Developments in mapping of seabed habitats for Marine Protected Area planning and monitoring

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I. INTRODUCTION

An important component of the information required to improve marine resource management and planning is an understanding of the extent, distribution and structure of seabed habitats [1,2]. While mapping of intertidal and shallow subtidal habitats has primarily been conducted using airborne remote sensing platforms, mainly aerial photography [3], although more recently using satellite based methods [4]. The maximum depth suitable for these methods is determined to a large extent by water clarity, and in many locations this depth can be less than 5-10 m. The data is also restricted to raster or vector layers of habitat classes, such as seagrass, mangrove and saltmarsh [3], with no information on bathymetry. Mapping of deeper subtidal habitats is generally conducted using acoustic tools, which in recent years has developed from using single-beam echosounders that require considerable mapping interpolation [5] to swath echosounders that can provide full coverage of bathymetry and backscatter at high resolution [6, 7]. Mapping classes delineated using acoustic remote sensing and associated ground truthing are commonly based on geophysical features [7,8,9] or a combination of biological and physical features [10]. Such classification schemes reflect the limited capacity of acoustic remote sensors to delineate biotic composition, while recognising the influence of physical factors on the resulting benthic communities.

In Australia a spatial framework exists for classifying marine areas using bathymetry, sediments, demersal fish assemblages and sponges into bathymetric units, provincial bioregions, biomes, geomorphic units and features, and seabed facies [11]. This marine bioregionalisation complements the Interim Marine and Coastal Regionalisation (IMCRA) which provides a hierarchical spatial planning framework for coastal and continental shelf waters. However, many of these scales are considerably coarser than that required for the assessment of the distribution of biological habitats and communities which often exist at the scale of metres to kilometres [6]. They are also considerably coarser than the scale at which the majority of seabed mapping data is collected.

Marine bioregional assessments in New South Wales delineates some ecosystem, habitat and community classes, generally more detailed within estuaries, where habitats are defined by macrophyte type such as seagrass, mangrove, and saltmarsh [12], and nearshore rocky reefs down to ~20 m depth [13]. Due to the lack of detailed seabed habitat data within the 'ocean ecosystem' class, the NSW continental shelf was divided into several depth zones (0–20 m, 20–60 m and 60–200 m), with little information available on subtidal sediments or reef in the two deeper depth zones. These classes were effectively used as 'surrogates' for diversity in marine conservation planning as spatial information on a wide range of individual species was generally limited [13].

The mapping and spatial analysis of seabed habitats and biological assemblages in the marine environment is being increasingly used to further advance the effective planning and monitoring of Marine Protected Areas (MPA) within Australia [5,14,15]. Recent high resolution swath acoustic mapping of the seabed of New South Wales (NSW) continental shelf waters has significantly improved information on the extent, distribution and structure of seabed habitats and associated assemblages [16]. Combining maps of seabed habitats from a number of sources with information on species composition has allowed a greater range of biodiversity surrogates and improved assessment of the effectiveness of Marine Protected Area locations and specific zoning arrangements for representing biological diversity in NSW [17]. A key MPA zoning criteria is that their 'no-take' zones contain a comprehensive, adequate and representative selection of marine biodiversity, usually defined at the levels of ecosystems, habitats and communities. Maps of seabed habitats are an essential component of the information required to maximise the likelihood that this planning criteria is achieved.

There are six Marine Parks in NSW cover 345,000 hectares, or around 34 percent of NSW State coastal waters, and contain various types of zones, ranging from 'no-take' sanctuary zones to general use zones where most recreational and commercial activities are allowed. The Solitary Island Marine Park (SIMP) is located on the mid north coast of NSW and is one of the largest marine parks in the State, covering an area of 710 km^2. It is positioned in a transition zone where the tropical East Australian Current (EAC), cooler counter-currents, and upwelled waters overlap on the shelf [18].

The primary ecosystem and habitat data used to develop the current zoning scheme in Solitary Island Marine Park included estuaries (barrier lagoons, and intermittently closed and open lakes and lagoons, and aquatic macrophytes such

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as seagrass, mangroves and saltmarsh) [12]; rocky shores; sandy beaches; subtidal soft-sediments; open ocean; and island fringing and subtidal reefs [19]. Subtidal reefs were defined from 1:150,000 Australian Hydrographic Charts and mapped from acoustic transects [20]. However, the broad-scale extent of this data resulted in limited knowledge of the extent and structure of seabed habitats on the continental shelf component of the marine park. During planning there was limited data on benthic communities and their spatial extent across the region, with surveys primarily focussed on shallow reefs [20,21,22]. There is also evidence that benthic community composition within the region can be highly variable at scales of 100's of metres to 100's of kilometres [22,23], some of which results from the presence of offshore islands.

In order to describe the application of seabed mapping to MPA planning in NSW, this paper aims to detail the main physical and biological features of selected areas of the seabed in areas within the Solitary Island Marine Park region. Data is collated from previous geological, hydrographic and aerial photography surveys combined with new swath acoustic bathymetry, backscatter and video data, with an emphasis on the seabed habitats and the sessile assemblages. Associated reports also include further information on specific ecosystems and habitats not discussed here (including seagrass, mangroves, saltmarsh, intertidal rocky shores, beaches, and the pelagic ecosystem) [24].

II. METHODS

Swath acoustic seabed surveys were conducted with a Geoswath 125 kHz interferometeric sidescan and associated auxiliary sensors aboard the 8.5 m catamaran RV Glaucus operated by the NSW Department of Environment, Climate Change and Water (NSW DECCW). The system consists of a pair of 125 kHz transducers, sound velocity sensor and Motion Reference Unit (MRU) pole mounted on a V bracket and deployed over the port-side of the vessel, with an Omnistar Differential Global Positioning System (DGPS) receiver located onboard. The swath mapping system collects geo-referenced depth and sidescan backscatter data to generate high resolution bathymetric and backscatter data. Swath coverage along a track was determined by a number of parameters including water depth, power/pulse length, sea conditions and performance of the motion sensor, with the maximum total swath widths often limited to around 250 m (125 m per side). Vessel speed was generally around 5 knots, which with a ping rate of between 6 pings sec^{-1} resulted in resolutions across track of 1.5 cm and along track of ~30 cm.

Soundings were corrected for heave, pitch, roll and yaw of the vessel. Sound vertical profiles were calculated from at least two CTD casts per day, and depth data corrected for tidal variation using pressure sensors adjusted to chart datum. Depth data was also corrected for tidal variation using data from the Coffs Harbour, Yamba and Jervis Bay Tide Gauge Stations provided by the NSW Department of Commerce Manly Hydraulics Laboratory. Tides used in post-processing of the data were standardised relative to Australian Hydrographic Datum.

Field surveys with the Solitary Islands Marine Park were targeted at a number of discrete areas (Figure 1). These reef features are marked on the admiralty charts, but there has never been any fine scale mapping of the seabed in these areas. In general, transects were run in order to provide complete coverage over areas of interest, or opportunistically when transiting between areas. Adjacent transects were run with between 10-25% overlap to improve data coverage at the edge of swaths and provide some quality assurance information on the system whilst underway.

In the northern section of the marine park an area offshore of the Minnie Water region was surveyed (which includes an area within Commonwealth waters in the Solitary Islands Marine Reserve). In the middle section of the marine park several large areas were surveyed, including an area south-west of North Solitary Island and from south-east of Jones Point to east of North Rock. Mapping was conducted immediately adjacent to North Solitary Island and North West Rock, and a series of discrete north-south and east-west transects in this area. In the southern section of the marine park surveys were targeted around and adjacent to South West Solitary (Groper) Island, around and offshore of South Solitary Island, and around and offshore of Split Solitary Island. In total, around 192 km^2 of swath coverage was obtained in Solitary Islands Marine Park, with an additional 40 km^2 within Commonwealth waters.

Field collected raw data files were filtered and gridded using GS+ software (GeoAcoustics Ltd., U.K.), with sidescan sonar transects processed into georeferenced mosaics of bathymetry at a grid resolution of 5 m x 5 m. Backscatter data were also gridded (mosaiced) into 5 x 5 m bins after manipulation (including trace normalisation) using GeoTexture (GeoAcoustics Ltd., U.K.). Both spatial layers were imported into bathymetric grids and sidescan mosaics were exported from GS+ as Surfer grid files, converted to ascii format, imported to ArcGIS v9.1 (ESRI Software, USA) as a raster image for use within GIS. The coordinate system of the data frame was set as WGS 1984 UTM Zone 56. Specifications on filter types and their settings used during processing of sidescan sonar data are detailed in [16].

The bathymetry was viewed as a hill-shaded relief (90-120^o azimuth and 30-45^o elevation) to provide a quasi three-dimensional image to aid the digitising process. Backscatter, viewed as a greyscale image, was also used to aid the digitising process. Backscatter data assists in the delineation of reef and non-reef in areas of uncertainty associated with motion artefacts in the bathymetry data. Areas of rocky reef were digitised by hand at a constant scale of 1:2,000 using a combination of the bathymetry and backscatter. Overall, rocky reef areas are characterised by regions of relief, greyscale heterogeneity (texture) and higher backscatter intensity (i.e. darker areas), whereas unconsolidated substrates form regions of relatively little relief, varied to homogeneous textural complexity and weaker (lighter) backscatter.

Rocky reef areas were digitised with a minimum mapping unit of approximately 20 m^2 depending on the complexity of the seafloor features. Polygon shape files were produced for all areas surveyed and compared and aligned to existing nearshore reef boundaries interpreted previously from aerial photography [25]. In areas of overlap, boundaries mapped from sidescan sonar data were preferentially used.

Ground-truthing of acoustic data was provided by a digital underwater video camera which was deployed along selected transects within swath acoustic survey areas. Information on the distribution of visually dominant benthic biota was also collected from video. Transects were generally positioned across depth gradients in areas of heterogeneous backscatter. Within SIMP, a total of 8.8 linear km of video footage was collected in two areas; six transects totalling 7.1 linear km from Sidney Shoals (Figure 2), and one transect covering 1.7 linear km to the south – east of South Solitary Island. Video was captured in colour for areas shallower than 40 m, and black and white for areas deeper than 40 m due to signal attenuation.

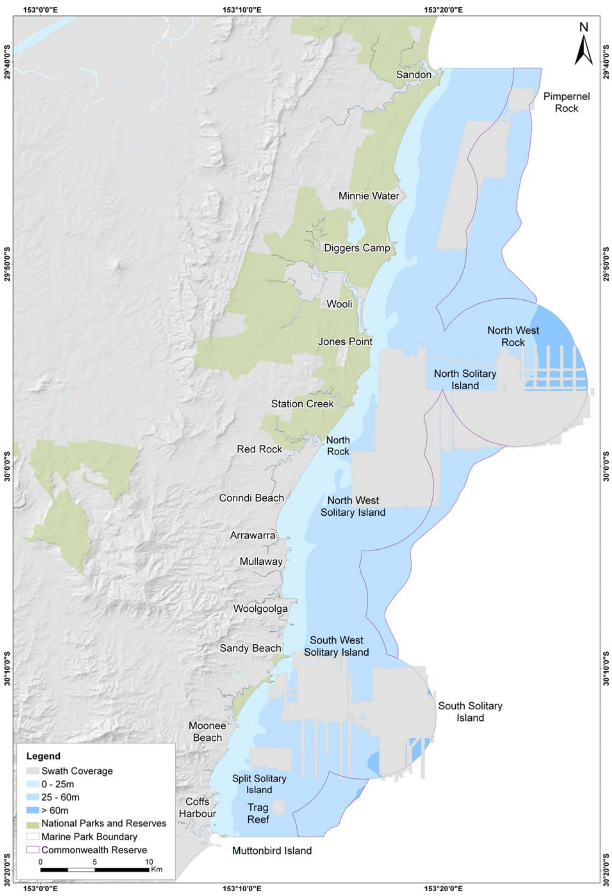

Figure 1. Coverage of sidescan sonar surveys conducted within the Solitary Islands Marine Park and Solitary Islands Marine Reserve (Commonwealth).

Differential GPS location (WGS84), time (UTC), vessel speed, and vessel heading (COG) were overlayed onto video footage and simultaneously logged to a text file. Video footage with associated overlay was recorded in real time on MiniDV tapes and later copied to computer and compressed to a single .mpeg video file. Footage was processed by visually interpreting physical and biological characteristics of the seafloor in 10 sec intervals. At the tow speed of around 1 knot, each of these intervals corresponded to a linear distance of between 5 and 10 m along the seafloor. Physical and biological seabed characteristics were entered into a spreadsheet alongside the geographical midpoint of each interval (Table 1). Video frames were captured as still images from selected clear sections of video footage using FrameShots software. Captured images were used to build a reference collection of habitat classes.

In order to allow analysis of habitat data and meaningful representation of features on a map, detailed physical and biological attributes were aggregated into functional physical and habitat classes based on substrate type and dominant species, or groups of species. Physical classes were defined objectively: those areas where reef was present were classified as reef, areas of mixed combinations of reef/sand/cobble/boulder/pebble were defined as mixed sediment, and areas of sand were classified as sand.

TABLE 1. GEOPHYSICAL AND BILOGICAL ATTRIBUTED FOR CLASSIFICATION OF SEABED HABITATS FROM VIDEO DATA

Rocky reef		Unconsolidated	
Attributes	Modifiers	Attributes	Modifiers
Structure	Patchy	Texture	Fine
	Continuous		Coarse
Texture	Boulder		Cobbles
	Cobble/Boulder		Pebbles
Profile	High	Relief	Ripples
	Low		Waves
Biological	*Ecklonia radiata*	Biological	Molluscs
	Phyllospora comosa		Echinoderms
	Pyura		
	Sponge dominated		
	Turf		
	Barrens		

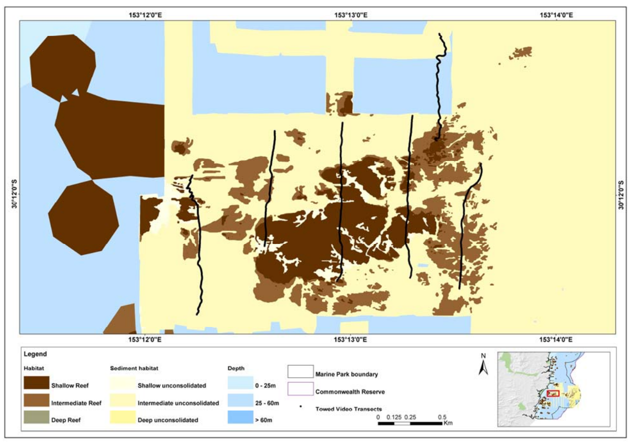

Figure 2. Position of vessel tracks used for video surveys of Sidney Shoals within the Solitary Islands Marine Park

Classified video transects were imported into ArcGIS as a point shapefile with a single point for each classified interval. While the spatial coverage of video was insufficient to interpolate between transects and create a map distribution of habitat classes, the bathymetric position of classified points was used to describe depth related trends in habitat distribution. The physical attribute class was used to assist visual interpretation of swath acoustic and other bathymetric image data.

III. RESULTS

To date a total area of approximately 275 km^2 of continental shelf waters within the Solitary Islands Marine Park and adjacent waters has been swath mapped. This data, combined with maps of shallow reefs digitised from aerial photos, underwater video surveys and Geographical Information System (GIS) analysis is used to create a number of spatial products such as digital elevation models (with analysis of slope and rugosity), vector based seabed habitat maps and spatially-linked data on macro-benthic floral and faunal assemblages.

Overall, there are extensive subtidal rocky reefs throughout the marine park, and while many of these are adjacent to the mainland and the offshore islands, other reefs are present as discrete subtidal features (Figure 3). There are shallow reefs (those <25 m depth) in much of the marine park, mainly adjacent to headlands and offshore islands, many of which also contain intertidal rocky shores. Reefs closer to shore are more common in the southern half of the marine park.

Mid-shelf reefs occur extensively throughout the marine park, including fringing reefs around three of the islands. There are numerous intermediate reefs (those 25-60 m depth) both mid-shelf and offshore. A considerable amount of deep reef (those >60 m depth) was identified during swath acoustic surveys offshore of South Solitary and North Solitary Islands. While the swath-mapping has revealed considerably more rocky reef throughout the marine park than was defined previously from the broad-scale bathymetry and single-beam acoustic transects, the location and extent of all subtidal reefs has not been mapped, particularly those in depths greater than 60 m.

Between Wooli and Sandon rocky reef occurs primarily on the midshelf and as small reefs adjacent to headlands at Sandon, Minnie Water, Diggers Camp and Jones Point (Figure 3). The reefs adjacent to the headlands are mostly shallow and only extend up to around 1 km offshore. A large area of reef located on the midshelf south-west of Sandon Bluffs covering about 10 by 5 km also contains extensive shallow and intermediate reefs, including at least four individual continuous reefs and numerous patchy reefs that are generally less than 200 m long. This reef system extends east of the marine park boundary into the Solitary Islands Marine Reserve (Commonwealth waters), and joins up with the reef system surrounding Pimpernel Rock. It is likely that more reef habitat exists in this region as many of the reefs identified through analysis of the swath acoustic data had not previously been identified from the broad-scale bathymetric data.

The seabed between Wooli and Woolgoolga contains a number of extensive rocky reef systems, including a large area of reef south-west of Jones Point and adjacent to the offshore islands in this region (Figure 3). Extensive shallow reef occurs offshore of Mullaway, around North Rock and north-east of Jones Point, offshore of North West Solitary Island and several kilometers south of North Solitary Island. The majority of shallow reefs adjacent to North Solitary Island occur as a narrow fringe around the island. The deep reef identified south-east of North Solitary Island is characterised by its low relief linear features that run north-east and south-west. The majority of reefs that have been swath mapped are generally patchy and have low relief, in most places rising less than 5 m from the surrounding seabed, although this is not the case adjacent to most offshore islands (Figure 4).

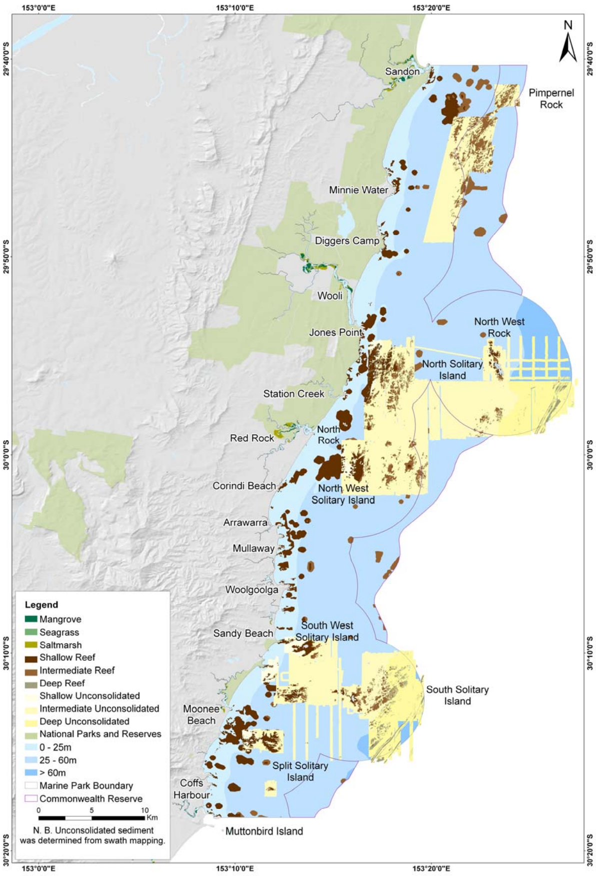

Figure 3. Distribution of known seabed habitats in the Solitary Islands Marine Park and Solitary Islands Marine Reserve (Commonwealth)

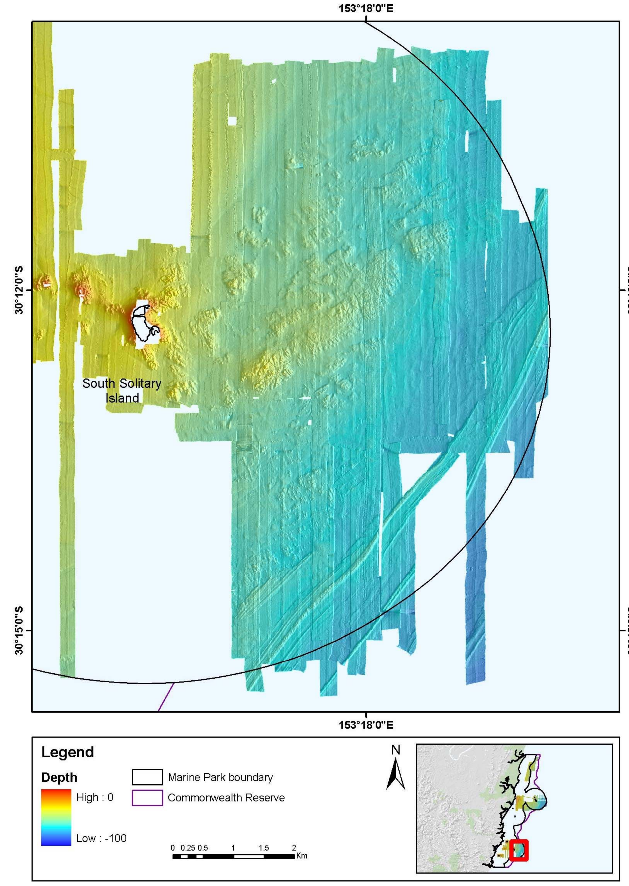

Figure 4. Hill-shaded bathymetric model of the seabed adjacent to and east of South Solitary Island within the Solitary Islands Marine Park

South of Woolgoolga and there are a number of extensive rocky reef systems, mostly associated with or adjacent to the offshore islands (Figure 3). This includes a large area of continuous reef surrounding South West Solitary (Groper) Island, around and offshore of South Solitary Island and Split Solitary Island. Around 5 km to the north of Split Solitary a reef known as Sidney Shoals consists of a continuous central reef area, surrounded by a large area of patchy reef. North of Sandy Beach to Woolgoolga shallow reefs extend offshore of most headlands. An extensive area of deep reef was identified around 5 km east and south-east of South Solitary Island, and is characterised by its linear features that run north-east and south-west through the area. The reef is of low relief and mostly has a low slope.

While swath mapping has only been conducted over a proportion of the marine park, it is clear that much of the seabed consists of unconsolidated sediments of varying sediment size and morphology, which is reflected in the variation in the backscatter intensity. For example, a large area south of North Solitary Island is dominated by areas of lighter backscatter, which is likely to consist mostly of fine to coarse sands (Figure 5). Further west a number of distinct unconsolidated features exist, with higher backscatter indicating the presence of coarser sediment. Similar to other reefs, unconsolidated sediments within the area of patchy reef further inshore have higher backscatter intensity, and are therefore are likely to be coarser and contain varying amounts of pebbles and cobbles.

Video surveys conducted on and surrounding the Sidney Shoals ranged between depths of 10 and 35 m. The seabed was characterised by an irregular mosaic of high and low profile bedrock reef, overlaid with patches of sand and mixed sediments including pebbles, cobbles, and boulders. Reef between 10 and 20 m depth was dominated by coral habitat comprising plate, encrusting, and massive coral types (Figure 6a). Interspersed amongst plate and massive corals were encrusting sponges, bryozoans, and sea urchins including *Centrostephanus rodgersii* and *Phyllacanthus* spp. At depths between 20 and 35 m reef habitats were a mosaic of *Ecklonia radiata*, mixed algae, and sessile filter feeders (Figure 6b). Urchin barrens were found on the shallowest sections of Sidney Shoals, generally in areas of complex reef containing crevices and ledges (Figure 6c). On the deeper sections of the reef system sponges dominated the benthic assemblages, with evidence of a range of species with varying morphology (Figure 6d).

Video transects in the area south-east of South Solitary Island covered depths between 60 and 72 m. Theacoustic coverage from the area shows that the area contains elongate linear sections of high profile reef, and low profile sections of sand and mixed sediments (Figure 4). Analysis of video footage showed that the deep reef (>60 m) and mixed sediments in this area support an abundant and diverse array of sessile invertebrates and other filter feeders. Sponges, corals, gorgonians, sea pens, sea whips, and stalked ascidians were observed on all areas surveyed where reef or mixed sediments were present (Figure 7a,b). Importantly, these communities were not limited to areas of continuous reef, and were found in areas of mixed sediment where hard sediments (e.g. reef/pebble/cobble/boulder) comprised as little as 10% of the substrate. This suggests that the distribution of this habitat may extend beyond the areas defined as reef by acoustic habitat mapping, however, given the relatively small area covered by video transects it is not possible to estimate the extent of this habitat.

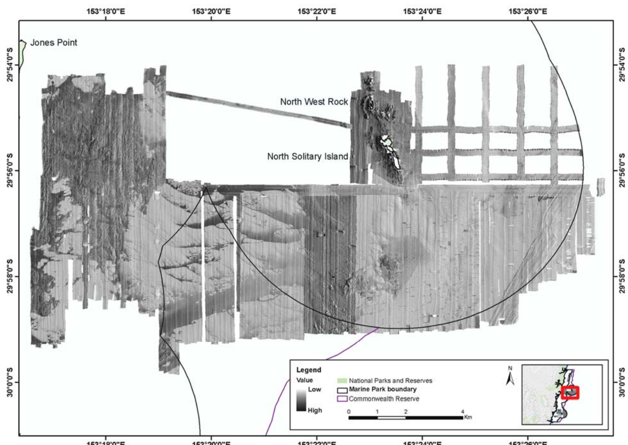

Figure 5. Acoustic backscatter of the seabed offshore of Jones Point and North Solitary Island in the Solitary Islands region

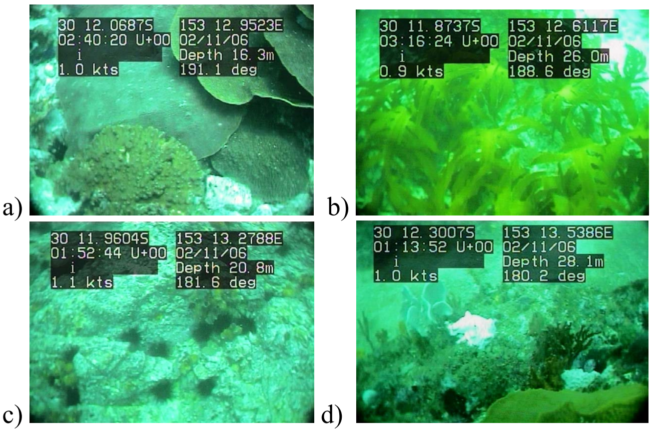

Figure 6. a) Coral dominated habitat, b) *Ecklonia* on mixed sediment, c) urchin barrens and d) sponge dominated reef habitat

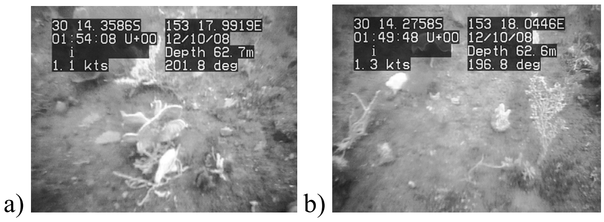

Figure 7. Sponge dominated habitat south-east of South Solitary Island

IV. DISCUSSION

Firstly, the broad distribution of consolidated habitats (i.e. bedrock) within the Solitary Islands Marine Park reflects the patterns of bedrock geology which vary in their geomorphic attributes (e.g. grainsize, hardness, bedding, jointing) and resistance to weathering. Consistent with the pattern along most of the NSW coast there are prominent rocky reef outcrops seaward of most headlands in this region, although the present surveys have also identified significant rocky reef systems in areas on the continental shelf that are not continuous to shore, or are continuous to shore associated with offshore islands. There are also a number of significant reef features that occur offshore of ocean beaches in the region. A broad description of the geology and morphology of the continental shelf in the northern NSW region has previously been described [26,27].

Extensive areas of subtidal rocky reefs in the inshore, mid-shelf and offshore areas of the marine park were identified through swath mapped using a combination of high resolution acoustic bathymetry and backscatter. The reefs varied considerably in their profile and extent of patchiness, although there was no particular latitudinal or cross-shelf trend in reef structure. The region is characterised by a series of islands ranging from 2-12 km from the mainland coast. Shallow rocky reefs fringe the islands and are also a dominant feature of the seabed habitats across the inner and mid-continental shelf.

Overall, benthic communities on rocky reefs throughout the marine park contain a mix of tropical, subtropical and temperate species, reflecting latitudinal and cross-shelf gradients of water temperatures and ocean currents [28]. Like most shallow inshore reefs in NSW, shallow inshore reefs in the marine park are characterised by abundant macroalgae [29,30], dominated by the kelp *Ecklonia radiata*, and various species of *Sargassum* and *Caulerpa* [20,21,31]. The abundance of *Ecklonia* also varied considerably over spatial scales of around 100 m resulting in small scale changes in habitat types defined by [32] (i.e. *Ecklonia*, turf and deep reef habitats).

These reefs generally also contain an understorey of coralline algae and a diverse range of foliose algae, including species of *Zonaria*, *Rhodymenia* and *Ulva*. There are also sponges, ascidians, and other sessile invertebrates on shallow reefs, but these are not generally the dominant assemblages. Corals do occur on the shallow inshore reefs, but primarily as a small component of the understorey assemblage. Barnacles and solitary ascidians (sea squirts), such as the pyurids *Herdmania momus* and cunjevoi *Pyura stolonifera*, can also be dominant on shallow exposed reefs, as can areas of bare rock. While there was limited video coverage in depths <10 m, there is a known 'fringe habitat' that occurs to a depth of around 3 m along much of the NSW coast, dominated by foliose algae (e.g. *Ecklonia radiata*, *Sargassum* spp. and *Zonaria* spp.) and smaller amounts of coralline algae [32], and it is likely that such a habitat occurs within this region. However, the algal species composition of the fringe habitat can vary, with some shallow reefs dominated by the phaeophyte *Dictyopteris muelleri*, with other macroalgae including *Ulva*, *Sargassum* and *Padina* also important components of the benthic cover [33].

On intermediate reefs (i.e. those between 25-60 m depth) the benthic assemblages in the marine park are dominated by a range of sessile invertebrate species of sponges, stalked ascidians, octocorals, soft corals, anemones and bryzoans, often referred to as 'sponge gardens' [34]. Sponges were present with a diversity of growth forms including elongate, branching and erect, tubular and vase, although the cover of particular forms was highly variable, as was the presence of other sessile invertebrates such as soft corals and ascidians. The high diversity in growth forms of sponges on much of the reef indicates a high species diversity as sponge morphological diversity can provide a qualitative estimate of sponge species diversity [35], although large plasticity in growth forms for some species [36] is likely to be a problem when examining spatial diversity.

Overall, the abundance of macroalgae decreases with increasing distance from shore resulting in deeper reefs and those around offshore islands being dominated by 'sponge gardens' and coral habitat [see references in 24]. In general, the richness of coral species increases in an offshore direction, and the northern islands generally support a higher cover of coral and a lower cover of turfing and calcareous algae than the southern islands [21,31,37]. There is a trend towards tropical coral species in offshore areas and subtropical to temperate species on inshore sites [38]. The greatest diversity occurs at North Solitary Island, where

43 species have been recorded, although some of these are ephemeral [21]. Compared to tropical areas, soft corals are less abundant here, being replaced by a mixed invertebrate assemblage of solitary ascidians, barnacles and other sessile, suspension-feeding species.

On the deep reefs (i.e. those >60 m deep) benthic assemblages are dominated by sponges and a mixed assemblage of sessile invertebrates. These include such groups as stalked ascidians, sea-whips, gorgonians, hydrozoans and black coral. While a variety of sponges and other sessile invertebrates also occur on shallow reefs, they are not generally the dominant assemblage.

Given the small area sampled through the use of towed video, there are also operational limitations (in both time and costs) which results in benthic habitats mostly being mapped as reef and unconsolidated classes, with the dominant floral or faunal sessile assemblages (e.g. kelp, corals, sponges etc.) described as general patterns defined by depth and distance offshore. It is difficult to map the exact extent of these specific habitats that define lower hierarchical classification levels as they can only be defined using video techniques, and often video transect spacings are greater than the spatial patches of the habitats. In addition, as variation in dominant species composition can occur at spatial scales of 10's m to 10 km's in the reef habitat types defined at the level of biological facies and micro-communities, it is difficult to predict the exact dominant assemblage based on knowledge of physical factors such as geomorphology, depth, distance offshore and exposure. This is particularly the case in the Solitary Island Marine Park region which is strongly influenced by both tropical and temperate oceanic conditions and benthic assemblages occur within a complex array of varying seabed habitats.

Areas of unconsolidated seabed in the northern NSW region consist mainly of material from rivers and streams, relic quartzose (i.e. material resembling or containing quartz) and carbonate rich sands [28]. Overall, unconsolidated habitats are extensive throughout the continental shelf waters of the SIMP, and are dominated by coarse sediments reflecting the absence of finer coastal sediments, and the influence of strong tidal currents and oceanic swells. There is considerable along-shore and cross-shelf variation in morphological zones on the continental shelf of northern NSW that reflect sediment processes at previous sea-levels and recent transport by currents [26]. While a number of broad zones have been identified, the swath mapping revealed significant fine-scale structuring of unconsolidated habitats, influenced primarily by the presence of sand ripples and waves, and variations in particle size and shell content [39]. There are also areas that contain small amounts of boulders, cobbles and/or pebbles, particularly adjacent to areas of rocky reef. Further details on the broad-scale distribution of soft-sediments in the Solitary Islands Marine Park are presented in [17].

These gradients in sediment type, in combination with depth, can result in considerable differences in macrofaunal composition [6,40]. As many as 241 species of infauna has been identified from soft sediment habitats in the marine park (which excludes potentially diverse groups such as polychaete worms and isopods [41]. Approximately 85% of the species identified in the soft-sediment samples to date have not previously been listed for the SIMP region, and there was increasing species diversity and composition from shallow sites (20 m) to intermediate sites (50 m) [41]. Differences in species composition were also found between samples taken from coarser grained gravely substrates, sand and mud areas. Most of the animals within this habitat occur as infauna, although the habitat also commonly contains larger sessile macrofauna (e.g. sponges, ascidians, bryzoans, seawhips) that increase the diversity and complexity of the habitat [1,6]. It is likely that variations in seabed complexity will influence the faunal assemblage as various taxa are known to associate with microhabitat features such as shells, burrows and biogenic depressions [42]. This suggests that analysis in relation to CAR planning criteria for these habitats requires a sound understanding of the physical structure of the habitat and how this influences macrofaunal assemblage distribution and composition.

A key objective of Australia's National System of Representative Marine Protected Areas (NSRMPA) is the conservation of biodiversity [43], primarily through the inclusion of a representative selection of biodiversity within fully protected marine parks or 'no take' sanctuary zones in multiple-use marine parks. The previous determination of sanctuary zones in the SIMP was previously constrained by limited seabed mapping coverage and little information on the spatial configuration of reef assemblages [19]. A recent refinement of a Habitat Classification System used for assessing zoning arrangements of reefs in SIMP include distance-from-shore attributes (i.e. distance to the mainland coast) [44]. This was based on the composition of fish species, although the composition and abundance of dominant habitat forming sessile biota also has a cross-shelf component, and in combination with the local oceanography, influences the spatial distribution and abundance of reef fish assemblages. The recent swath mapping with the SIMP has significantly improved the effectiveness of surrogates in the planning process by defining the extent and distribution of reefs throughout the region and allowed a better understanding of the spatial structuring of unconsolidated habitats.

Mapping tools to collect such high resolution bio-physical data of the seabed have developed considerably in recent years, and their increasing application to a range of research and management issues reflects this. Side-scan sonar results in considerably wider coverage than single-beam systems and have been used to map individual habitats [45], or a range of habitat types [46,47]. The application of interferometric sidescan sonar that collects geo-referenced depth and sidescan amplitude data provides the capability to use both bathymetry and backscatter to delineate habitat types [48]. Multi-beam echo-sounders acquire bathymetric and backscatter soundings across a wide swath of seabed using a number of acoustic beams, although the width of the acoustic swath is beam width and depth dependent. The system allows an assessment of surface roughness based on the variation of backscatter amplitude.

Recent studies have examined the relationships between multi-beam acoustic backscatter, physical habitat and benthic assemblage structure and the potential for using such systems for routine seabed mapping [49,50]. Further development of backscatter analysis techniques will allow identification of a broad range of seabed habitat types and finer detail on the dominant benthic community. These techniques still require the use of video to ground truth classifications (particularly on rocky reef areas), and obtain detailed information on macrofauna and flora and physical parameters. The video footage can also be used to quantify cover of biota and measure objects when fitted with paired laser beams [51], and allow accurate morphological measurements through 3-D reconstruction [52] or the use of stereo cameras [53].

While broad scale bioregional assessments are useful for defining overall marine park boundaries [e.g. 13], insufficient fine-scale seabed habitat data (particularly on the continental shelf) is often available to ensure MPA zoning results in a comprehensive and representative protection of biodiversity. Therefore, mapping of seabed habitats is increasingly becoming regarded as an essential requirement for planning a network of MPAs [9,14,54]. Particularly in relation to representativeness, a habitat-based approach can be an effective alternative to an MPA design based on the distribution of individual species [54], as they can often be effective as surrogates of species diversity [55]. This is particularly important as detailed spatial information on the distribution of a wide range of individual species is generally limited and information on the spatial distribution of habitats is required for evaluation of the primary CAR criteria.

The swath mapping program outlined here has provided more detailed information on the spatial distribution and extent of seabed habitats on the continental shelf of the SIMP region. As habitats can be defined at a number of hierarchical levels and spatial scales, further analysis of ground-truth data and quantification of parameters such as slope and rugosity will allow further delineation of seabed habitat types. This is important, as while there is some capacity to predict communities within broad habitat types such as rocky reef and unconsolidated sediments, intra-habitat variation in assemblage structure should also be considered to ensure community diversity is provided protection within 'no-take' zones (44,56].

In addition to evaluating the primary criteria of CAR, seabed habitat maps can also provide the spatial information required to select MPA boundaries that maximises habitat heterogeneity. The spatial information can also be used as a GIS framework for more detailed community descriptions to be developed as further resources become available to conduct finer-resolution seabed mapping and biological assessments. The broad nature of video surveys means that only dominant macrofauna and flora can be delineated and unique features at the assemblage or species level can be missed. Therefore, additional biological information is needed if the protection of small-scale unique features or species is to be incorporated into the MPA planning process. It is also important that locations are of sufficient size with suitable boundaries to minimise the loss of protected species to adjacent areas [57]. Much of this information often already exists but requires analysis in relation to the MPA planning criteria. The high resolution data provides the capacity to design targeted biological surveys that aim to identify important and unique features requiring some level of protection that may not be protected by the present marine park zoning plan.

In conclusion, habitat mapping is an essential component of the overall research needed to increase the likelihood that MPA zoning results in a comprehensive and representative selection of biological diversity. Swath mapping techniques with increased resolution and often complete coverage should improve the ability to incorporate MPA planning criteria with detailed spatial information on seabed habitat distribution, particularly when it incorporates spatial heterogeneity and habitat linkages [44]. The high resolution depth data can also be used to examine reef roughness, slope and depth, and the habitat layers can be draped over the DEM to provide a visual 3-D representation of the substrate surface. Continual software developments are also providing the capacity for improvements in data integration and visualisation and improved data processing flow.

V. REFERENCES

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