habitats occurring in deeper sections of the estuary is lacking.

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 an understanding of deeper benthic habitats within the estuary, so that they can be adequately protected within the Port Stephens-Great Lakes Marine Park (PSGLMP). The primary objectives of this study were therefore to: (i) to develop a typology for subtidal habitats within the Port Stephens estuary; (ii) examine patterns in habitat distributions with changing depth, current velocity, and substrate; (iii) develop a methodology that could be used for rapid visual assessment of subtidal habitat types; and (iv) apply this methodology in a broad-scale assessment of habitat types in the estuary.

Materials and methods

Study area

The study site selected for the investigation was the Eastern Port of the Port Stephens estuary (Fig. 1), a tide-dominated drowned river valley (Roy *et al.* 2001), all of which is contained within the PSGLMP. The PSGLMP is largest marine park in NSW (98,000 ha) and has multiple zoning categories which regulate different types of activities. Approximately 17% of the park is currently classified as sanctuary zone where all extractive activities are prohibited (NSWMPA 2010a). The Eastern Port is approximately 12 km long (east-west) and 5 km wide (north-south) with an area exceeding 50 km^2, and contains areas of deep water (i.e. depths of up to 40 m) which support a high diversity of biota (Smith *et al.* 2010). The Eastern Port is known to contain a range of habitats, some of which are considered to be uncommon in NSW (Carraro and Gladstone 2006; Poulos *et al.* 2013): however, the full extent of benthic habitats has yet to be fully classified or mapped.

Habitat classification

Within Australia, the Interim Australian National Aquatic Ecosystem (ANAE) Classification Framework was 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 ANAE and NISB are semi-hierarchical and hierarchical attribute-based classification systems, using broad habitat classes subdivided by biotic and abiotic modifiers (e.g. substrate, depth, current velocity), which can be used to generate habitat typologies to meet specific management objectives (AETG 2012; Mount *et al.* 2007).

The broad structural macrobiota classes contained within the NISB (i.e. seagrass, macroalgae, filter-feeders) do not allow discrimination between some of the different seagrass and filter-feeder habitats known to occur within the Eastern Port of the Port Stephens estuary (Creese *et al.* 2009; Poulos *et al.* 2013). There was therefore a need to determine suitable modifiers (i.e. benthic habitats types) to use within the NISB HCS. Previous studies have shown that significant variation in benthic habitats can occur across sites and between depths at a range of spatial scales (m to km) (Malcolm *et al.* 2011; Underwood *et al.* 1991). Therefore, quantitative assessments of benthic habitats were conducted, in mid-2014, at five study sites (Fig. 1), at a range of depths. Due to the presence of strong tidal currents, assessments were conducted over the period of slack water (one hour either side of high tide). A broad-scale assessment of habitats throughout the Eastern Port was then conducted, between July 2014 and January 2015, using towed video transects.

Field methods

Quantitative assessment of sub-tidal structural macrobiota can be conducted using a variety of methods (Kingsford and Battershill 1998), including photo quadrats (Kohler and Gill 2006), line transects (Underwood *et al.* 1991), and video transects (Carleton and Done 1995; Harriot *et al.* 1994; Smith *et al.* 2008). Photo quadrats and video transects were selected for this study as they provide an accurate method of assessment, while allowing retention of a permanent record which can be re-evaluated as required (Preskitt *et al.* 2004).

For the quantitative assessment of benthic habitats, four transects, separated by at least 10 m, were established from haphazard starting points at each study site. Transects commenced at a depth of 2 m (Extreme Low Water Spring tidal level) and extended perpendicular to shore to a maximum depth of 15 m, or to the point where cover of structural macrobiota was negligible (i.e. the sand line). On each transect, five photo-quadrats (photos) were taken along each depth contour, at one metre depth increments (i.e. 5 photos at 2 m, 5 photos at 3 m, etc.). Photos along each depth contour were separated by 1.2 m, with each photo covering an area approximately 0.7 m by 0.5 m. Photos were taken perpendicular to the seabed, using a measuring rod to hold the camera a uniform 0.5 m above the substrate. A total of 1280 photos were taken, with the number at each site varying due to differences in sand-line depth (Table 1).

Towed video transects were conducted using a DeepBlue Splashcam (http:// http://www.splashcam.com/) standard definition video camera, with coordinates from a Garmin GPS map 60C (http://www.garmin.com) differential GPS overlaid on each video frame. Transects were systematically located in all areas of the estuary deeper than 5 m, with lateral transects, spaced at intervals of approximately 500 m, used to locate areas containing structural macrobiota. Areas identified as containing structural macrobiota were then assessed using longitudinal and lateral transects spaced at intervals of 50 to 100 m. Approximately 130 km of towed video transects were completed in the study, at an average speed of 2.5 km hr^{-1}, generating 52 h of video footage. Towed video operations were restricted to 1-2 h each day at high tide, due to strong tidal currents and low visibility at other times, and a total of 44 d was required for conducting the towed video transects.

Image analysis

To obtain quantitative data from photos, the CPCe software package (Kohler and Gill 2006) was used to analyse 20 random points in each photo. Each point was categorised 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). CATAMI provides a standardised method for classifying substrata and marine biota, using a hierarchical system based on taxonomic classification, or on morphological characteristics where taxonomy is not easily distinguished (e.g. for macroalgae, sponges, bryozoans, cnidarians and ascidians). Data from the five photos along each depth contour on each transect were aggregated to provide percentage cover values for CAAB classes. The four transects provided four replicates at each depth at each site, thereby incorporating spatial variation in habitats at the site scale as well as along depth gradients.

Towed video transects were assessed by playing footage back at between one and two times actual speed, and noting habitat types and habitat boundaries as they appeared. Habitats types were classified visually using the modified NISB HCS methodology developed in this paper.

Habitat boundaries were used to generate a habitat map for the port, with interpolation used to define habitat types between towed video transects.

Statistical Methods

A modelling approach was used to evaluate changes in community structure across the factors of position (site), current velocity, depth and the physical habitat type (% sand). First, cover of CAAB classes were subjected to multivariate statistical analysis using the PRIMER-E and PERMANOVA+ (http:// http://www.primer-e.com/) software packages (Anderson *et al.* 2008; Clarke and Gorley 2006). Pairs of samples were compared using the Bray-Curtis similarity measure, and the resulting similarity matrix was subjected to non-metric multidimensional scaling (nMDS), to allow visualisation of patterns in assemblage structure. Initial analyses were conducted utilising untransformed and square-root transformed data, and it was evident that applying a transformation to the data reduced the ability to distinguish between assemblages. This was because transformations reduce the contributions of dominant species to similarities between samples (Clarke and Gorley 2006), and abundances of dominant species and classes were the primary drivers of similarities within clusters in the assemblage data. All subsequent analyses were therefore conducted using untransformed data.

Cluster analyses with similarity profile (SIMPROF) permutation tests were used to assess significant structure among samples. This routine identified clusters of samples that have significantly different structure and facilitates the identification of discrete community types. Similarity percentage breakdowns (SIMPER) were subsequently used to identify the CAAB classes primarily responsible for similarities within discrete clusters. The distance-based linear model (DISTLM) routine was used to model the relationships between the patterns of benthic assemblages, and the predictor variables of depth, site (as distance from the estuary mouth), broad substrate type (reef/sand - summarised as the percentage of sand), and mean current velocity for each sample (Anderson *et al.* 2008). Current velocities were extracted for each depth at each site using the existing 2D hydrodynamic model of the estuary, which incorporates the entire embayment, major tributaries, and a section of adjacent offshore waters (Poulos *et al. in press*). A step-wise procedure and the R^2 selection criterion were used to find the best model, and marginal tests determined the strength of the relationship for each predictor variable (Anderson *et al.* 2008).

Results

Patterns in benthic community structure

A total of 25,600 random points, on 1,280 photo-quadrats, were examined to obtain quantitative data on benthic assemblages within the Eastern Port. Variations in assemblages with depth, and between sites, were visible in the nMDS plot for assemblages at each site at each depth (Fig. 2– showing centroids for the 4 replicates at each site/depth combination). Cluster analysis using SIMPROF identified eight significantly different clusters of samples within the assemblage data (labelled A-H in Fig. 2).

Similarity percentage analyses (SIMPER) identified that similarities within clusters were primarily driven by dominance of single CAAB classes (Table 2). An examination of samples lying outside clusters, further identified that the majority of these samples had a strong resemblance to assemblages from one of the clusters, but with differing proportions in some CAAB classes. Where outlying samples did not resemble one of the clusters, they were generally found to contain assemblages that were either transitional between clusters, or depauperate, with <10% cover by structural macrobiota.

Based on these objective analyses, we propose a typology containing seven distinct sub-tidal benthic habitat types within the Eastern Port:

1. "*Posidonia*" habitat, dominated by the seagrass *Posidonia australis* (aligned with cluster A);
2. "*Ecklonia*" habitat, dominated by mono-specific stands of the macroalgae *Ecklonia radiata* (cluster B);
3. "*Halophila*" habitat, dominated by *Halophila ovalis* (cluster C);
4. "Branching algae" habitat, dominated by erect coarse branching algae, primarily red algal species, *Sargassum*, and *Caulerpa cactoides*, with other macroalgae growth forms in lower abundance (combination of clusters D and E, as both of these were dominated by erect coarse branching algae);
5. "Filter-feeder" habitat dominated by mixed filter-feeder assemblages containing sponges in a variety of growth forms (e.g. branching, massive, encrusting), ascidians, octocorals, hydroids, and bryozoans (cluster F);

6. "*Dendronephthya"* habitat dominated by mono-specific stands of the soft coral species *Dendronephthya australis,* with other filter-feeders present in lower abundance (cluster G); and
7. *"Barrens"* habitat dominated by encrusting calcareous algae, with high abundances of the urchin *Centrostephanus rodgersii* (cluster H).

DISTLM analysis identified significant correlations between benthic communities and each of the predictor variables (i.e. depth, location, substrate type, and current) ($p<0.001$ for all). The overall best model included all variables and explained 34% of the variation in community patterns (R^2=0.338). In the analysis using individual variables (i.e. marginal tests), depth ranked highest (R^2=0.174) (e.g. in Fig. 2, samples grade from shallow at the top of the plot to deep at the bottom) followed by current (R^2=0.097), site (R^2=0.085), and substrate (R^2=0.069). Covariance between predictor variables occurred, with depth and current increasing with distance from shore, and site and percentage sand increasing with distance from the estuary mouth.

Development of visual classification methodology

The habitats identified in the quantitative assessment can be distinguished from each other visually, on the basis of dominant species or CAAB classes, thereby allowing the use of dominant species and CAAB classes as modifiers within the NISB HSC framework. A visual habitat classification methodology, using the NISB HCS framework, modified with additional decision rules defining habitats on the basis of dominant species and CAAB classes was therefore developed (Fig. 3). The modified methodology uses a hierarchical system with habitats initially classified by substrate coverage (i.e. covered or uncovered by structural macrobiota), with a covered habitat being one with >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 CAAB classes, with dominance defined as occurring when a species or class covers the largest proportion of the substrate (Mount *et al.* 2007).

Broad scale habitat assessment

The visual habitat classification methodology (Fig. 3) was further tested in a broad-scale assessment of habitat types in the Eastern Port using 130 km (52 hours) of towed video footage. This assessment located additional areas of the seven habitat types, and identified three further habitat types within the Eastern Port:

1. "*Zostera"* habitat dominated by the seagrass *Zostera capricorni*, often with *Halophila ovalis* present in lower abundance;
2. "Sand" habitat dominated by sand with minimal benthic cover; and
3. "Mud" habitat consisting of bioturbated mud with numerous burrows, but with minimal benthic cover.

In total, ten distinct subtidal habitat types were identified in this study comprising: three habitats dominated by seagrass species (*Posidonia australis*, *Halophila ovalis*, and *Zostera capricorni*); two habitats dominated by filter-feeders (a mixed filter-feeder assemblage, and the soft coral *Dendronephthya australis*); three habitats dominated by macroalgae (kelp - *Ecklonia radiata*, branching macroalgae, and encrusting coralline algae - urchin barrens); and two habitats with minimal benthic cover (sand, and mud). Large areas of previously undocumented macroalgae-dominated habitat types were located and *Dendronephthya australis* habitat was found to occur exclusively outside current sanctuary (no take) zones. The ten habitats identified formed a new habitat classification typology which was used to produce a habitat map for the Eastern Port (Fig. 4).

Discussion

Habitat Classification Systems (HCS) are used to logically partition environmental datasets, so that they can act as surrogates for biodiversity or ecological function, and typologies provide an extension to traditional classification systems by grouping classes for a specific purpose or management objective (AETG 2012; Ward 2014). In this study, significantly different, and visually distinguishable, assemblages of structural macrobiota were used to develop a habitat classification typology for the Eastern Port of Port Stephens, with the objective of defining habitat surrogates for biodiversity. This typology provided an efficient method for visually assessing dominant marine habitats, effectively delimiting distributions of structural macrobiota. Structural macrobiota can play an important role in marine ecosystems as they create spatially complex habitats, which are associated with increases in local species diversity (Lilley and Schiel 2006). Studies examining structural macrobiota within estuaries have identified that seagrasses, macroalgae, and filter-feeders can harbour a range of species not found on adjacent substrata lacking biogenic structure (Ferrell and Bell 1991; Poulos *et al.* 2013).

The study identified habitats dominated by seagrasses, macroalgae, and filter-feeders, and found that many habitats within the Eastern Port were similar to marine habitats identified in other studies from central and southern NSW, and Victoria (Ball *et al.* 2006; Underwood *et al.* 1991). In NSW, the typology developed for rocky reefs, by Underwood *et al.* (1991), describes the *Ecklonia* and Barrens habitats identified in this study. In addition, Underwood *et al.* (1991) identify a 'Fringe' habitat consisting of abundant foliose algae which is equivalent to the Branching algae habitat in this study. However, the coastal 'Fringe' habitat occurred at very shallow depths (2-3 m) while the Branching algae habitat within the estuary occurred to depths of at least 8 m at some sites. Underwood *et al.* (1991) also identified a 'Deep Reef' habitat characterised by large sponges at depths > 9 m, which aligns with the Filter-feeder habitat identified in this study. However, the coastal 'Deep Reef' habitat was associated with hard substrate (i.e. reef), while the estuarine Filter-feeder habitat occurred on both reef and sand. The coastal typology developed by Underwood *et al.* (1991) had no provision for seagrasses or the *Dendronephthya* habitat found in the Eastern Port. In Victoria, a HCS generated for Victoria's Marine National Parks, contained 18 classes with 'Dominant Biota', including classes matching all of the habitats identified during this study, with the exception of the *Dendronephthya* soft coral habitat (Ball *et al.* 2006).

A comparison of habitats from this study with similar studies in northern NSW and Queensland, identified that the Eastern Port has less in common with northern sections of the east Australian coast. A study conducted in Moreton Bay in southern Queensland identified only a single habitat that was comparable to the habitats identified in this study (i.e. *Zostera /Halophila*) (Stevens and Connolly 2005), with the other eight habitats identified from Moreton Bay consisted of complex assemblages, with no clearly dominant taxa. This suggests that the boundaries between habitats within Moreton Bay may be less clearly defined than those within Port Stephens. Similarly, a study examining habitats on rocky reefs in northern NSW only identified habitats matching the Branching algae and Filter-feeder habitats from this study, but found a number of coral-dominated habitats that were absent within the Eastern Port (Harriott *et al.* 1999).

The correspondence between habitats identified in this study and marine habitats from southern NSW and Victoria is not surprising given the geographical location of the estuary (i.e. central NSW), and the large tidal flows which ensure that salinity levels are essentially marine within the Eastern Port (i.e. 35 to 35.5 psu) (DPWS 1998). The Eastern Port can therefore be classified as a marine tidal delta (Roy *et al.* 2001), where subtidal communities will tend to be dominated by marine species, rather than estuarine species (Attrill and Rundle 2002). These marine-dominated estuarine communities will potentially be impacted by extreme weather events, which can cause reductions in salinity and increases in turbidity within the estuary (pers. obs.).

Benthic communities in the Eastern Port were found to be influenced by depth, current, substrate type, and location. Previous studies have demonstrated that depth influences the distributions of seagrasses (Abal and Dennison 1996), macroalgae (Nielsen *et al.* 2002), and sponges (Underwood *et al.* 1991), and the results from this study concur with these findings. However, the majority of variation in assemblage structure (66%) is presently unexplained. Some of the unmeasured factors which may contribute to patterns include: wave exposure, which has been shown to impact soft coral communities (Fabricius and Alderslade 2001); sedimentation which impacts both soft corals (Fabricius and Alderslade 2001) and other filter-feeders (Irving and Connell 2002); turbidity which affects photosynthesis, and therefore seagrasses, macroalgae (Nielsen *et al.* 2002), and sponges (Roberts *et al.* 2006); and substrate composition, with sediment type (Dixon-Bridges *et al.* 2013), and reef type (Malcolm *et al.* 2010; Rees *et al.* 2014), both known to influence benthic communities. Further investigation is required to identify which, if any, of these factors affect benthic assemblages in the Port.

Application of study results to estuary management

This investigation has identified that the existing marine HCS for NSW (Malcolm *et al.* 2011) does not adequately describe all benthic habitats occurring in the Port Stephens estuary; this may well be the case for other similar estuaries. While the existence and distributions of shallow benthic habitats such as seagrass and mangroves are well documented (Creese *et al.* 2009), some areas of the Port Stephens estuary have been shown to contain habitats which have not previously been mapped or adequately described. We therefore suggest that subtidal benthic habitats within the Port Stephens estuary can best be described using a new typology based on the NISB system, with modifiers to include three seagrass habitats (*Posidonia australis*, *Halophila ovalis*, and *Zostera capricorni*), two filter-feeder habitats (Filter-feeder, and *Dendronephthya*), three macroalgae habitats (*Ecklonia*, Barrens, and Branching algae), and two substrate habitats lacking biogenic cover (Sand, and

Mud). Of particular interest is the extent of the habitat dominated by the soft coral, *Dendronephthya australis,* which is only known to occur in abundance within Port Stephens (Poulos *et al. in press;* Poulos *et al.* 2013). This habitat is considered to be under threat from anthropogenic impacts (anchor damage (Harasti *et al.* 2014), fishing-line entanglement (Smith and Edgar 2014; Vegter *et al.* 2014)) and from increasing sedimentation and potentially poor water quality (Poulos *et al.* 2013). The broad-scale assessment of habitats performed during this study revealed that the *Dendronephthya* habitat occurs entirely outside current sanctuary zones, indicating that it may not be adequately protected under the current PSGLMP zoning plan.

The results from this study provide new and valuable insights into the range of habitats within a large NSW estuarine embayment and some of the factors that drive distribution patterns. Importantly, it also highlights discrete and important habitats that are not adequately protected within current management arrangements. The modified NISB habitat classification methodology developed during this study is both rapid and cost-effective and has the potential to be a useful tool for ongoing monitoring of benthic habitat types and their boundaries. It also provides a framework for wider evaluation of the type and extent of habitats in other large estuarine embayments for which such data are currently lacking.

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Table 1: Depth of sand line and number of photo-quadrats taken at study sites

Site Name	Sand line	Photo-quadrats
Fly Pt	>15 m	280
Halifax	>15 m	280
Little Beach	15 m	270
Pipeline	14 m	250
Redpatch	12 m	200

Table 2: CATAMI Codes for Australian Aquatic Biota (CAAB) driving >50% of the similarity between samples within significantly different clusters identified by SIMPROF – numbers in brackets indicate contribution to similarities within clusters

Cluster	CAAB classes driving similarity between samples within clusters
A	CAAB 63600903 – Seagrasses: Strap-like leaves (81%) (i.e. *Posidonia australis*)
B	CAAB 80300902 Macroalgae: Large canopy forming: Brown (87%) (i.e. *Ecklonia radiata*)
C	CAAB 63600903 – Seagrasses: Elliptical leaves (51%) (i.e. *Halophila ovalis*) CAAB 80300903 Macroalgae: Erect coarse branching (27%)
D	CAAB 80300903 Macroalgae: Erect coarse branching (43%) CAAB 80300902 Macroalgae: Large canopy forming: Brown (17%) CAAB 80300907 Macroalgae: Erect fine branching (13%)
E	CAAB 80300903 Macroalgae: Erect coarse branching (84%)
F	CAAB 10000000 Sponges (59%) CAAB 35000000 Ascidia (12%) CAAB 11001000 Cnidaria: Hydroids – (9%)
G	CAAB 11168902 Octocorals: Branching (3D) (46%) (i.e. *Dendronephthya australis*) CAAB 10000000 Sponges (18%) CAAB 11001000 Cnidaria: Hydroids – (8%)
H	CAAB 80300934 Macroalgae: Encrusting: Red: Calcareous (50%) CAAB 25200000 Echinoderms: Sea urchins (33%)

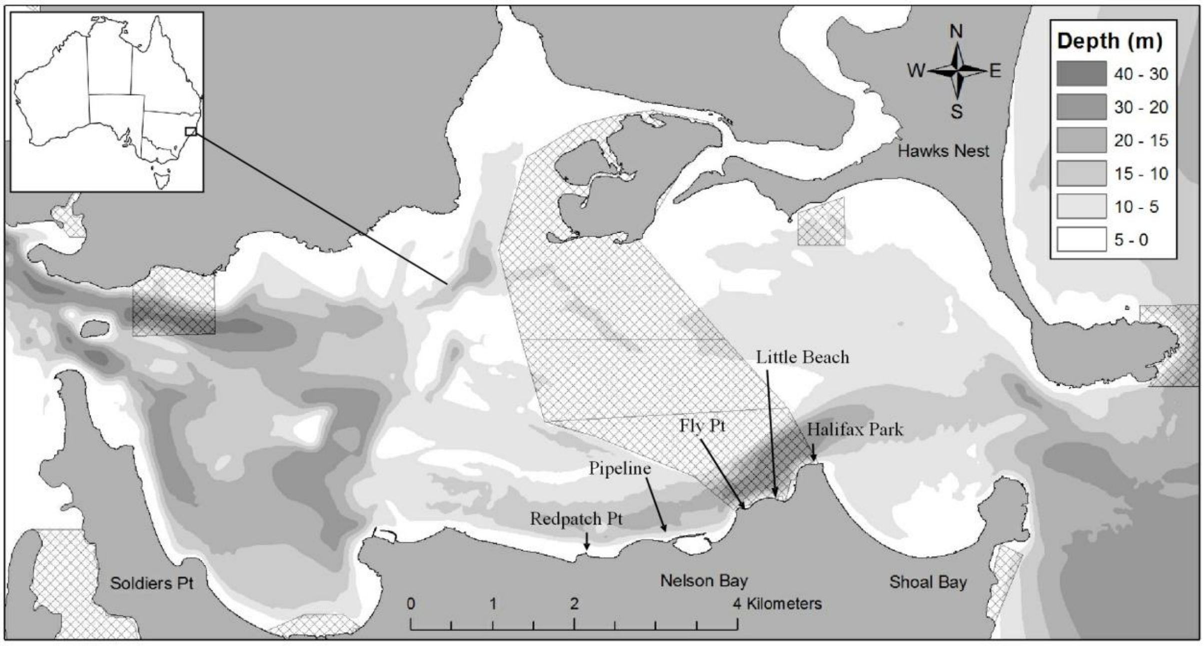

Fig. 1. Eastern Port of the Port Stephens estuary. Cross-hatching indicates Sanctuary Zones.

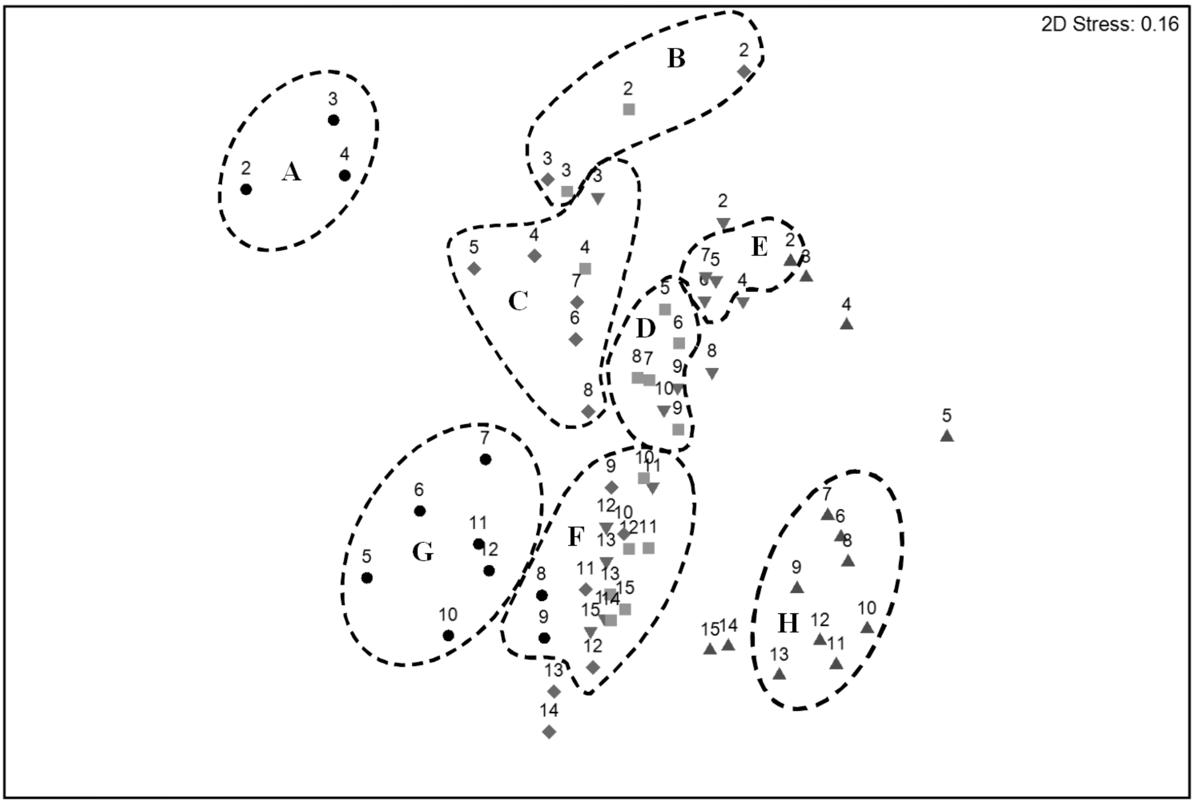

Fig. 2: nMDS plot of benthic community data by depth and location. Markers represent mean assemblages (n=4), circle = Redpatch Point, diamond = Pipeline, square = Fly Point, inverted triangle = Little Beach, triangle = Halifax. Numbers indicate sample depths. Dashed lines and capital letters (A-H) indicate significantly different assemblages from SIMPROF (corresponding to clusters in Table 2).

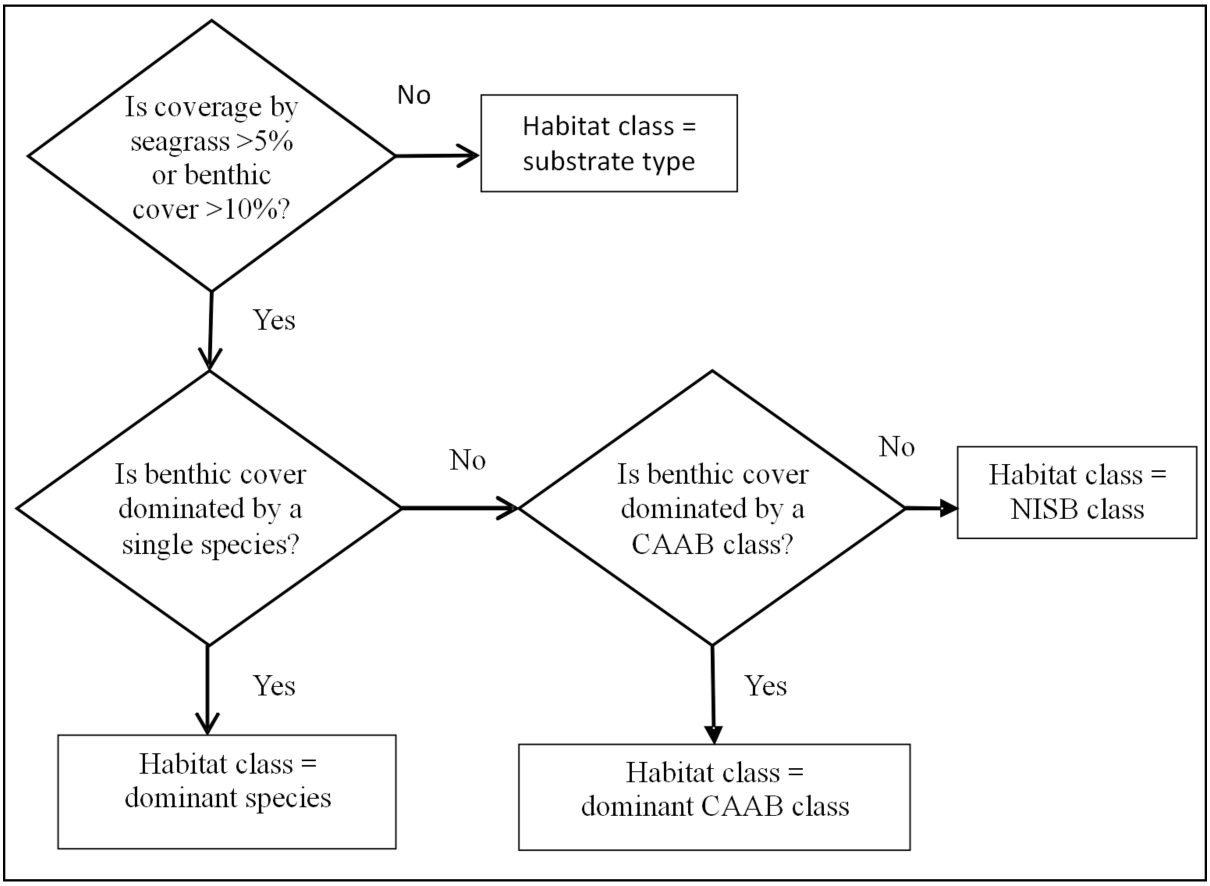

Fig. 3: Visual habitat classification methodology based on the National Intertidal/Subtidal Benthic (NISB) Habitat Classification System with modifiers based on; dominance by individual species; or CATAMI Codes for Australian Aquatic Biota (CAAB) classes

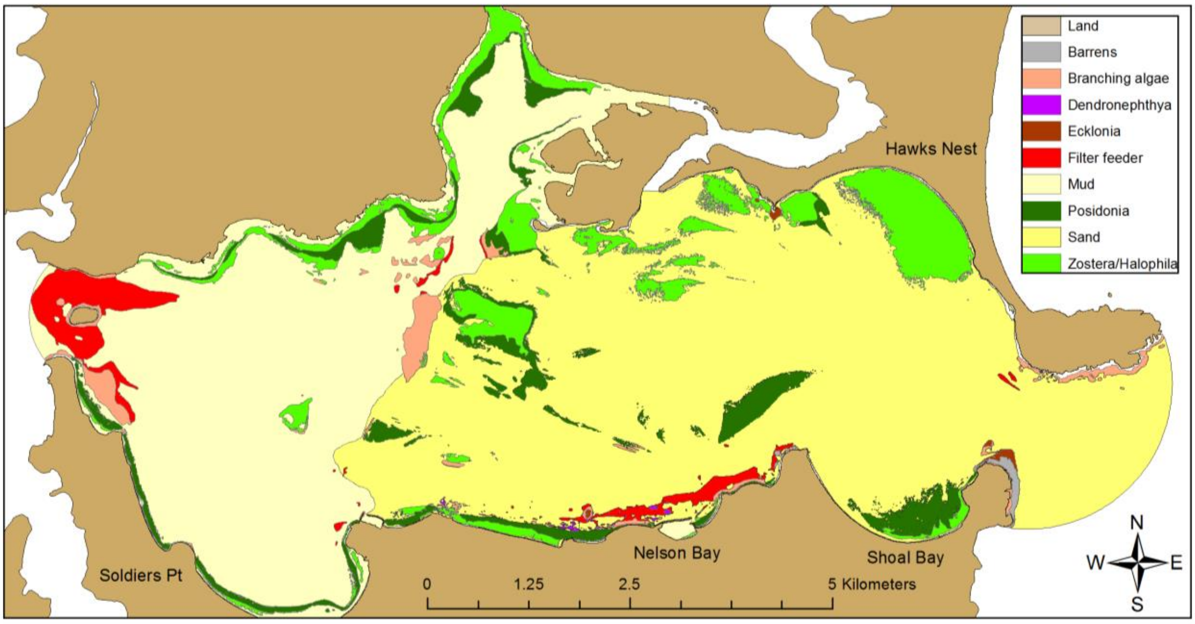

Fig. 4: Habitat map for the Eastern Port showing subtidal habitat classes (Sand, Mud, Barrens, *Ecklonia*, *Zostera*, *Halophila*, *Posidonia*, *Dendronephthya*, Branching algae, Filter-feeder)