FRDC FINAL REPORT

LINKING HABITAT MAPPING WITH FISHERIES ASSESSMENT IN KEY COMMERCIAL FISHING GROUNDS

Alan Jordan, Vanessa Lucieer and Miles Lawler

August 2005

FRDC Project No. 2003/050

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Ph. (03) 6227 7277 Fax (03) 6227 8035

The bathymetric information presented in this report should not be used for navigational purposes

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Tasmanian Aquaculture and Fisheries Institute
Marine Research Laboratories

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1. Project summary

2003/050	Linking habitat mapping with fisheries assessment in key commercial fishing grounds

PRINCIPAL INVESTIGATOR: Dr A. Jordan

ADDRESS:
Marine Research Laboratories
Tasmanian Aquaculture and Fisheries Institute
University of Tasmania
Private Bag 49,
Hobart TAS 7053
Ph: 03 6227 7226 Fax: 03 6227 8035

OBJECTIVES:

1. To map the fine-scale biological and physical structure of rocky reef habitats in south-east and north-east Tasmania abalone fishing blocks

2. To contribute to the survey design and outcomes of the FRDC abalone project (2001/074) and ongoing abalone assessment by linking information on reef and macroalgal extent and structure to abundance and population parameter assessments

3. To further develop cost-effective techniques for fine-scale habitat mapping and classification

NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED TO DATE

- Detailed habitat maps in key abalone fishing blocks have provided researchers, industry and managers with an improved knowledge of the significant variation in the extent, distribution and structure of reef habitat within Tasmania and the likely influence this has on abalone stock productivity and long-term sustainability.
- The provision of spatial information on reef structure at a range of spatial scale will improve the selection of representative sites for continuing fishery independent abundance surveys and examination of spatial variations in population parameters.
- The information of the distribution and extent of urchin barrens provides an assessment of the reduction in productive abalone habitat and a reference point in which to monitor future patterns of extent and distribution in north-east Tasmania.
- The project has considerably progressed R&D in effective mapping techniques using single-beam acoustic methodology by examining aspects of field survey design, data post-processing and procedures for spatial interpolation.

- The outputs are an important contribution towards a framework for a national habitat classification scheme through the detailing of acoustic decision rules used for defining seabed habitats and contextual decision rules for final attribution and cartography.
- Provision of around 344 km^2 of additional spatial information on seabed habitats has considerably improved the usefulness of the Tasmanian node of the Australian Oil Spill Response Atlas.

The Tasmanian commercial fishery for blacklip abalone (*Haliotis rubra*) and greenlip abalone (*H. laevigata*) contributes a significant component of the total Australian abalone catch, with annual landings of around 2590 tonnes in 2003. The catch consists primarily of blacklip abalone (around 95%) which is taken throughout the State, with the greenlip catch restricted to the north coast and Bass Strait islands. The catch of blacklip abalone is not evenly distributed around the State reflecting a range of issues including stock abundance, fishing area accessibility and market preference for particular sized animals.

Spatial management of the fishery occurs at three levels of geographic zones (Eastern, Western and Northern), fishing blocks and fishing sub-blocks. The south-east region of Tasmania between southern Southport Lagoon and Whale Head, which makes up a large proportion of block 13 (sub-blocks C-E) consists of extensive reef habitat that supports annual blacklip abalone commercial landings averaging at around 395 tonnes over the past decade. This represents around 10% of the statewide catch despite representing only 0.8% of the Tasmanian coastline indicating the highly productive nature of this area. In contrast, the north-east fishing blocks 30 and 31 represent around 3% of the coastline but over the past decade have had annual average landings of only 33 tonnes (which in block 31 consists of a small proportion of greenlip abalone). While recent landings have been small, the region supported significant blacklip abalone catches during the 1980's (with a peak of 300 tonnes in block 30 in 1983 and 225 tonnes in block 31 in 1985). There is evidence that this was driven by this high fishing effort in the 1980s resulting in considerable serial depletion of reefs, which combined with poor recruitment has resulted in many reefs in this region becoming 'unproductive' in terms of abalone stocks.

The primary objective of this study was to map seabed habitats in abalone fishing blocks in north-east (blocks 30, 31) and south-east (sub-blocks 13C-E) Tasmania in order to better understand the extent, distribution and structure of rocky reef habitats within these regions. Such information was seen as an important component of the overall research required to improve the long-term sustainable management of abalone fishing in these blocks. The reefs were mapped at a number of scales in order to determine the overall amount of reef, spatial patterns of reef systems, fine-scale (~1-10 m) structuring (i.e. profile, proportion of sand), patterns of macroalgal assemblages and extent of urchin barrens.

Seabed habitats were mapped through a combination of aerial photography, single-beam acoustics, sidescan sonar and underwater video. Habitats were defined at several hierarchical levels with seven distinct seabed types identified (continuous reef, patchy reef, sand, hard sand, silty-sand, silt and seagrass) based primarily on visual differences in the first and second echo on the echogram and real-time attribution. Single-beam acoustic analysis and visual observation was also used to determine the surface and sub-surface distribution of the giant kelp (*Macrocystis pyrifera*). Detailed bathymetric contours were developed for the survey areas and patterns of reef profile were also identified from analysis of variations in the sounder detected bottom. Sidescan sonar analysis revealed the offshore distribution of rocky reef and unconsolidated unvegetated habitats in the north-east blocks. Video surveys were used to confirm habitat attribution from the acoustic analysis and obtain detailed information on fine-scale reef patchiness, dominant macroalgal assemblages and extent of urchin barrens.

Overall, approximately 344 km^2 of seabed was mapped during the project, with video surveys covering a total of around 50.6 km of reef habitat in the south-east and 20.9 km of reef in the north-east. Mapping revealed considerable differences in the estimated area of rocky reef habitat between the various abalone blocks reflecting a number of factors; primarily the length of coastline within the sub-block, local bathymetry, presence of offshore islands and large-scale geomorphology. The largest reef areas were identified in sub-blocks 31A, 13D and 13E, with 30A and 30B having the smallest areas. Sub-blocks 13C-E contain a large area of continuous dolerite reef habitat that extends from intertidal waters to depths of over 50 m, including the offshore islands and reefs around the Acteaon and Sterile Islands. This reef system is an unusual subtidal feature of south-eastern and eastern Tasmania as much of the inshore reef in this region is limited to a narrow coastal fringe. However, much of the reef in these sub-blocks (particularly 13D, E) is in depths >20 m and therefore much of the abalone fishing occurs within a much smaller area than that presented.

The north-east blocks contain extensive areas of granite dominated rocky reef habitat, particularly in sub-blocks 30C, 31A and 31B that are characterised by a highly patchy structure often containing a broad area of sand between the intertidal zone and the inner edge of the reef. The overall extent of reefs indicates up to four times the area of reef in the 0-10 m depth range in block 31 compared to those in block 30, although this pattern is not consistent in the 10-20 m depth range. In comparison, the area estimate for the 0-10 m depth indicates around twice the area in that depth range in block 31 than that present in the south-east sub-blocks of 13C-E.

A comparison between reef area and historical abalone catches at the fishing block scale indicates that while it is clear that the high catches historically taken from all of these blocks is due in large part to the extensive area of shallow reef habitat, there is no simple relationship between abalone abundance (reflected as catch) and available abalone habitat. It is likely that factors such as spatial structuring of reef, algal productivity and local hydrography are likely to be just as important in determining abalone productivity and the influence these have on such things as recruitment and maintenance of egg production through protection of large individuals on deeper but continuous reefs. The mapping has revealed considerable differences in the structuring of the reefs at a number of spatial scales between the north-east and south-east that may account for some of the historical catch trends. In addition, urchin barrens were most extensive in sub-block 30A where maximum barrens coverage was around 55% in the 15-20 m depth strata and only slightly less in the 10-15 m and 20-25 m strata. As there was little evidence of barrens in depths <10 m there appears to be little direct loss of abalone habitat in the depths targeted by much of the fishery although there may be a large loss of algal production on adjacent deeper reefs reducing the productivity of shallow reefs.

Overall, such information provides a better understanding that the structure and distribution of rocky reef habitat varies considerably between fishing blocks within Tasmania and that this strongly influences the productivity and long-term sustainability of abalone fishing at this geographic scale. The historical trends in abalone landings between the north-east and south-east blocks indicates a substantially higher risk of stock collapse associated with high levels of fishing pressure within blocks where reef is patchy at a range of spatial scales. Such patchiness is likely to strongly influence factors such as recruitment, abundance of available drift algae and detection of stock decline due to serial depletion of isolated reefs. Such information should be incorporated into a more formal risk assessment conducted as part of the ongoing fishery assessment process and related management arrangements.

The spatial data will also provide an important benefit to abalone abundance survey design at several spatial scales relevant to abalone assessments, including the sub-block and site scale. Firstly, within sub-blocks the identification of isolated patch reefs in the north-east will be useful when planning manipulative experimental work in the region. Secondly, maps of high resolution available at a large-scale will assist the identification of abalone habitats where appropriate relative indexes of abundance could be established. The habitat maps will also provide significant benefit to the detailed assessment of spatial patterns of fishing effort through the use of GPS data loggers on commercial vessels. It has also provided an important reference point of the extent and distribution of urchin barrens in which to monitor future spatial patterns in north-east Tasmania.

The component of the project to further develop cost-effective techniques for fine-scale habitat mapping and classification has provided considerable benefit to other research groups conducting seabed mapping. Firstly, developments in the processing of the sidescan sonar backscatter collected during this project will assist others conducting similar analysis. The further development of protocols for single-beam acoustic surveys will also benefit groups using similar techniques. While recognising the use of various remote sensing platforms for seabed mapping throughout Australia, this project has provided an important contribution towards developing a framework for a national seabed habitat classification scheme. As well as being available on the accompanying CD-ROM, the habitat and bathymetric maps generated from this project are available on the Tasmanian node of the Australian Oil Spill Response Atlas and the SEAMAP Tasmania web site (www.utas.edu.au/tafi/seamap) therefore making the information available to a range of industry and government sectors and the wider community.

KEYWORDS: **Seabed habitats, rocky reefs, abalone, macroalgae, urchin barrens**

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We gratefully acknowledge the assistance provided by the crew of FRV *Challenger* for their assistance in the field. Special thanks to Andy Bickers for providing the sidescan sonar and endless enthusiasm and Taina Honkalehto for her acoustics support when it was most needed. We also would like to thank Craig Mundy and the rest of the TAFI abalone team for their input and Colin Buxton for his continued support for this work.

2. Background

The south-east region of Tasmania between southern Southport Lagoon and Whale Head (abalone sub-blocks 13C-E) consists of extensive reef habitats that support a range of commercial and recreational fisheries. Annual commercial landings include 360 tonnes of blacklip abalone (*Haliotis rubra*) in 2003, with an estimated value of around $15 million, representing 15% of the Tasmanian catch and a considerable amount of world production. Abalone catches in this block has increased considerably since the early 1990's when landings were around 150 tonnes p.a. Given the large increase in landings, and that the fishery in this area in almost entirely dependent on new recruits to the fishery, the sustainable management of this region is critical.

In contrast, the north-east region (abalone blocks 30 & 31) has seen a significant decrease in abalone landings from around 400 tones in the mid 1980s to around 50 tonnes during the 1990s and only 36 tonnes in 2003. There is evidence that this was driven by high fishing effort in the 1980s resulting in localised recruitment failure. Landings in recent years have remained at very low levels in block 30 but remained slightly higher in the adjacent block 31. The potential for further recruitment failure due to the shift in effort to block 31 has been highlighted in the 2000 and 2001 Tasmanian Abalone Fishery Assessment Reports (Tarbath *et al*. 2001, 2002). In this region there are many reefs that have in recent years become 'unproductive', with little evidence of abalone recruitment to these areas (Tarbath *et al*. 2002).

An additional need for habitat mapping, particularly in blocks 30 and 31 in the north-east is the mapping of urchin barrens caused by intense grazing by the long-spined sea urchin *Centrostephanus rodgersii*. There is evidence of significant barren areas in the north-east from specific site surveys (Johnson *et al*. 2004). The structure of these 'unproductive' reefs compared to those that have remained productive under high fishing mortality has not been examined but is an important question for the future management of the fishery.

Abalone are dependent on reef habitat for food and shelter throughout their entire post-settlement life-history, and the availability of suitable habitat is probably an important component of productivity and stock abundance at local and regional scales. The extent of reef habitat and structure of the habitat varies considerably around Tasmania. For example, in south-east Tasmania around 30% of coastal reef habitat occurs adjacent to only 1% of the coastline (Barrett *et al*. 2001), resulting in significant differences in reef area between abalone fishing blocks. Some differences also occur in the macroalgal structure of the reefs, although as this is related to depth and relief, level of exposure and hydrographic conditions there are many reefs of similar structure given comparable conditions. However, the extent to which patterns in habitat area and structure relates to spatial variations in productivity of the key reef fisheries in Tasmania is unknown.

Abalone abundance surveys are being conducted in these regions as part of the FRDC project (2001/074) 'Linking fishery-dependent and independent assessments of abalone fisheries' which aims to establish an appropriate relative abundance index for a range of abalone habitats. Abalone are known to be more abundant on reefs with complex topography, possibly due to predation and recruitment factors. Their abundance is further influenced by depth, exposure and algal biomass. Abalone growth rates and size at maturity can also vary over small spatial scales. There is, however, little understanding of what factors determine such variations, but it is likely that habitat structure may be important, possibly due to its influence on predation, food availability and recruitment.

The project described here will contribute to on-going abalone assessments by identifying and mapping abalone habitat at a fine spatial scale. This is important in order to examine correlations between habitat variables and catch rates and population parameters. It will also substantially increase the suitability of site selection in estimates of abalone abundance. Maps analysed at the large scale (ie. ~1:100,00) can also lead to more effective spatial management of the abalone fishery at the block scale by examining the relationship between habitat distributions and fisheries productivity. It will also help assess the impact of habitat change on ongoing productivity, a key question for the management of the fishery in north-east Tasmania. One component of this relates to the expansion of urchin barrens resulting in a significant decrease in reef productivity. While the barrens are known to occur in the north-east no comprehensive mapping has been conducted at the scale of fishing blocks.

Fine-scale mapping of reefs can provide considerable information on patterns of physical and macroalgal structure and this is now achievable given recent technological advances in echosounders and backscatter analysis, digital underwater video, differential GPS and Geographic Information Systems (GIS). TAFI has developed a cost-effective toolkit for conducting this mapping and has been working with agencies from SA, Vic, WA and NSW to apply this technology to coastal mapping throughout Australia. An important component of this R&D is the development of a hierarchical habitat classification scheme that can be applied at a range of mapping scales.

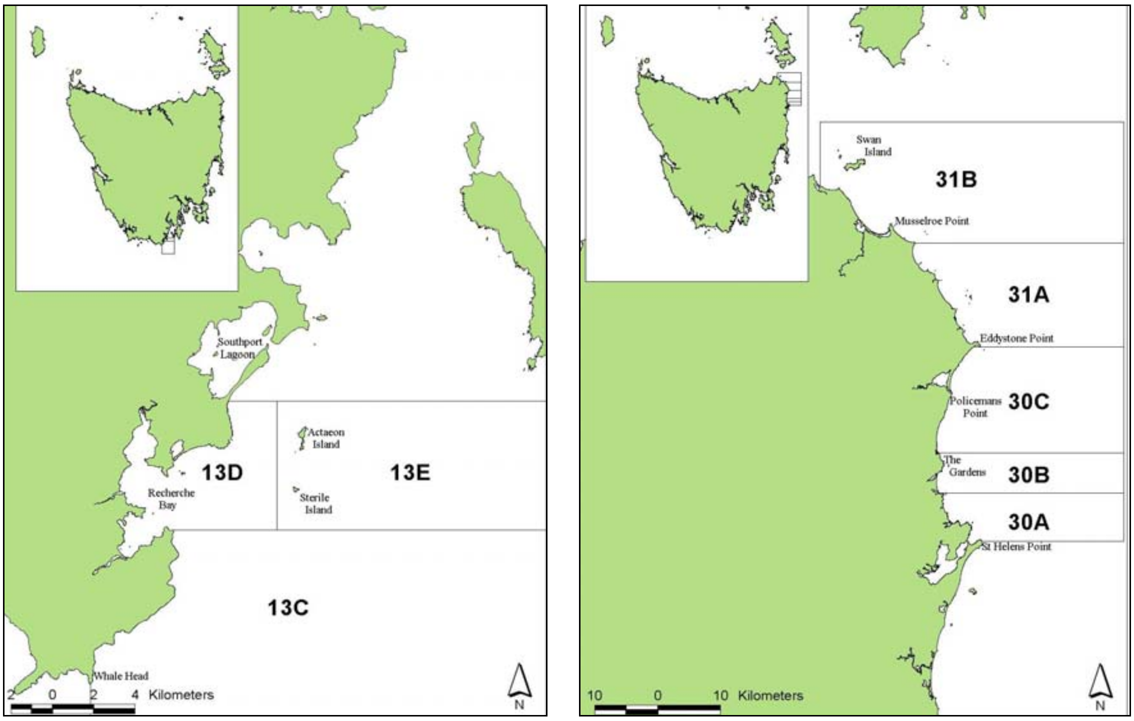

Fig. 1. Spatial distribution of abalone fishing blocks in south-east (sub-blocks 13C-E) and north-east (sub-blocks 30A-C and 31A, B) Tasmania.

3. Need

The need for fishery independent abundance surveys and assessment of physical and species interactions for abalone in Tasmania are high priority issues in the Tasmanian Abalone Strategic Research Plan and a review of abalone research needs (FRDC project 98/170). This is reflected in the current abalone FRDC project (2001/074) and ongoing abalone abundance surveys. The project reported here will significantly contribute to this research by providing fine-scale maps of the biological and physical structure of abalone habitats which will help to optimise abalone abundance and population studies by having better criteria on which to select survey sites. It will also further improve abalone assessments by providing estimates of reef habitat for several key blocks and assisting in the correlation of environmental and habitat variables on catch rates and population parameters. In particular, there is a need to examine the structure of reef habitats in north-east Tasmania where many areas have become ‘unproductive’ for abalone in recent years and there are considerable urchin barrens present, the extent of which is required through detailed mapping.

In addition, further R&D is needed in the area of cost-effective acoustic and video assessment techniques and the transfer of technology to other agencies. The increase in coastal mapping in Australia also requires a framework and consistency for classifying habitats at a range of hierarchical scales, which requires a significant input from mapping projects such as reported here for the classification scheme to be comprehensive and representative.

4. Objectives

1. To map the fine-scale biological and physical structure of rocky reef habitats in south-east and north-east Tasmania abalone fishing blocks

2. To contribute to the survey design and outcomes of the FRDC abalone project (2001/074) and ongoing abalone assessment by linking information on reef and macroalgal extent and structure to abundance and population parameter assessments

3. To further develop cost-effective techniques for fine-scale habitat mapping and classification

5. Methods

5.1 Aerial photography

Colour aerial photographs were used to obtain information on the distribution of shallow seabed habitats throughout the study areas. Images that were taken since December 2001 were selected for good water clarity, low sun angle and low wind conditions resulting in minimal surface disturbance (Fig. 2). Thirteen photographs were obtained for the along the north-east coast between St Helens Pt and Swan Island and two photographs for the south-east region. The images were scanned at 600 dpi (dots per inch), saved as a 24 bit colour *.tiff* image and registered to the 1:25 000 coastline supplied by the Land Information Service Tasmania (LIST) with a minimum spatial accuracy of 12.5m on the ground. The images were rectified within ArcInfo (Environmental Systems Research Institute - ESRI) and found to have an average positional error of 5.7 m.

Reef areas interpreted from the aerial photograph assumed that no vegetation existed on the sand (i.e. drift algae) and all dark areas in the image were initially classified as reef. Areas that were patchy and covered an area of less than the minimum mapping unit of 0.03 hectares were combined into single polygon areas. The reef delineation process was carried out preserving the maximum detail obtainable from the photograph with boundaries digitised using ArcView 3.2. Often the photograph did not allow determination of the outer reef boundary due to increasing water depths and lack of contrast between reef habitat and adjacent unconsolidated areas. Reef polygons were loaded into ArcPad 6.0 and used to guide field transects onto some of the small reef areas in the centre of beach zones and were positionally verified from video transects.

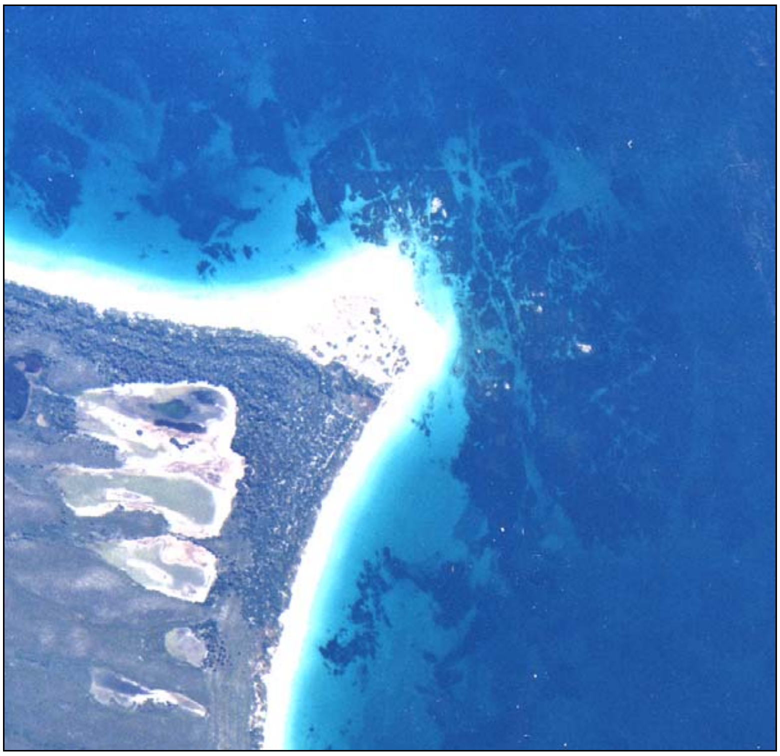

Fig. 2. Representative aerial photograph of coastal habitats in north-eastern Tasmania

5.2 Field surveys

5.2.1 Single beam acoustics

A 6 m research vessel was equipped with a Simrad ES60 scientific sounder connected to a 120 kHz Simrad transducer that was mounted on an outrigger on the starboard side of the vessel and suspended 0.7 m below the water surface (Fig. 3). The sounder was set with a power output of 100 W, a pulse length of 0.256 ms and a ping rate of 2 ping sec^{-1}. The echogram was displayed on a laptop computer and the sounder output logged using the ES60 logging software. In addition, water depth and position were logged on a laptop computer into the software program *Seabed Mapper 2.4* at 2 second time intervals with position and depth obtained from a Garmin 135 GPS/sounder map unit coupled with a Omnilite 132 DGPS differential unit. Vessel speed was approximately 6 knots during all acoustic transects resulting in the ES60 points being logged every 1.5 m and a *Seabed Mapper* point approximately every 6 m.

In many shallow areas (generally <5 m) it was possible to determine habitat type and boundary position (primarily reef and unconsolidated) through visual observation over the side of the vessel or using an underwater glass viewer. This information was logged in real time into *Seabed Mapper* resulting in a second set of point data that could be used for boundary attribution. Additional point data on the position of the giant kelp (*Macrocystis pyrifera*) was also logged in real time.

Fig. 3. Set-up of pole-mounted echosounder transducer on 5 m vessel used for inshore surveys.

5.2.1.1 Regular surveys

Extensive field transects were conducted with the single-beam sounder throughout the two survey areas of south-east and north-east Tasmania. A combination of fixed transects (i.e. predetermined spacings and displayed in *ArcPad*) and targeted tracks were conducted, the spacing of which was determined by assessment of habitat distribution from aerial photographs, knowledge of geomorphology, exposure, bathymetry, hierarchical level of classification required and available survey time. Within the south-east region (abalone fishing blocks 13 C-E) the transects were generally at around 100 m intervals running approximately perpendicular to the coast (Fig. 4). A similar transect survey design was used in the north-east region (blocks 13 C-E), although in some sections of the coast a combination of poor weather, small boat access, navigational hazards and absence of reef detected in aerial photographs resulted in wider transect spacing (Fig. 5). In this region, the patchy nature of the reef meant that often habitats were crossed at closer intervals when the 100 m transect spacing did not identify a habitat boundary.

In the case where habitats were identified on a transect, but not on those adjacent, habitats were re-surveyed with closer track spacing to ensure adequate boundary delineation, and this is referred to as a process of ‘adaptive sampling’. The nature of transect sampling results in more attributed points along the transect than between them, so in areas where habitats changed frequently, both cross-shore and along-shore transects were often conducted. This results in a complex array of survey tracks that aims to minimise uncertainty due to track spacing in boundary delineation during the interpolation process.

5.2.1.2 Track spacing survey

A field survey was also conducted to examine the effect of variable track spacings using single beam acoustics to determine the distribution and extent of reef habitat. The survey was conducted over a 1.25 km^2 area on the north east coast of Tasmania where there was little existent bathymetric and substrate data (Fig. 6). Transects were conducted in depths between 2 and 16 m using parallel and horizontal transects spaced at 50 m intervals resulting in 25 perpendicular transects with an average length of 900 m and four horizontal transects 1230 m in length. Where possible, transects were extended beyond the actual sampling area to avoid disturbances in the acoustic signal from maneuvering the boat in the area of interest. ArcPad was employed in the field to display the transect positions to ensure that they were followed as accurately as possible. Real time acoustic data was collected by interpreting the echogram from the laptop monitor on board the vessel and entering the data into *Seabed Mapper* 4.0.

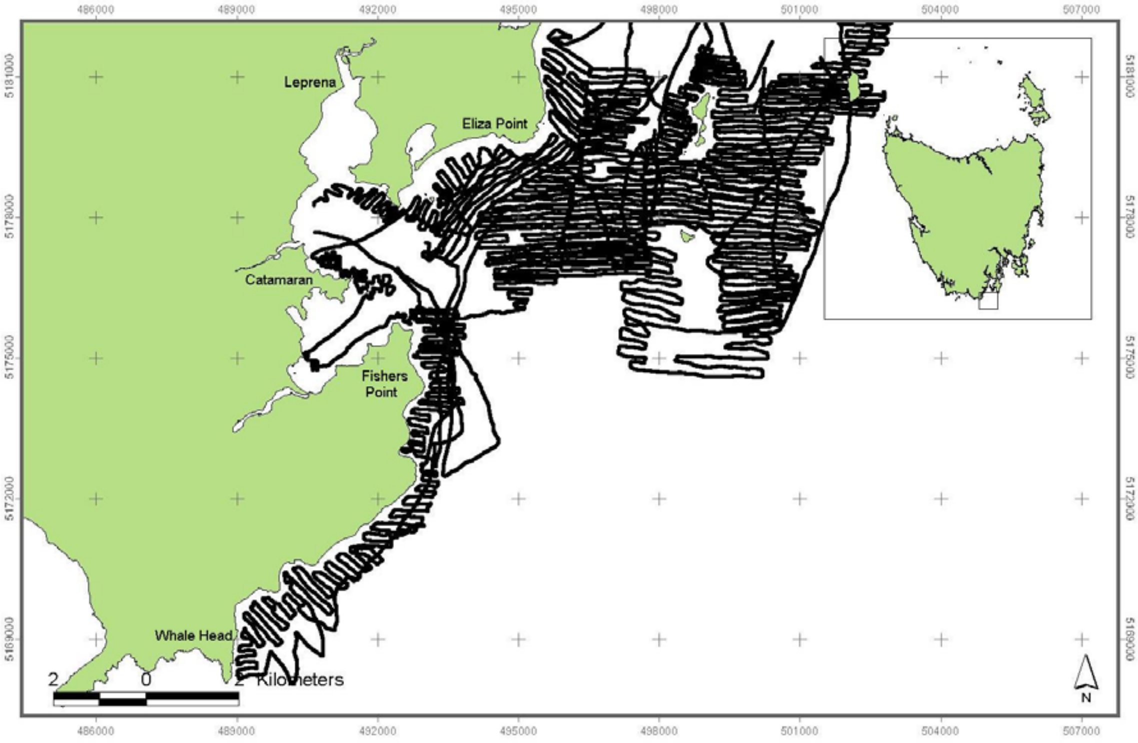

Fig. 4. Position of vessel tracks used for acoustic surveys along the south-east coast of Tasmania

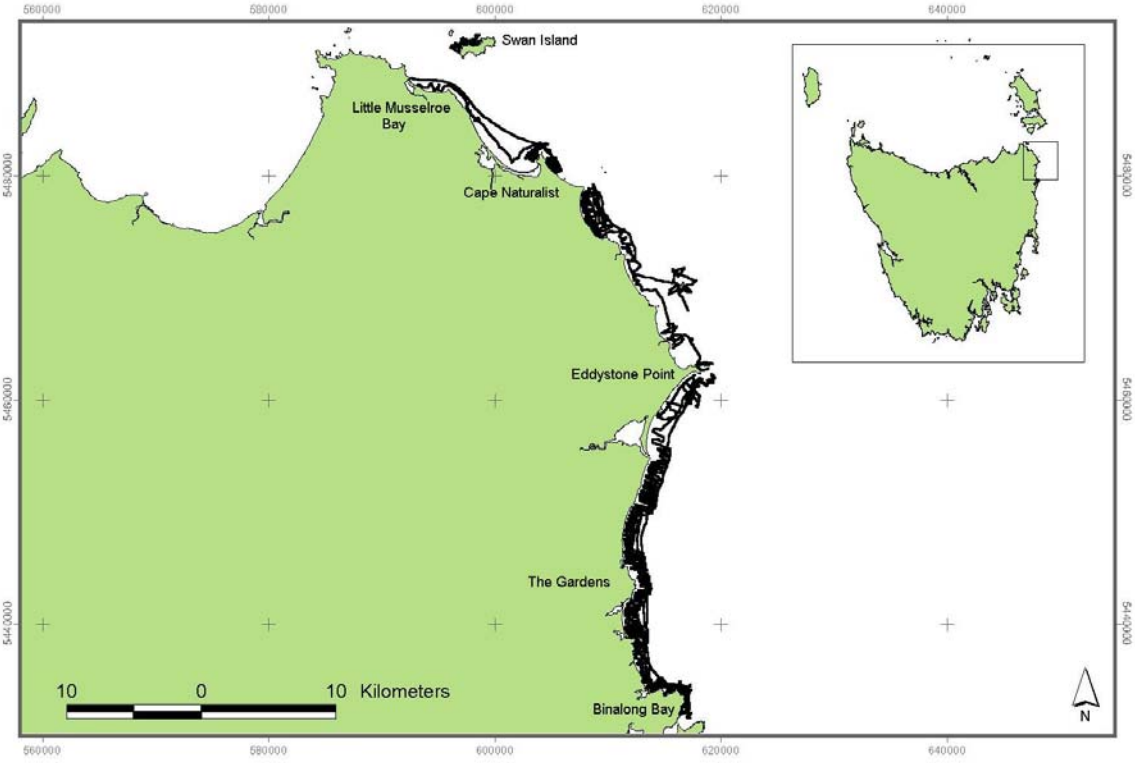

Fig. 5. Position of vessel tracks used for acoustic surveys along the north-east coast of Tasmania

5.2.2 Sidescan sonar

A sidescan sonar was deployed from the 24 m research vessel *FRV Challenger* during field surveys of north-east Tasmania to examine the extent and distribution of seabed habitats on the inner continental shelf in depths generally >20 m. The sidescan was a standard Edgetech 272T 100kHz towed fish and 260TH surface unit, which has a maximum range of 200 m per side (depending on depth). A laptop digital acquisition system (Chesapeake Technologies) consisting of three programs - SonarWiz®, SonarWeb® and Real Time Mosaicking ® (RTM) was used to log the sidescan sonar signal. While surveying, SonarWiz software was used to acquire sidescan data through an analogue to digital card mounted in the laptop which saves as a .XTF file containing depth sourced from single beam echo sounder, position from a GPS and a backscatter amplitude time series for each ping. A maximum of 4096 samples were recorded per channel for each ping in 256 (8 bit) quantised levels. The positioned sonar output was displayed with RTM software in real-time and Arcpad used to provide live navigational capabilities.

A series of transects running approximately parallel to the coast were conducted between northern Swan Island and The Gardens, with the greatest density of transects between Cape Naturalist and Eddystone Point (Fig. 6). The towfish was deployed from a crane on the starboard side of the vessel.

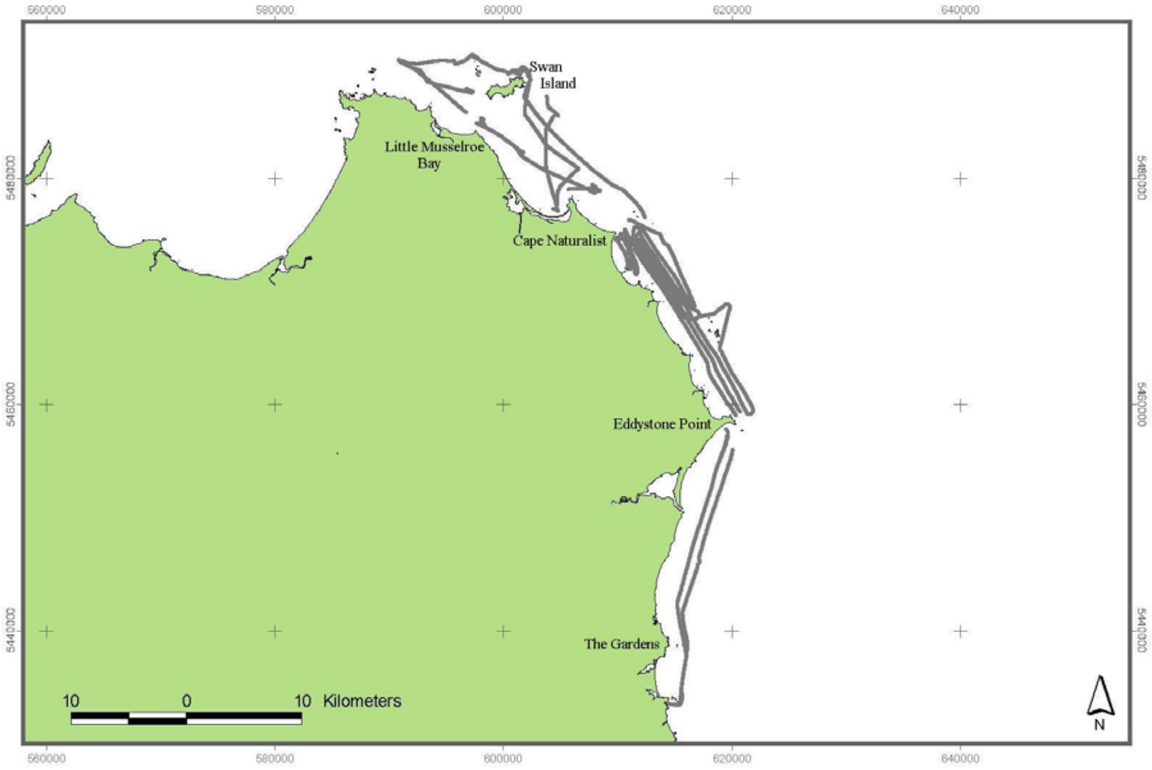

Fig. 6. Position of sidescan sonar transects conducted along the north-east coast of Tasmania.

5.2.3 Video surveys

Initially, a submersible digital colour video camera was deployed at a minimum of 5 transects covering an approximate distance of 100 m each transect to validate each acoustically defined habitat category. The video camera contained around 40 kg of weight and towed at a speed of 1 knot to ensure the camera was positioned as close to the GPS antenna as possible, and was often visible directly under the vessel in depths <20 m. The camera was suspended approximately 1 m from the sea floor giving a field of view (FOV) that varied between 1-2 m wide. Differential GPS location, time, date and water depth were overlayed onto the video from the GPS sounder using a genlock device and logged in a file on *Seabed Mapper* 4.0 for use in the analysis.

In addition to validation sites, a video camera was deployed to verify echosounder and sidescan classifications, confirm habitat boundaries and obtain more detailed information on reef patchiness and dominant macroalgal assemblages. In the south-east, video surveys covered a total of approximately 50.6 km of seabed targeted at reef habitats throughout the various sub-blocks out to depths of around 30 m (Fig. 7). In the north-east, video surveys covered a total of approximately 20.9 km of seabed along the coast and were conducted out to depths of around 30 m (Fig. 8).

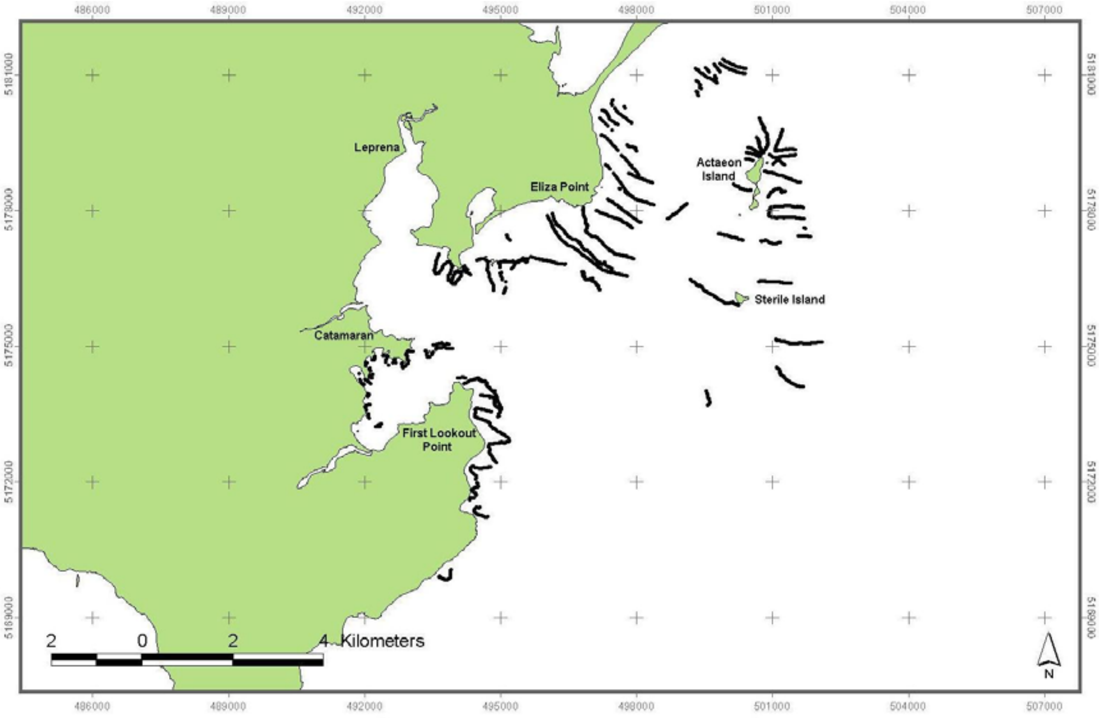

Fig. 7. Position of vessel tracks used for video surveys along the south-east coast of Tasmania

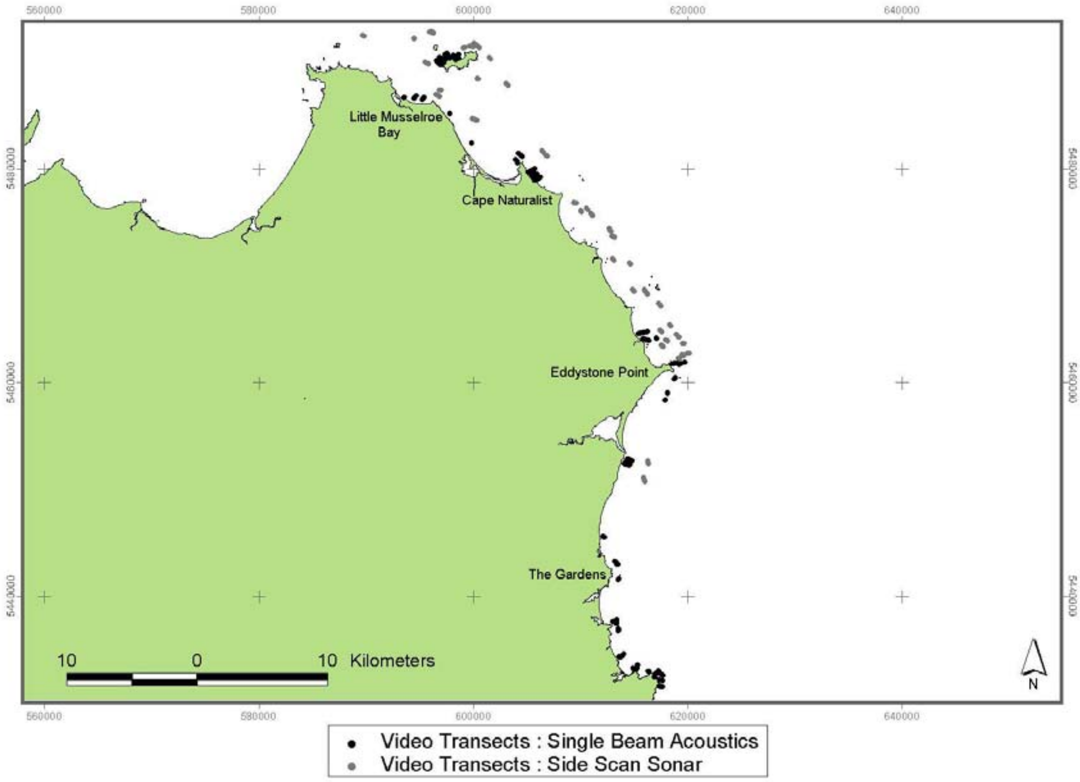

Fig. 8. Position of vessel tracks used for video surveys along the north-east coast of Tasmania

5.3 Laboratory analysis

5.3.1 Single-beam acoustics

Analysis of the ES60 echograms were undertaken in the laboratory to remove any poor data due to signal attenuation (sometimes due to propeller wash at the surface) and confirm the field habitat classifications and position of habitat boundaries. The echogram was displayed in *Echoview* software (*SonarData Pty Ltd*), which is designed to display and analyse acoustic data from scientific echosounders. Habitat boundaries were defined firstly between consolidated and unconsolidated substrates by comparing against reference echograms that were confirmed through video ground-truthing. In addition, data files exported from *SeaBed Mapper* 4.0 were cleaned for erroneous points, which were recognised by spurious depth data or missing substrate values and saved as .csv files and imported into ArcView 3.2.

A number of acoustically distinct seabed types were identified in the echogram and ground-truthed by surveying with digital video. Different seabed types were characterised by differences in the echogram seen through the strength of the tail of the first and the whole second echo (reflected in its colour and thickness intensity) (Fig. 9, Table 2), which reflects variations in roughness and hardness, respectively (see Kloser *et al.*, 2001). These differences were most evident between consolidated (rocky reef) and unconsolidated substrates due to the large differences in roughness and hardness.

A total of three habitat categories (rocky reef, sand and hard sand) were specifically defined through variations in the first and second echo in the echogram. Habitat categories were defined within a hierarchical classification scheme for subtidal seabed habitats that are based on either abiotic or biotic structuring variables, or a combination of the two (Table 1). A minimum of five video transects covering an approximate distance of 100 m each transect are commonly conducted to ground-truth each acoustically defined habitat category. Rocky reef was further classified (low, medium and high, Table 2) based on profile, which is defined as the absolute rise or fall of reef depth over 10 linear meters calculated from the sounder detected bottom. Pairs of depths 10 m apart are compared and the vertical difference between them defined as the reef profile. As greater than one depth point is collected every 10 m all reef profile measures are averaged over arbitrary 10 m bins. These binned reef profile data were used to create figures of reef profile along selected acoustic transects.

The acoustic attribution of unconsolidated vegetated (primarily seagrass) was also partly defined on the basis of acoustic reflectance of the biota above the sounder detected bottom (Fig. 9) and further research is being conducted to quantify this component of the acoustic backscatter. However, this habitat type occurred over only a very small geographic area in the south-east. Due to the strong acoustic reflectance of the giant kelp (*Macrocystis pyrifera),* additional point data on the sub-surface distribution of this species was also determined from the echogram.

Position and habitat categories defined in both *Echoview* and logged in the field within *SeaBed Mapper 2.4* were then exported into *ArcView 3.2*. These habitat attributes were then compared and field assigned habitat categories changed to *Echoview* assigned categories if differences occurred. As habitat type was also defined in shallow areas (generally <5 m but up to 10 m in clear water) through the aerial photographs, (primarily rocky reef and unconsolidated) and boundary position in these depths were compared with the acoustically defined boundaries.

Table 1. Hierarchical subtidal seabed habitat classification system used in the SeaMap Tasmania project with (A) defining levels 4-7, and (B) listing specific habitat attributes and modifiers. The categories in bold were those defined acoustically (see Table 2).

A

<table>
<tr><th colspan="8">Primary biotopes – Level 4</th></tr>
<tr><td colspan="4">Consolidated substrate - Rocky reef *</td><td colspan="4">Unconsolidated substrate</td></tr>
<tr><th colspan="8">Secondary biotopes - Level 5</th></tr>
<tr><td colspan="2">Unvegetated</td><td colspan="2">Vegetated</td><td colspan="2">Unvegetated</td><td colspan="2">Vegetated</td></tr>
<tr><th colspan="8">Biological facies – Level 6</th></tr>
<tr><td>Attached epifaunal groups</td><td>Dense sponge</td><td>Attached floral groups</td><td>Macroalgae</td><td>Sediment type</td><td>Sand
Silty-sand
Silt</td><td>Attached floral groups</td><td>Seagrass
Algae</td></tr>
<tr><th colspan="8">Micro-communities – Level 7</th></tr>
<tr><td>Attached epifaunal species</td><td>e.g. <i>Pyura australis</i></td><td>Attached floral species</td><td>e.g. <i>Macrocystis pyrifera</i>
<i>Ecklonia radiata</i></td><td>Attached epifaunal groups</td><td>Sparse sponge</td><td>Attached floral species</td><td>e.g <i>Posidonia austalis</i>
<i>Caulerpa trifaria</i></td></tr>
<tr><td>Unattached faunal groups</td><td>e.g. Fish seastars</td><td>Unattached floral groups</td><td>e.g. Red algae</td><td>Attached epifaunal species</td><td>e.g. <i>Sarcoptilus grandis</i></td><td>Attached epifaunal groups</td><td>e.g. Ascidians</td></tr>
<tr><td>Unattached faunal species</td><td>e.g. <i>Asterias amurensis</i></td><td>Unattached floral species</td><td>e.g. <i>Enteromorpha compressa</i></td><td>Unattached faunal groups</td><td>e.g. Brittle stars
Fish</td><td>Attached epifaunal species</td><td>e.g. <i>Polycarpa viridis</i></td></tr>
<tr><td>Unattached floral groups</td><td>e.g. Red algae</td><td>Attached epifaunal groups</td><td>e.g. Sponge
Bryzoans, Ascidians</td><td>Unattached faunal species</td><td>e.g. <i>Asterias amurensis</i></td><td>Unattached faunal groups</td><td>e.g. Fish</td></tr>
<tr><td>Unattached floral species</td><td>e.g <i>Laurencia majuscula</i></td><td>Attached epifaunal species</td><td>e.g. <i>Pyura australis</i></td><td>Emergent epifaunal groups</td><td>e.g. Bivalves
Polychaetes</td><td>Unattached faunal species</td><td>e.g. <i>Neoodax balteatus</i></td></tr>
<tr><td></td><td>Urchin barren</td><td>Unattached faunal groups</td><td>e.g. Fish seastars</td><td>Emergent epifaunal species</td><td>e.g. <i>Maoricolpus roseus</i></td><td>Emergent epifaunal groups</td><td>e.g. Bivalves
Ghost shrimps</td></tr>
<tr><td></td><td></td><td>Unattached faunal species</td><td>e.g. <i>Asterias amurensis</i></td><td>Unattached floral groups</td><td>e.g. Red algae</td><td>Emergent epifaunal species</td><td>e.g. <i>Corbula gibba</i></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Unattached floral species</td><td>e.g. <i>Enteromorpha compressa</i></td><td>Unattached floral groups</td><td>Red algae</td></tr>
<tr><td></td><td></td><td></td><td></td><td>Attached floral groups (low % cover)</td><td>e.g. Seagrass
Macroalgae
Filamentous algae</td><td>Unattached floral species</td><td>e.g. <i>Colpomenia sinuosa</i></td></tr>
</table>

B

Rocky reef		Unconsolidated			
Unvegetated & Vegetated		Unvegetated		Vegetated	
Attributes	Modifiers	Attributes	Modifiers	Attributes	Modifiers
Substratum texture	Solid Broken Cobble Boulder	Substratum texture	**Hard (high shell content)**	Substratum texture	Hard (high shell contect)
Structure	Continuous Patchy Guttered	Relief	Hills Waves Ripples Flat	Bed structure	Continuous Patchy Sparse
Profile	High Medium Low			Sediment type	Sand Mud
Slope	slight sloping steep vertical overhang	Slope	slight sloping steep	Slope	slight sloping steep
Swell/wave exposure	e.g. high exposure	Swell/wave exposure	e.g. sheltered	Swell/wave exposure	e.g. very sheltered
Sponge morphological groups	e.g. branched encrusting				
Rock type	e.g. Dolerite Granite				

Table 2. Decision rule table used for acoustically defining selected seabed habitats with a minimum of 15 m of continuous substrate in along track direction required for all habitat categories. These are combined with contextual decision rules and ground-truthing data prior to final attribution.

Habitat Category	Attribution decision rule	View of echogram-tail first echo	View of echogram-second echo
Rocky reef			
High Profile Reef	Consolidated substrate with a change in vertical profile >4 m over a horizontal distance of 10 m.	High signal strength on the first echo with long tail	Medium to high signal strength
Medium Profile Reef	Consolidated substrate with a change in vertical profile greater than 1-4 m over a horizontal distance of 10 m.	Medium to high signal strength on the first echo with long tail	Medium to high signal strength
Low Profile Reef	Consolidated substrate with a change in vertical profile <1 m over a horizontal distance of 10 m.	Medium to high signal strength on the first echo with long tail	Medium to high signal strength
Vegetated Unconsolidated			
Vegetated unconsolidated	Defined by the signal intensities and shape of the 1st and 2nd echo detected bottom and the acoustic reflectance of the biota above the sounder detected bottom.	Medium signal strength on the first echo with long tail	Low to medium signal strength
Unvegetated Unconsolidated			
Sand	Based on the return signal intensities and shape of the 1st and 2nd echo reflecting sediment with a dominant proportion of sand particles.	Medium signal strength on the first echo with short to medium tail	Medium signal strength
Silty-sand	Based on the return signal intensities and shape of the 1st and 2nd echo and incorporates sediment with a mostly even proportion of sand and silt particles.	Low to medium signal strength on the first echo and short to medium tail	Low to medium signal strength
Silt	Based on the return signal intensities and shape of the 1st and 2nd echo and incorporates sediment with a dominant proportion of silt particles.	Low signal strength on the first echo with short tail	Low signal strength
Hard sand	Based on the return signal intensities and shape of the 1st and 2nd echo reflecting sediment with a dominant proportion of sand particles and a proportion of shell material and/or ripples present.	Medium signal strength on the first echo with medium tail	Medium signal strength

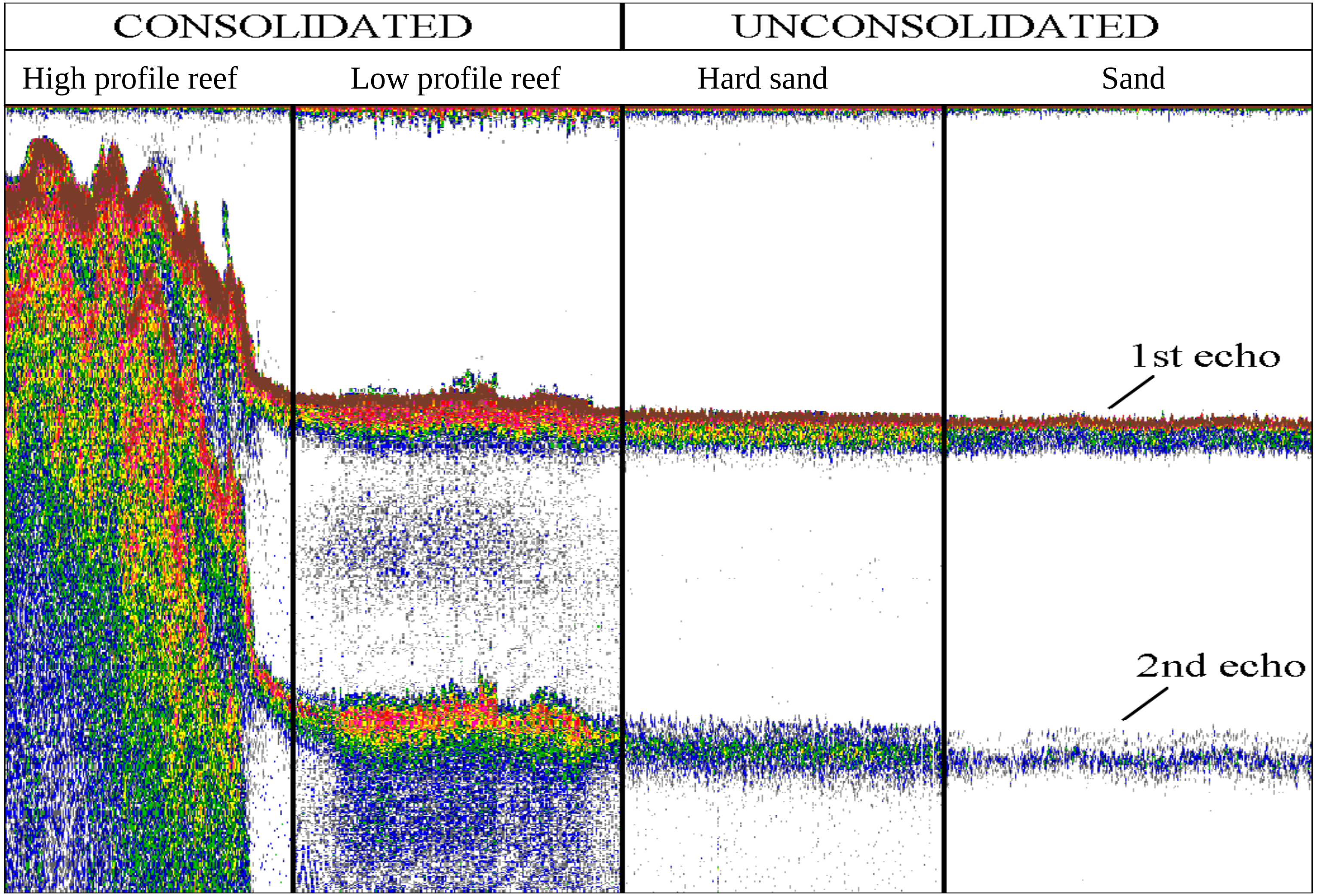

Fig. 9. Echogram of several habitat categories defined during the acoustic surveys of north-east and south-east Tasmania.

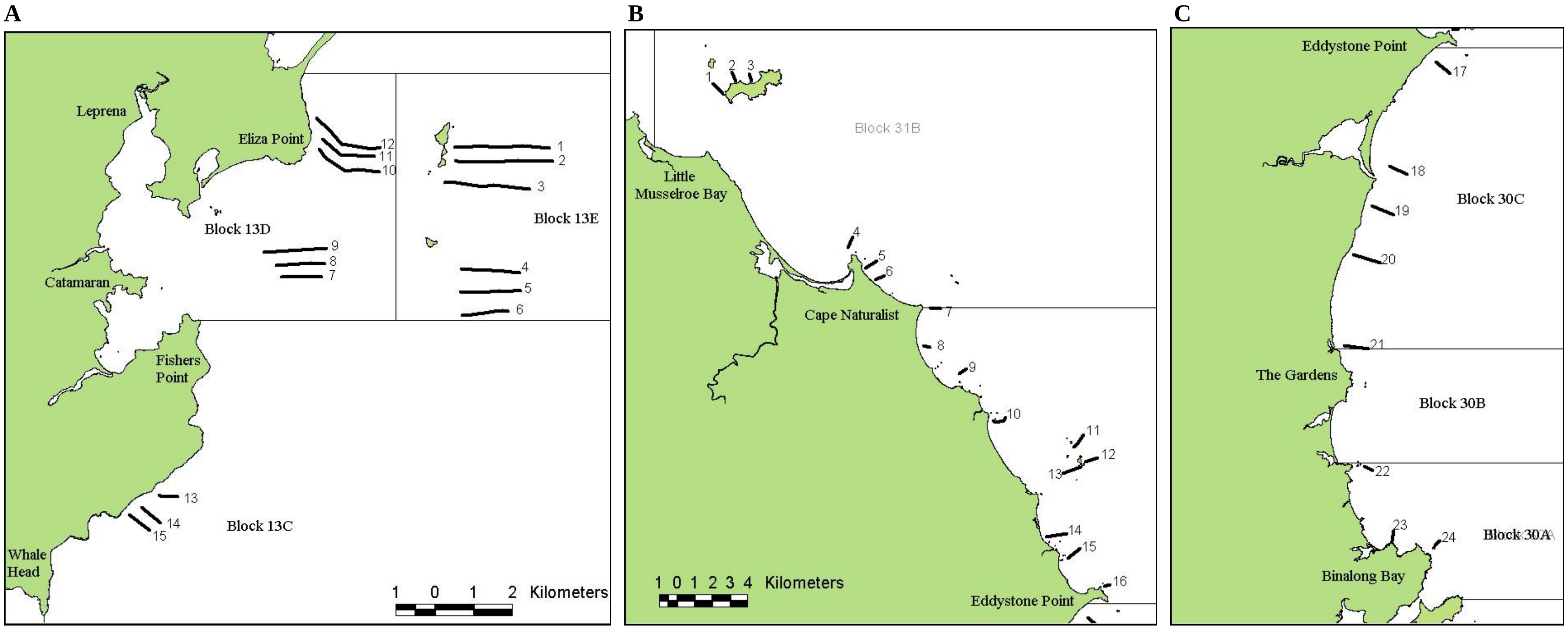

Fig. 10. Location of transects used to estimate reef profile in south-east (A) sub-blocks 13C-E, and north-east Tasmania (B) block 31 and (C) block 30.

5.3.2 Sidescan sonar

The unprocessed signal shows considerable detail on the composition and texture of the seabed but is not geo-referenced and contains the nadir and water column (see Appendix 3a). Post-processing and mosaicing was done of the raw image using SonarWeb software to produce a composite image with a resolution of typically 1 m per pixel. The water column was removed by ‘bottom tracking’ and ‘slant range’ geometric distortions, which compress the record of areas below the transducer. Corrections were also made to the data to compensate for radiometric distortions related to the attenuation of signal with distance and grazing angle (Fish and Carr, 1991; Blondel, 1997). As the position and heading of the vessel for each ping is collected from the GPS, the processed data can be displayed correctly in geographical space. Compensation was made for the ‘layback’, which is the distance the towed body trails behind the GPS antenna mounted on the vessel. Multiple vessel tracks were processed into a full coverage mosaic of the area surveyed (see Appendix 3b). Further details of image acquisition and processing can be obtained in Bickers (2003).

The georeferenced colour images were loaded into ENVI software and assigned the datum file of UTM, AGD 66 Zone 55 South. A Guassian Low Pass Filter was applied to each of the images. Spatial filters emphasise or de-emphasise image data of various spatial frequencies. Spatial frequency refers to the roughness of the tonal variation occurring in an image. Images of high spatial frequency are described as ‘tonally rough’ (i.e. the grey levels change abruptly over a small number of pixels). Low pass filters are designed to emphasise (by applying a large area change in brightness and de-emphasises the high frequency components of an image (local detail)).

First a mask was made for each of the image files. This was completed using the Build Mask option within ENVI and selecting the white are outside of the transect to be disincluded from the analysis by selecting all input data band ranges to equal 255.

An unsupervised classification was performed on the data by creating an ISODATA image. The number of classes that were instructed to be found was 3 with a maximum of 4, over 9 iterations. The output images were saved as .iso format. Within ENVI these images were exported as ArcView grid files of format .bil. Using ArcTools the .bil files are converted to .grd for analysis within ArcView 3.2. The classified grids were opened within ArcView overlaid onto the original side scan jpg images. The grid values that corresponded to what was interpreted as reef were selected (these were generally class 2 and class 3). The selected grid cells were converted to polygons within ArcView 3.2. This technique allows for the automation of the polygon generation to be performed outlining the areas showing different patterns within the image using unsupervised classification. This method still required ground verification from video files to confirm the attribution of polygons.

5.3.3 Video analysis

The video footage was reviewed in the laboratory, and in conjunction with the field notes, used to identify the dominant cover forming species of the dominant macroalgae and coralline algae and the percentage cover of these species or assemblages. While information was obtained on macroalgae dominated communities from video analysis, the spatial coverage of video footage was insufficient to map habitats at the eco-unit level. However, information on these biological attributes was used to describe depth related trends in macroalgal community composition.

The cover of the dominant species or assemblage were estimated visually from 24 video transects in the block 30, 46 video transects in block 31 and 82 video transects in block 13. Five seconds of video were analysed for every 30 seconds of video, and at the towing speed of 1 knot this corresponded to approximately 2.5 m of video being analysed every 15 m along the video track. Visual estimates of total algal cover were scored into 25% bins (i.e. 0%, 1-25%, 25-50%, 50-75% and 75-100%). For each of the dominant algal species or groupings a visual estimate of their cover was made, again based on the 25% bins. Urchin barrens, where present, were assessed in the same manner. *Macrocystis pyrifera* was assessed as either present or absent. Information on the macroalgal cover was joined with depth and positional information from the vessel track log and this data set was used to estimate algal cover across the depth ranges for each of the sub-blocks.

The video data was also used to generate statistics on fine-scale reef patchiness (i.e. below the distance of the minimum mapping unit of 15 m), which were calculated for each of the five sub-blocks in the northeast and three sub-blocks in the southeast. In each sub-block five 100 m sections of reef video were analysed. Every 2 seconds a frame of video was scored as one of either reef, sand or sand-reef complex. Reef was recorded where continuous reef dominated over 95% of the video frame, sand was recorded where sand was dominant in over 95% of the video frame and sand-reef complex was recorded when there was a combination of reef and sand at <95% coverage of the video frame. Statistics on substrate were summed for each transect and these were used to calculate the average and standard error for each of the eight sub-blocks.

In addition, the accuracy of the interpolated polygons in the north-east region was assessed by comparing 4 random transects in the dataset with the generated habitat maps. To simplify the video processing, the speed of the video camera was standardised by converting the DGPS string of points collected along the video transect to a polyline using XTOOLS (ArcView 3.2 ESRI) and then dividing the line evenly into 2.73 m segments. This is the average distance along which a GPS point is sampled every 2 secs whilst at a vessel speed of 12 km/hour. Shorter distances are covered whilst drifting as the vessel is not under power when the video is deployed. The video play length time is then divided by the number of points along that transect. For example V01 = 14 mins; 43 secs, 24 point segments were made along the length (65.52m / 2.73m) * 60 = 36 seconds. Every 36 secs V01 was stopped and the habitat was recorded and attributed to the point. The video classifications were standardised by using a second operator familiar to the technique and scores were recorded and compared for two of the four transects.

5.4 Spatial analysis

Along tracks, a GPS point is logged every 2 sec resulting in habitats being attributed from the echogram every 2.7 m at the vessel speed of 5 knots. A minimum of six similar attributed points, relating to an average distance of around 15 m, were required for a polygon to be generated. Attributed points were connected at the 1:2,000 scale to form polygons through a *knowledge based interpolation* process where the points are joined with similar neighboring transect points to make one habitat polygon. For shallow Tasmanian coastal waters where rocky reef and unconsolidated habitats are the dominant habitat types this vector based methodology appears to best represent the complex pattern of habitats. In addition, much of the area of the coastal seabed exists within depths that are suitable for defining habitat boundaries through both aerial photography and real-time attribution (generally <10 m depth) that generate categorical data as a polygon. Combining this from polygon boundaries identified from acoustics in deeper water provides a consistent data model across all depths, but obviously greater uncertainties will exist with the acoustic data due to the need for interpolation, often within the same polygon.

It is difficult to verify the *knowledge-based* interpolation technique with unconsolidated habitats, as the boundaries are not visual or object based and the boundary is attributed by defining a position in the echogram. However, this is generally only an issue in sheltered waters in Tasmania where silt through to sand substrates exist over large distance due to the lack of steep depth gradients, in contrast to the majority of coastal waters that is exposed resulting in few boundaries between unconsolidated substrate (which is predominantly sand). While each habitat polygon can only occur as one category in the hierarchical classification table, within one map of coastal seabed habitats there may be varying levels of classification, spatial patterns (i.e. minimum mapping units) and uncertainties introduced due to differences in the resolution of airborne and vessel based instrumentation and survey design.

Depth measurements taken from the sounder were used to construct a contour layer corrected to Mean Sea Level after the depths were corrected for tidal variation. A Triangular Irregular Network (TIN) surface interpolation was applied in ArcView 3.2 for generating a Digital Elevation Model (DEM) and corresponding contour data sets based on the surface terrain. Contour lines were created for 5 m depth intervals out to the maximum depth of the acoustic transects.

6. Results and Discussion

6.1 South-east fishing sub-blocks 13C-E

6.1.1 Habitat distribution and structure

The abalone fishing sub-blocks of 13C-E in south-east Tasmania were found to contain extensive areas of rocky reef habitat that extend from intertidal waters to depths of over 50 m before meeting the sand edge (Figs. 11, 12). The extent and distribution of reef, however, varies between the various fishing sub-blocks, reflecting the coastal geology, which is dominated by a dolerite shoreline mixed with sandy beaches and dolerite offshore islands and reefs. The reef system extends up to 10 km offshore, particularly in the area around the Actaeon and Sterile Islands, and in the southern part of this area the reef extends further as the sand boundary was not defined on the offshore transects in depths greater than around 40 m. This extent of reef makes this system an unusual subtidal feature of south-eastern and eastern Tasmania as much of the inshore reef in this region is limited to a narrow coastal fringe (Barrett *et al*., 2001).

Rocky reef habitat in sub-blocks 13C-E in the 0-40 m depth range had a combined area of approximately 43.7 km^2, although the reef area is not evenly distributed throughout the region. Sub-block 13C is dominated by fringing reef that is restricted mostly to >1 km from shore (Fig. 13F, H) covering an estimated area of 9.4 km^2, which consists of relatively even amounts of reef in the various depth strata (Table 3). Much of the reef in depths >20 m in this sub-block occurs on the extent of the reef located south of Sterile Island (Fig. 13E, G). The reef within sub-block 13D consist of small amounts of fringing reef within Recherche Bay and a large area that extends to the offshore limit of the sub-block south-east of Eliza Point (Fig. 12). The reef area is estimated to be 15.9 km^2, much of which occurs in the 10-20 m depth range (Table 3). The moderately sheltered embayments in Recherche Bay also contains a mix of sand and some areas of silty-sand, seagrass and *Caulerpa* sp. in the most protected waters. Sub-block 13E contains an estimated reef area of 18.4 km^2, a large proportion of which occurs in the 10-30 m depth range (Table 3) in an area running east of the Actaeon and Sterile Islands.

Overall, there is a slight gradation in exposure to swell action from south to north along this coastline, with the southern zone being more subject to westerly swells that wrap around Whale Head. While the outer reef section of this area is particularly exposed, the Actaeon Islands and associated shallow reef area form a barrier that provides some protection to a substantial portion of reef inside this barrier.

Table 3. Area (km^2) of rocky reef habitat defined between depths of 0-40 m in abalone fishing sub-blocks 13C-E.

	Depth strata				
Sub-blocks	**0-10 m**	**10-20 m**	**20-30 m**	**30-40 m**	**Total**
13C	1.9	2.2	2.8	2.4	9.4
13D	3.1	7.9	2.8	2.1	15.9
13E	3.0	6.9	5.8	2.8	18.4

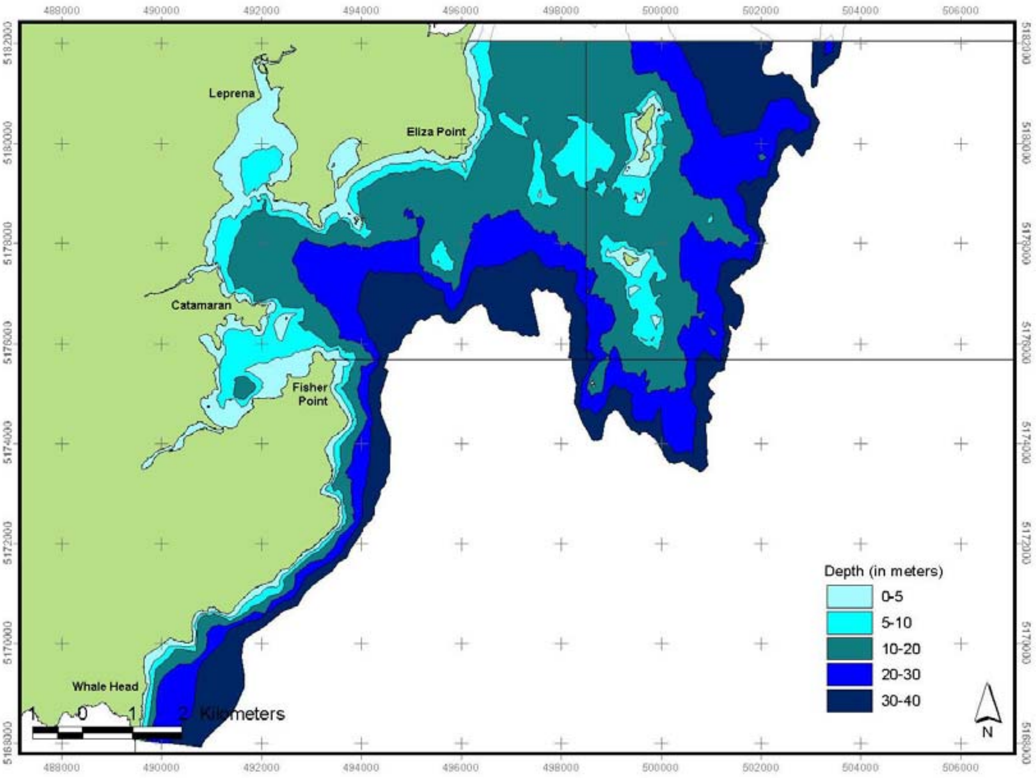

Fig 11. Distribution of depth strata in the south-east Tasmanian sub- blocks 13C-E at a scale of 1:85,800.

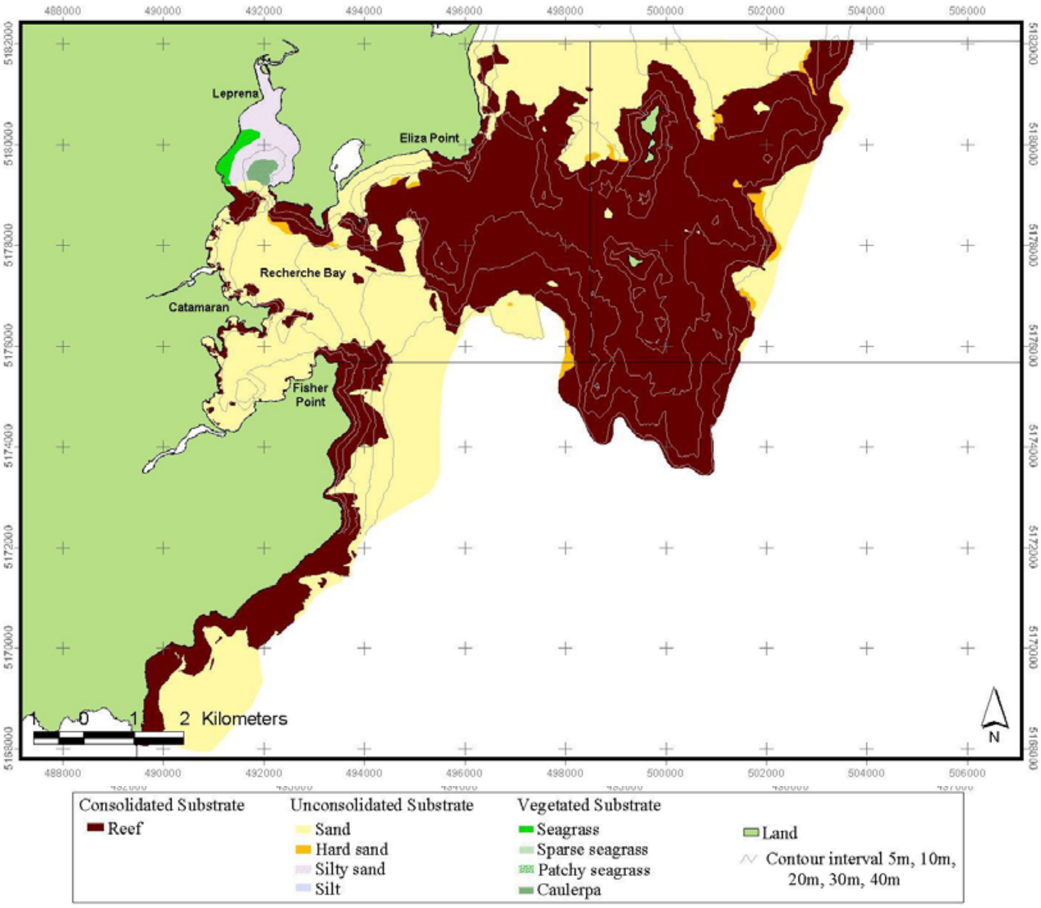

Fig 12. Distribution of seabed habitats in the south-east Tasmanian abalone fishing blocks 13C-E at

a scale of 1:85,800.

Fig. 13A. Index sheet showing the of position of 1:25,000 maps used to present the distribution of seabed habitats in the south-east Tasmanian abalone fishing blocks 13C-E.

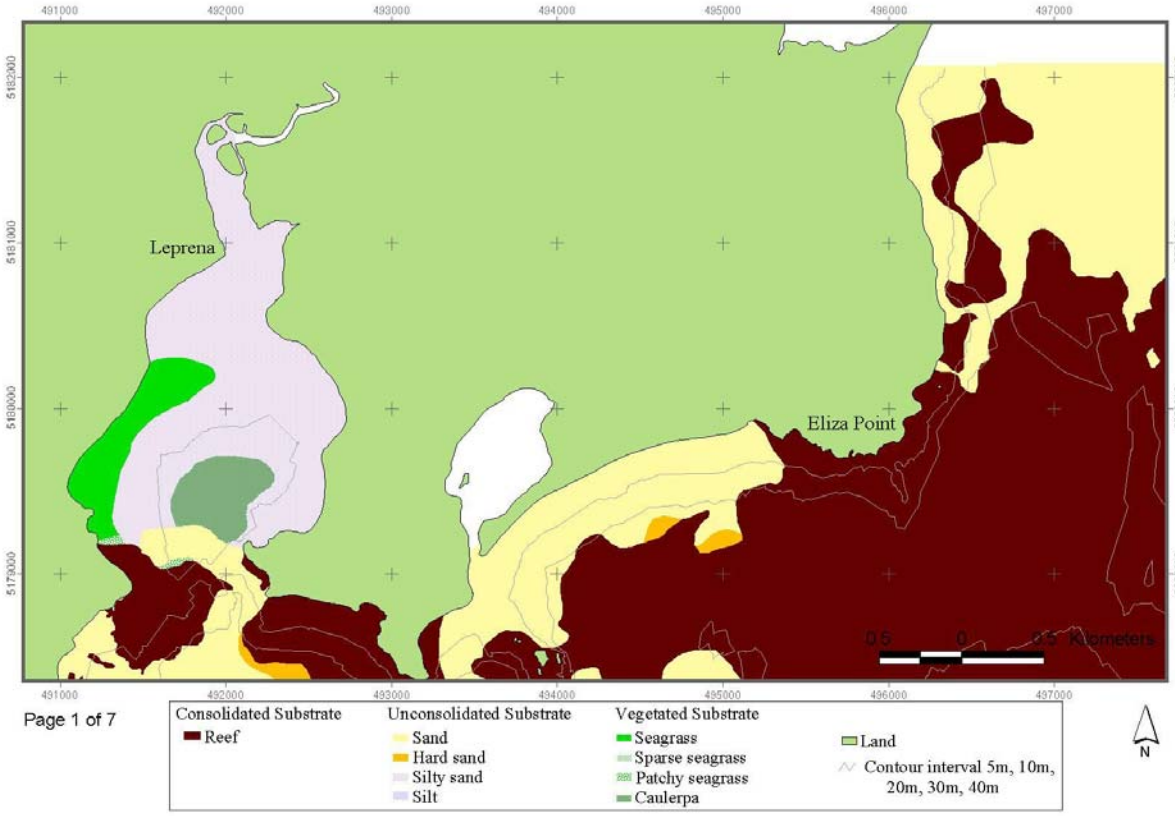

Fig. 13B. Distribution of seabed habitats in south-east Tasmania at a scale of 1:25,000 within area 1.

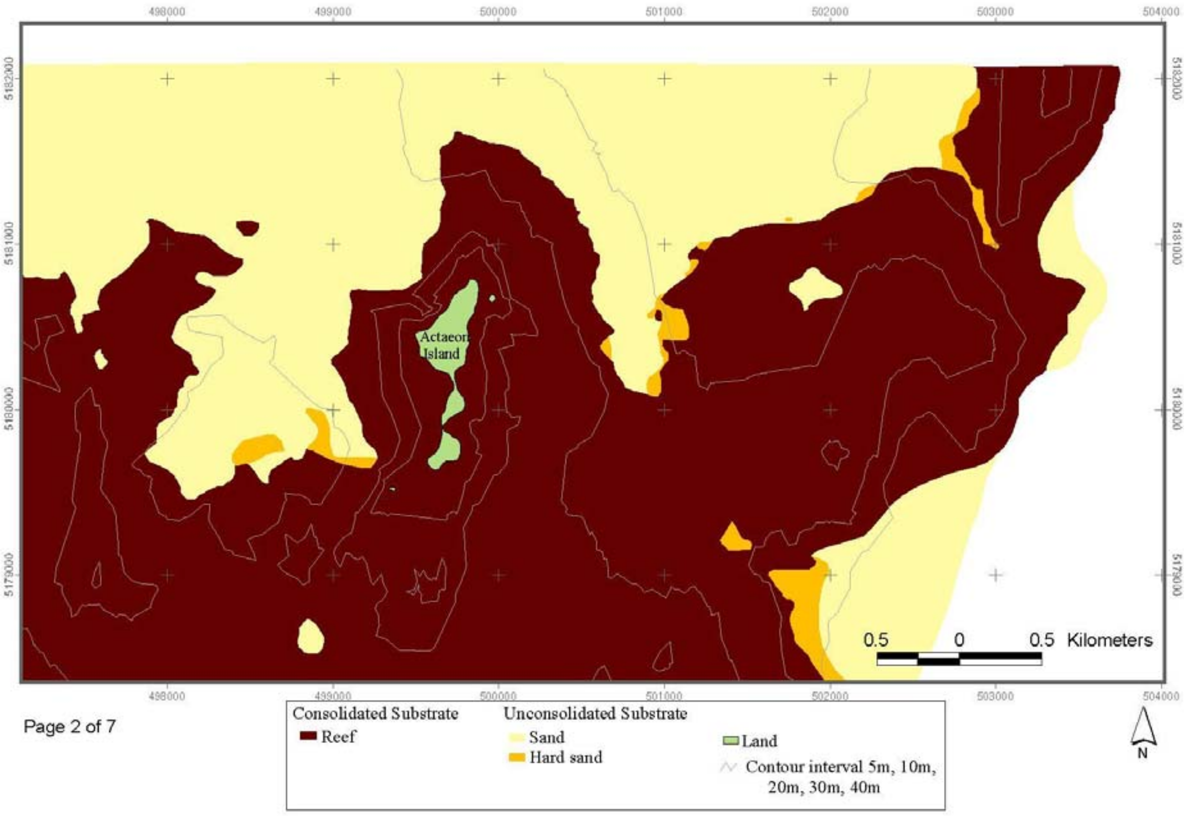

Fig. 13C. Distribution of seabed habitats in south-east Tasmania at a scale of 1:25,000 within area 2.

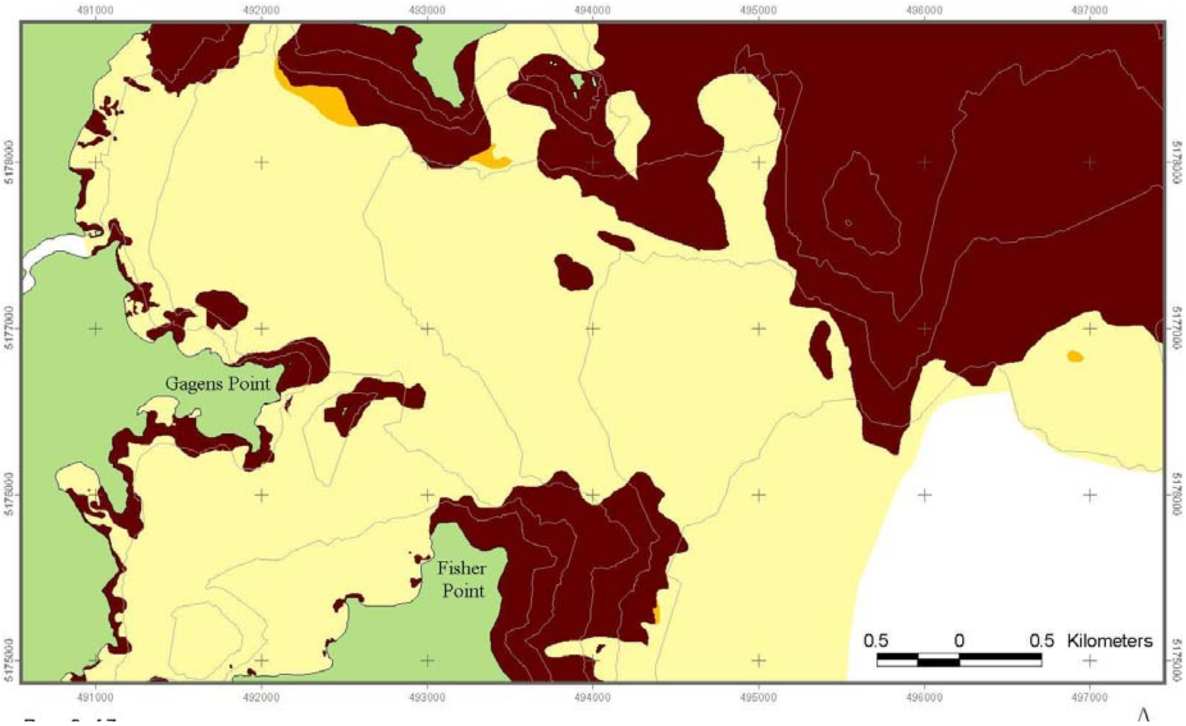

Fig. 13D. Distribution of seabed habitats in south-east Tasmania at a scale of 1:25,000 within area 3.

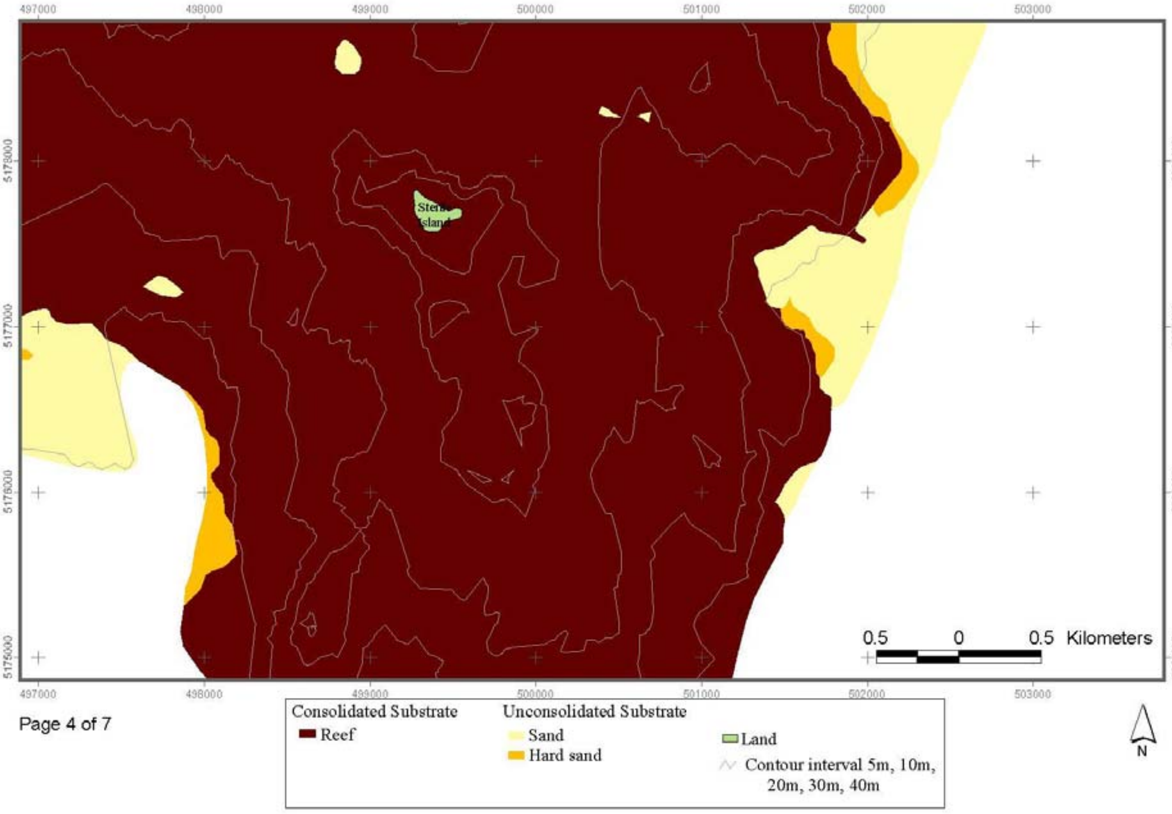

Fig. 13E. Distribution of seabed habitats in south-east Tasmania at a scale of 1:25,000 within area 4.

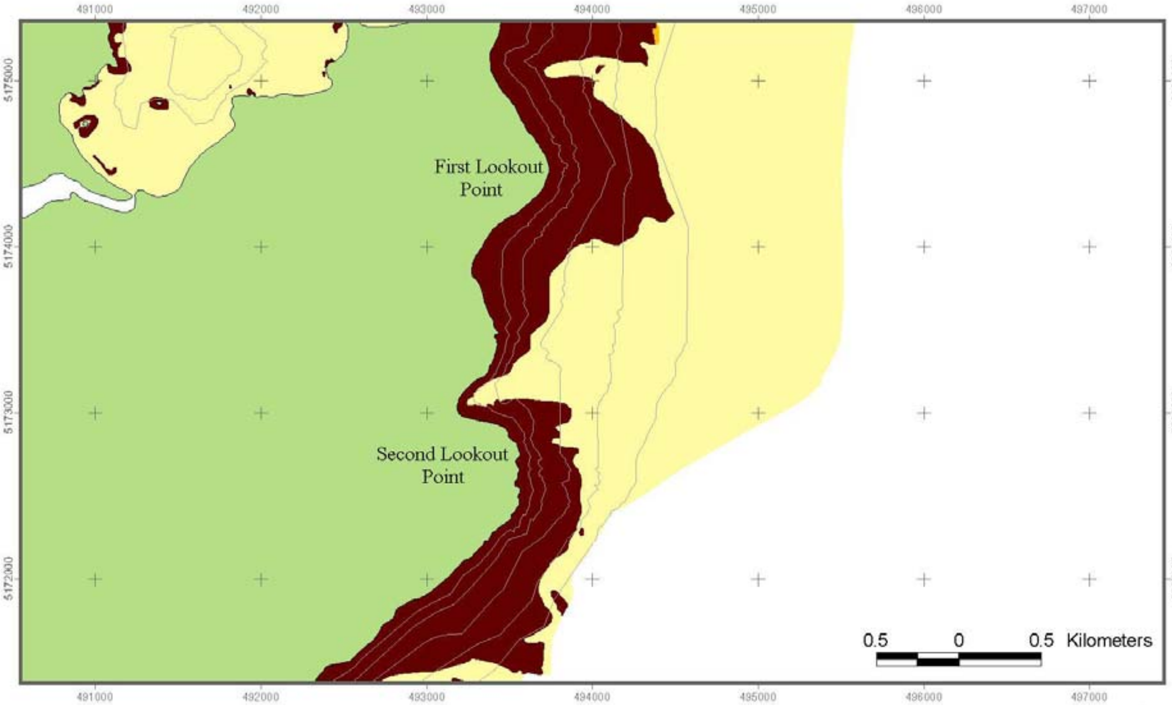

Fig. 13F. Distribution of seabed habitats in south-east Tasmania at a scale of 1:25,000 within area 5.

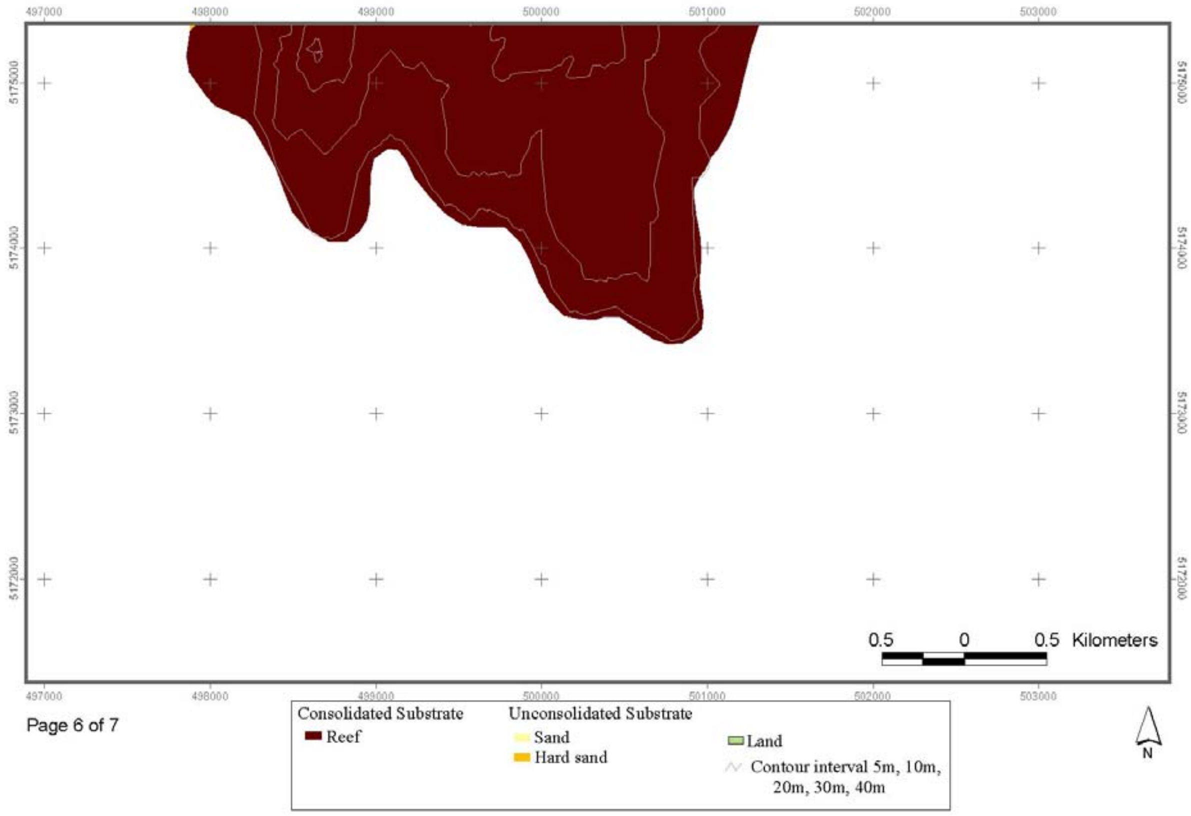

Fig. 13G. Distribution of seabed habitats in south-east Tasmania at a scale of 1:25,000 within area 6.

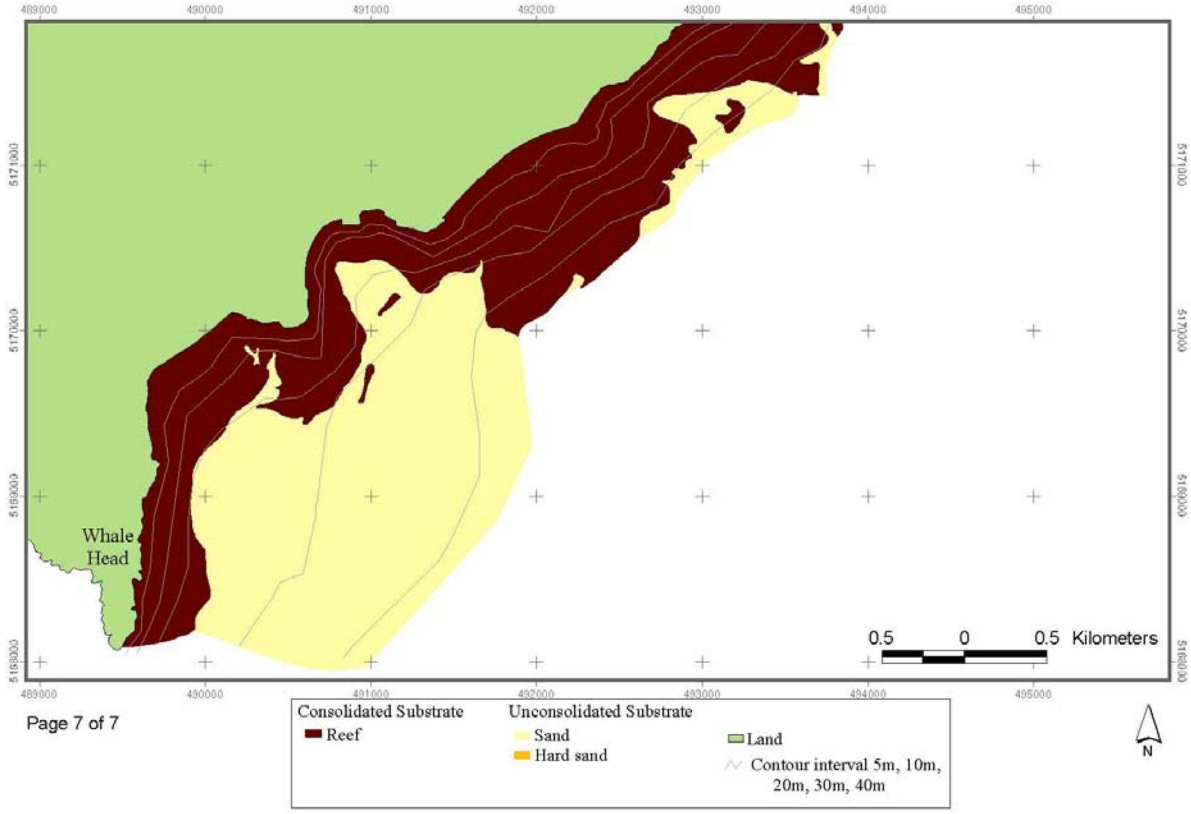

Fig. 13H. Distribution of seabed habitats in south-east Tasmania at a scale of 1:25,000 within area 7.

Reef profile was determined at a series of transects throughout the south-east sub-blocks (see Fig. 10A) to examine the fine-scale structure of the reefs. Overall, the sub-blocks of 13C-E are dominated by low profile reef (i.e. <1 m relief), although there are considerable differences between sub-blocks 13C and 13D and E (Fig. 14). Firstly, sub-block 13C was estimated to have around 50-60% of reef with low profile, with the rest consisting of medium profile and a small amount of high profile, the proportions of the latter two increasing with increasing depth. In contrast, sub-blocks 13D and E had over 80% of the reef being low profile with no evidence of high profile reef apart from the deeper edge in sub-block 13E (Fig. 14).

Many transects showed a high frequency of change between low and medium profile over small distance resulting in small-scale complexity that is very difficult to present as a continuous surface (see Appendix 4a-c). While there were sections of reef often >500 m long that were consistently of a specific profile, it was also common for profile to vary between low and medium over distances of <50 m. With transects spaced at a distance of 100 m, this high variability along the transect means that knowledge based interpolation is not effective in representing this variability. More statistical interpolation procedures are required to generate a continuous surface in these instances, and this is being examined in ongoing research.

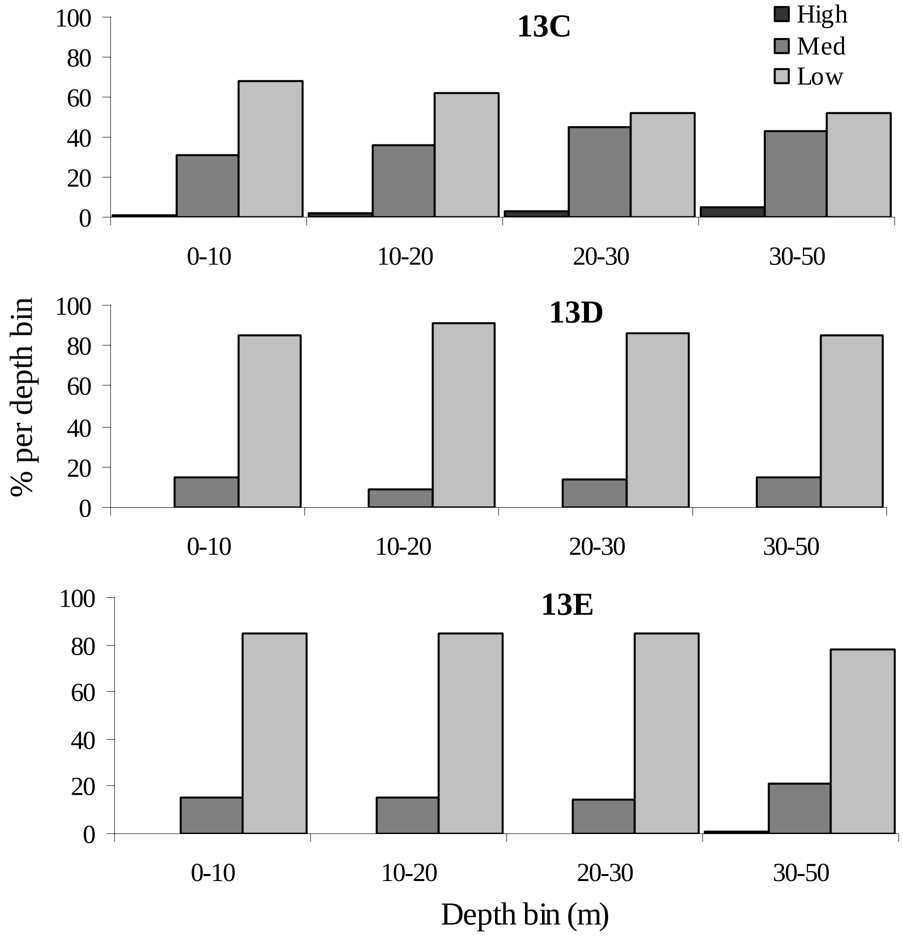

Fig. 14. Estimated proportion of low, medium and high profile reefs by depth strata in sub-blocks 13C-E in south-east Tasmania.

While the profile of reef varied between various sub-blocks, there was less variation in the amount of sand interspersed within the reef. The low proportion of sand and sand-reef complex identified from video within the sub-blocks indicates that the reef in this region is mostly continuous with little patchiness at the fine-scale. This pattern was found to be consistent between all sub-blocks where the cover of continuous reef was consistently around 90%.

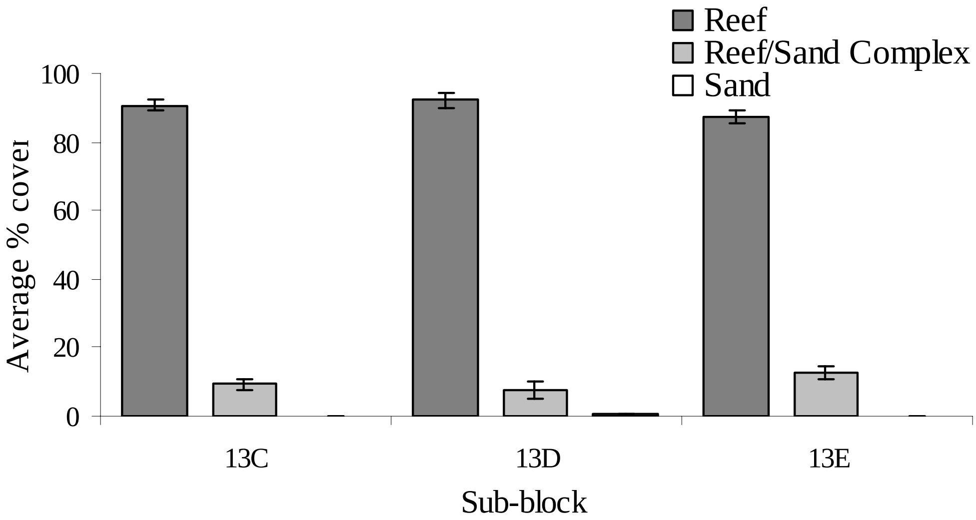

Fig. 15. Estimated proportion (+ s.e.) of continuous reef, reef-sand complex and sand from video analysis in sub-blocks 13C-E.

6.1.2 Algal composition

Analysis of video transects revealed the broad pattern of distribution and cover across depths of the dominant species in the macroalgal canopy (excluding *Macrocystis pyrifera*) and the understory assemblages of coralline and red algae and *Caulerpa* sp. Overall, the patterns were consistent with that previously identified for reef assemblages in south-eastern Tasmania (Barrett *et al*. 2001). However, there were local scale differences apparent due to variations in the level of exposure to swell of the reefs between the sub-blocks. Firstly, the patterns across depths were very similar between sub-blocks 13 C and E with *Durvillaea potatorum* and *Phyllospora comosa* dominant in the 0-10 m depth range and *Caulerpa* sp., red algae and *Ecklonia radiata* becoming increasingly abundant at greater depths (Fig. 15). An assemblage of coralline algae was present in both sub-blocks across all depths but consistently higher in the 0-10 m depth range.

Patterns of abundance were different in the shallow depths of sub-block 13D where *P. comosa* replaced *D. potatorum* at around 5 m and there was more *E. radiata* and red algae in the 0-10 m depth range. This reflects differences in exposure between the sub-blocks where both 13C and E are exposed to swell from most directions, in contrast to most of the reef in 13D, which are either sheltered in Recherche Bay or only moderately exposed on the inner reef margin adjacent to Eliza Point (where most of the video transects were located). A number of other species were identified in the video but were of low abundance including *Cystophora* sp., *Xiphophora chondrophylla*, *Acrocarpia paniculata*, *Carpoglossum* *confluens*, *Sargassum* sp., *Caulocystis uvifera*, *Lessonia corrugata*, *Codium fragile* and various sponges in the deeper reefs

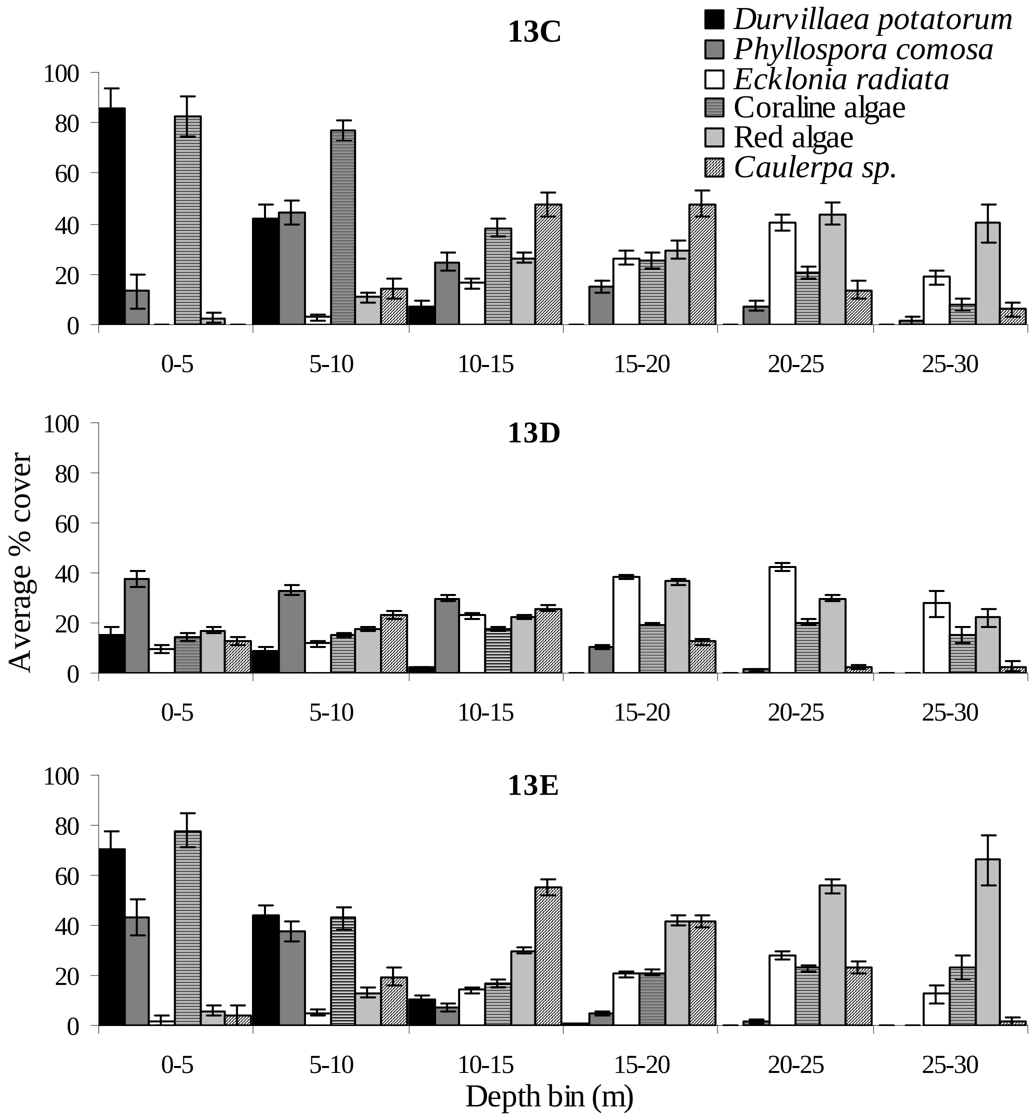

Fig. 16. Mean percentage cover (+ s.e.) for dominant canopy macroalgae and understory algae associated with reef habitats in 5 m depth strata within the southeast Tasmanian sub-blocks 13C-E.

A combination of visual assessment of the surface canopy and acoustic determination of the presence of sub-surface plants allowed an assessment of the distribution of *Macrocystis pyrifera*. The majority of this field assessment was conducted during the months of March and April 2004 and therefore does not represent the peak in abundance, which is mostly in spring and early summer. However, surface canopies were identified over an extensive area of the south-east sub-blocks 13C-E (Fig. 17). The largest continuous beds were present on reefs in the 5-20 m depth range around both the Actaeon and Sterile Islands, and even extending a further 1.5 km offshore on a shallow bank east of this region. Large surface canopies were also present on the shallow reef immediately south of Sterile Island but navigational hazards precluded running transects over this region (Fig. 17). There was also evidence of a considerable sub-surface population of *M. pyrifera* around this area, particularly on the deeper margins of the beds.

Two other large beds were also present to the east and south of Eliza Point corresponding with slightly shallower banks that are present in these areas (Fig. 17). Similar to the beds around the Actaeon Islands, there was a large population of sub-surface plants on the deeper margins of the beds. There were also several large beds adjacent to the prominent headlands in Recherché Bay consisting of both surface and sub-surface plants, and a mostly continuous surface canopy along the coastal fringe between Fisher Point and Second Lookout Point and immediately north of Whale Head (Fig. 17).

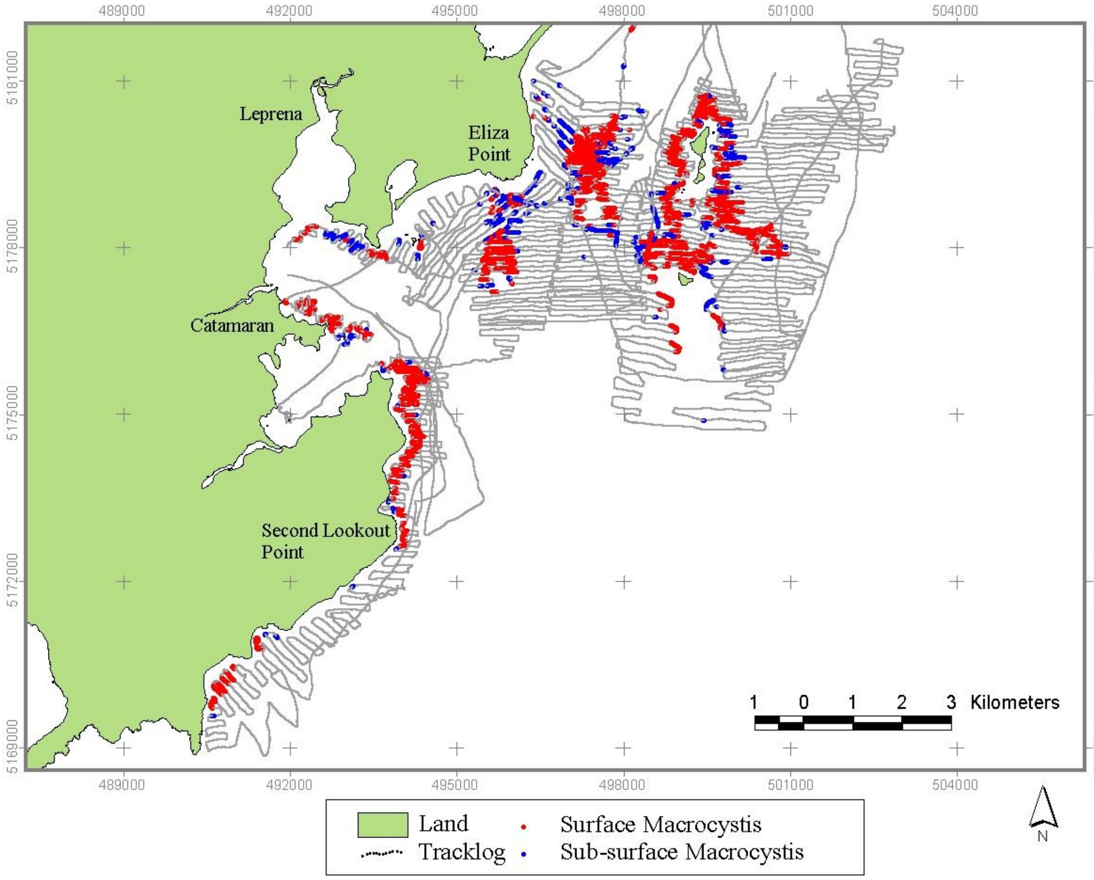

Fig. 17. Distribution of surface (red dots) and sub-surface (blue dots) beds of *Macrocystis pyrifera* identified during acoustic transects and blocks 13C-E.

6.2 North-east fishing blocks 30-31

6.2.1 Habitat distribution and structure

The abalone fishing blocks of 30 and 31 in north-east Tasmania were found to contain extensive areas of rocky reef habitat that extend along much of the coast, apart from the areas adjacent to several sand dominated beaches (Fig. 18). A feature of the reefs along this section of the coast is the often broad area of sand between the intertidal zone and the inner edge of the reef. This reflects the geomorphology of the region, which is dominated by a granite shoreline mixed with sandy beaches and several granite offshore islands and reefs. The only sections where reef was continuous to shore was adjacent to prominent headlands such as Eddystone Point (Fig. 19K), The Gardens (Fig. 19P) and Grants Point (Fig. 19S). In many areas there was evidence from the sidescan sonar transects of reef extending considerable distances offshore, particularly between Musselroe Point and Eddystone Point, and around Georges Rocks.

Overall, the extent and distribution of reef varies considerably between the various sub-blocks, and as the full extent of reefs was only determined in depths <20 m, the area of reef in each sub-block was not estimated in depths >20 m as the deeper boundaries of many reefs were not determined. The only region where all reefs <20 m deep were not mapped is south-east and east of Swan Island. This was due to the isolated nature of many of the coastal sections where it was difficult to determine the offshore reef extent in all sub-blocks. However, overall the extent of reefs in shallower depths revealed up to four times the area of reef in the 0-10 m depth range in sub-blocks 31A and 31B compared to those in block 30 (Table 4). This pattern was not consistent in the 10-20 m depth range with sub-blocks 30C and 31A having up to five times the reef area than that estimated in sub-blocks 30A, 30B and 31B.

Rocky reef habitat in sub-block 31B was dominated by two large areas of reef on the northern side of Swan Island and east and south-east of Musselroe Point (Fig. 19B, E). There was also smaller section of fringing reef running south of Tree Point (Fig. 19B, D). The reef adjacent to Musselroe Point consisted of a broad area of shallow patchy habitat (~< 10 m deep) adjacent to a considerably larger area of more continuous reef that extends up to 1 km offshore in places, and possibly further as the offshore acoustic transects were restricted to this distance due to sea conditions. Sub-block 31A contains considerably more reef than that immediately north as many of the sand dominated beaches, such as Purdon Bay, contain large reef systems that are less patchy than those found in sub-block 31B. There is also a considerable extent of offshore reef evident in the sidescan sonar, particularly between Eddystone Point and Cod Bay (Fig. 19I, J, K). The sidescan coverage indicates that reefs may be in continuous bands between the inner margin (which are intertidal around Eddystone Point and with an inner sand margin further north) and up to around 4 km offshore adjacent to Georges Rocks. Around these small islands there is a large area of continuous reef that extends from the intertidal out to a depth of at least 40 m (Fig. 19I). The reefs north of Boulder Point are considerably patchier in their distribution, apart from a large continuous area located south-east of Cape Naturalist (Fig. 19G, H).

Sub-block 30C is a large area that is dominated by an extensive reef that runs between Policemans Point and the Bay of Fires (Fig. 19N, O) and a separate reef located north of The Gardens (Fig. 19P). There is also an area of continuous reef running south-east of Eddystone Point, the offshore extent of which was not defined due to vessel limitations but is likely to run considerably further offshore if it is consistent with reefs immediately north (Fig. 19K, L). The reef habitat within sub-block 30B consists almost entirely of a large area that extends both north and south of The Gardens out to around 40 m deep (Fig. 19P, Q), and an area immediately north of Sloop Rock (Fig. 19R). The sidescan tracks showed little evidence of reef further offshore. Rocky reef habitat in sub-block 30A is dominated by continuous reef that extends from the southern end of Grants Point to Binalong Bay and from the intertidal zone out to depths of 40 m. There are also areas of continuous reef south of Sloop Rock and adjacent to all of the smaller headlands south to Binalong Bay (Fig. 19R).

Given the linear nature of most of the coast within blocks 30 and 31, there is little large-scale variation in exposure to swell action from the south and north along this coastline. The bathymetry in most places also results in swell reaching the inner reef margin as there is little offshore barrier. There are, however, considerable variations at the local scale due to the presence of several prominent headlands such as Grants Point, Eddystone Point and Musselroe Point that results in reef on the north-west side that is sheltered from the dominant southerly swell. The other area of sheltered reef is that on the north side of Swan Island that is only exposed to north-east swell, and due to its shallow depths, only exposed on the reef edge.

Table 4. Area (km^2) of rocky reef habitat defined between depths of 0-20 m in abalone fishing sub-blocks 30A-C and 31A, B.

	Depth strata	
Sub-blocks	**0-10 m**	**10-20 m**
30A	1.3	0.9
30B	1.2	1.1
30C	1.8	4.1
31A	6.8	5.0
31B	6.0	1.3

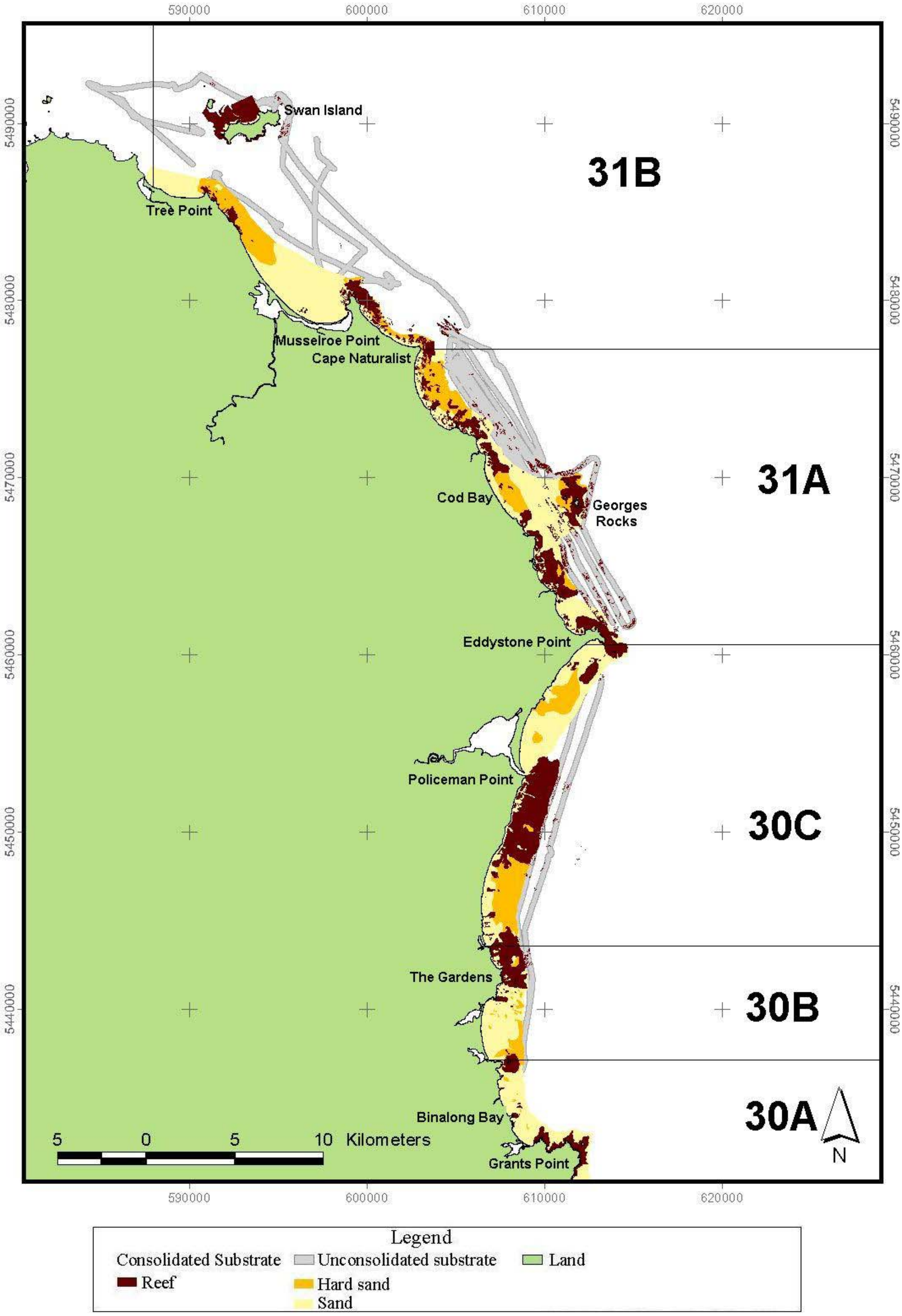

Fig. 18. Distribution of seabed habitats in the north-east Tasmanian abalone fishing blocks 30 and 31 at a scale of 1:270,000.

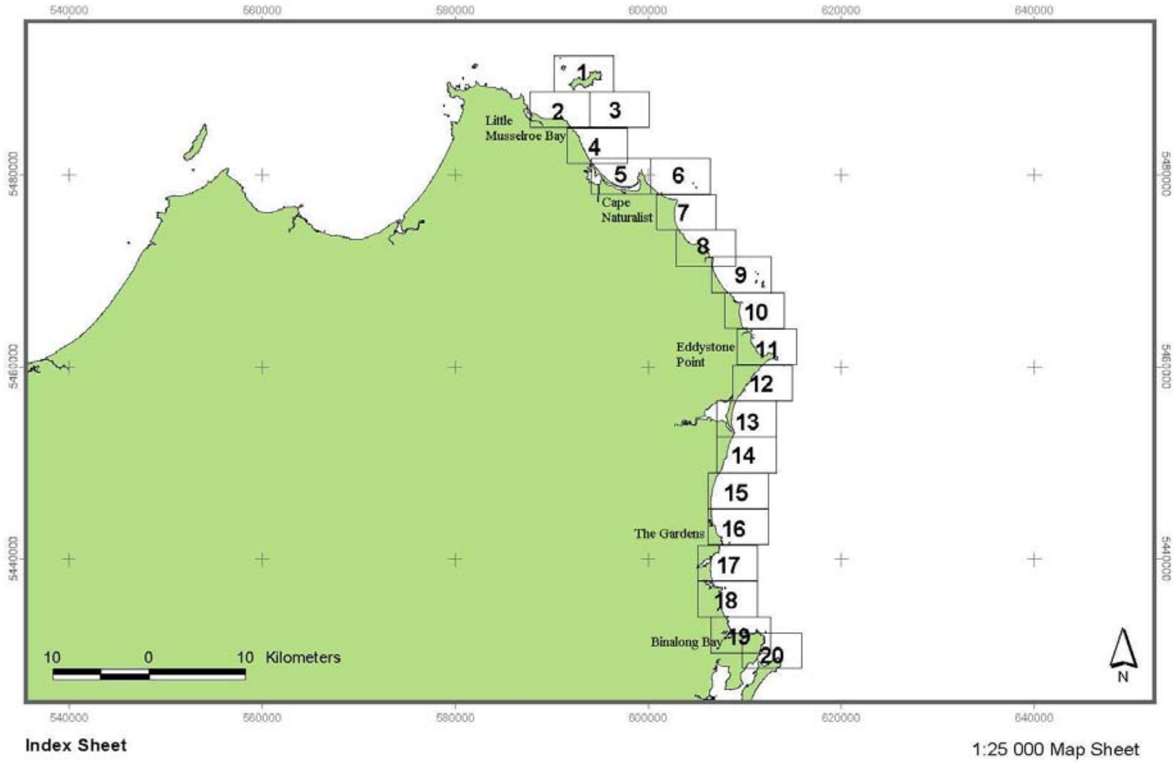

Fig. 19A. Index sheet showing the of position of 1:25,000 maps used to present the distribution of seabed habitats in the north-east Tasmanian abalone fishing blocks 30 and 31.

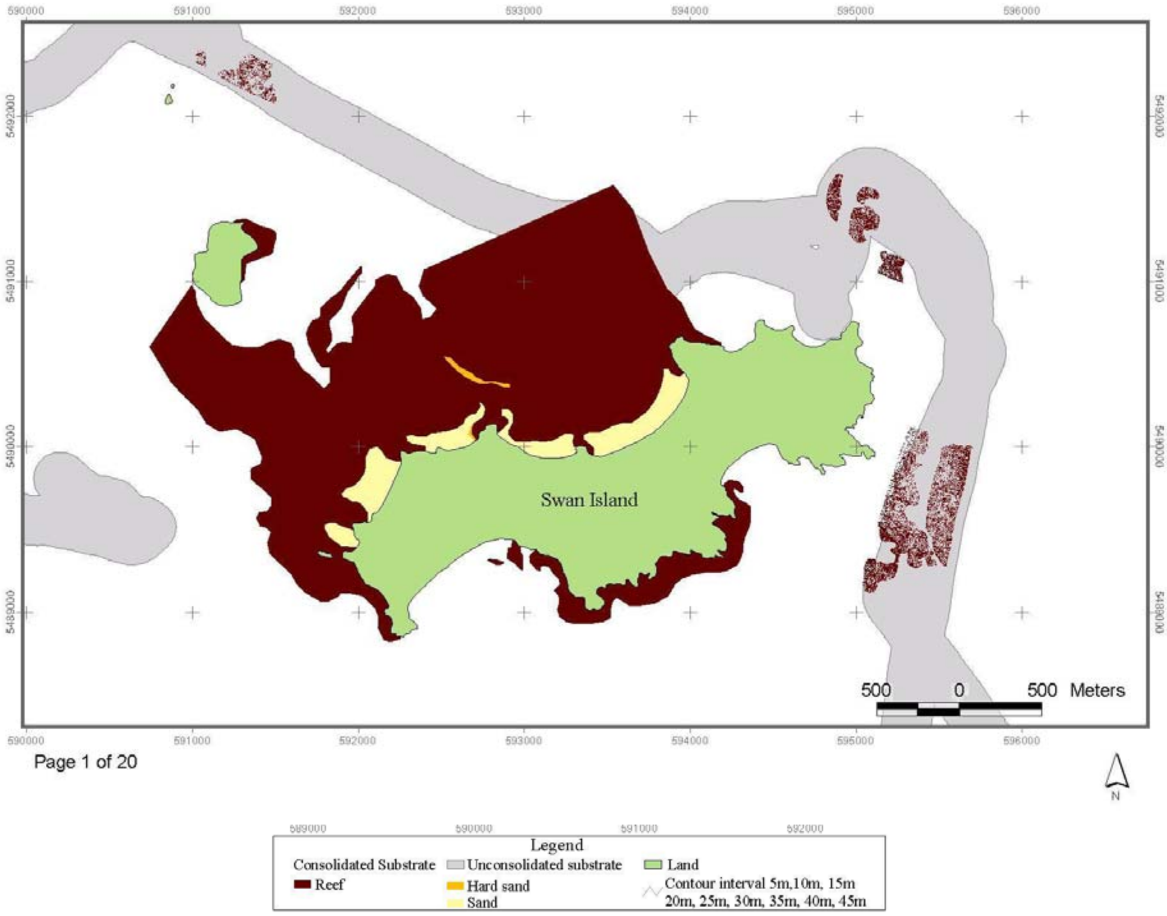

Fig. 19B. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 1.

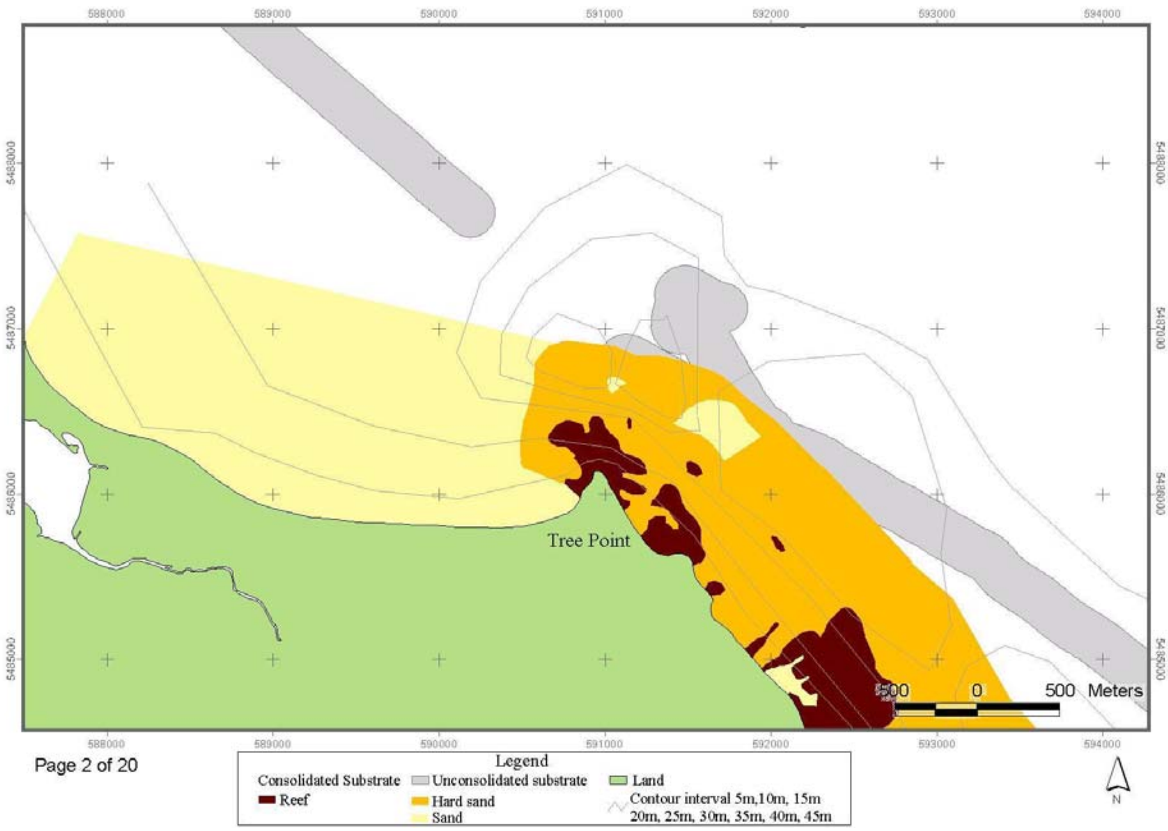

Fig. 19B. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 2.

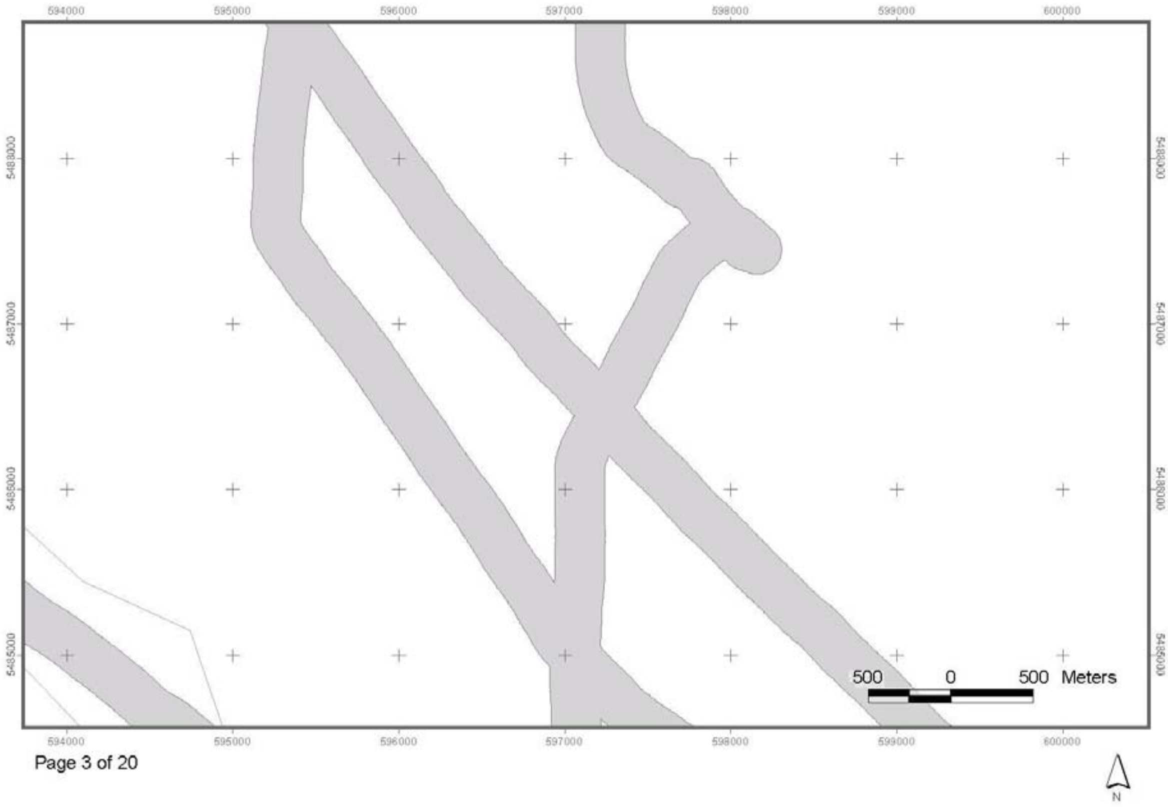

Fig. 19C. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 3.

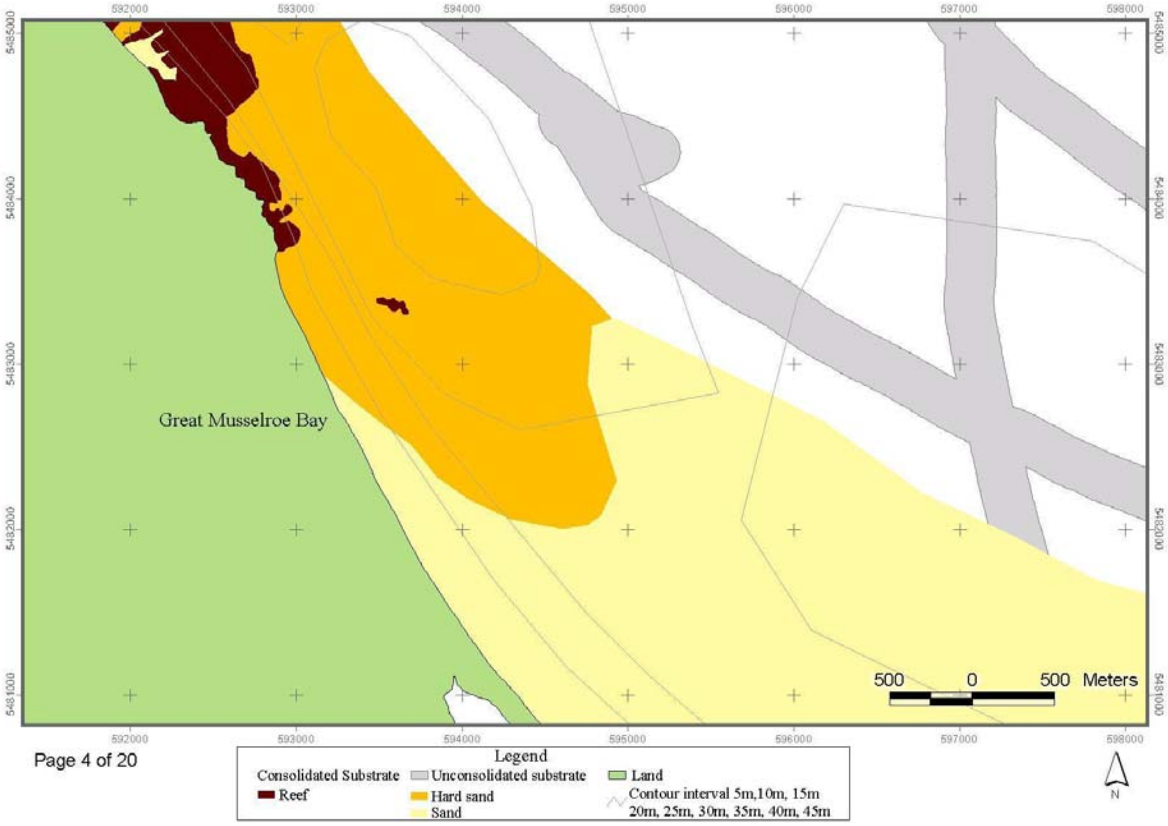

Fig. 19D. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 4.

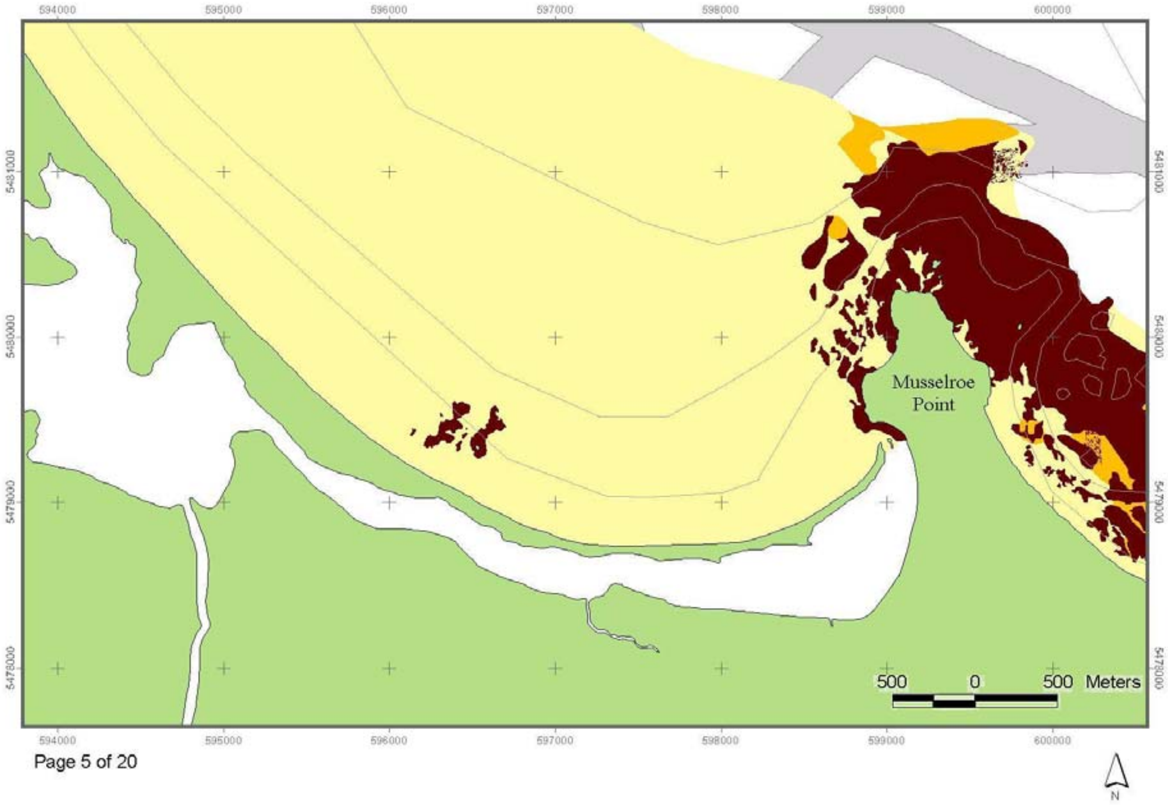

Fig. 19E. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 5.

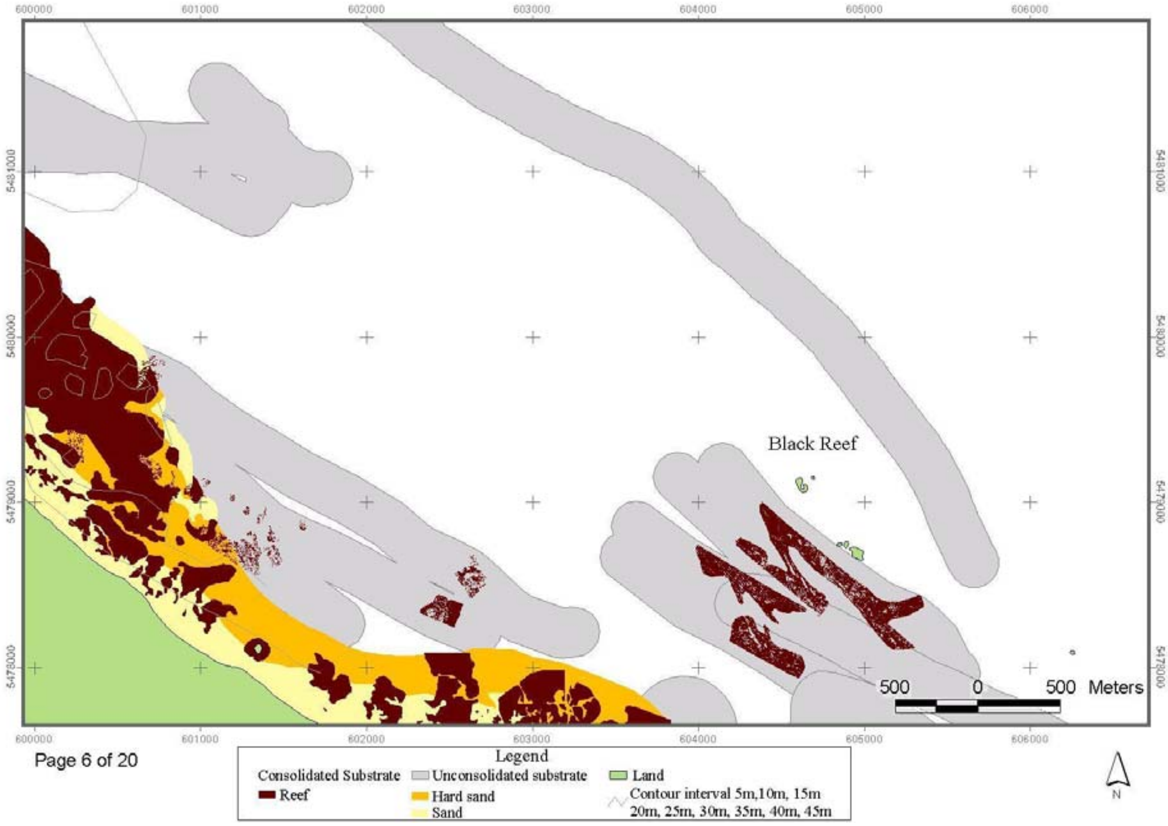

Fig. 19F. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 6.

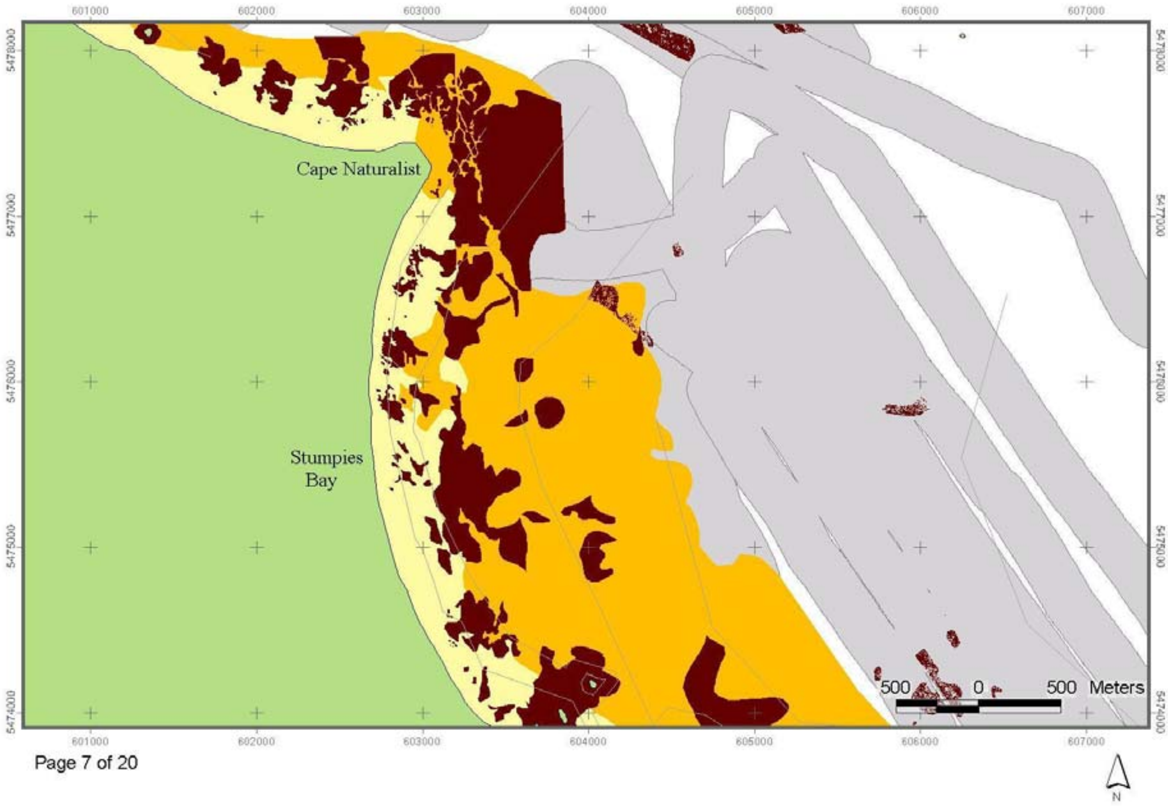

Fig. 19G. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 7.

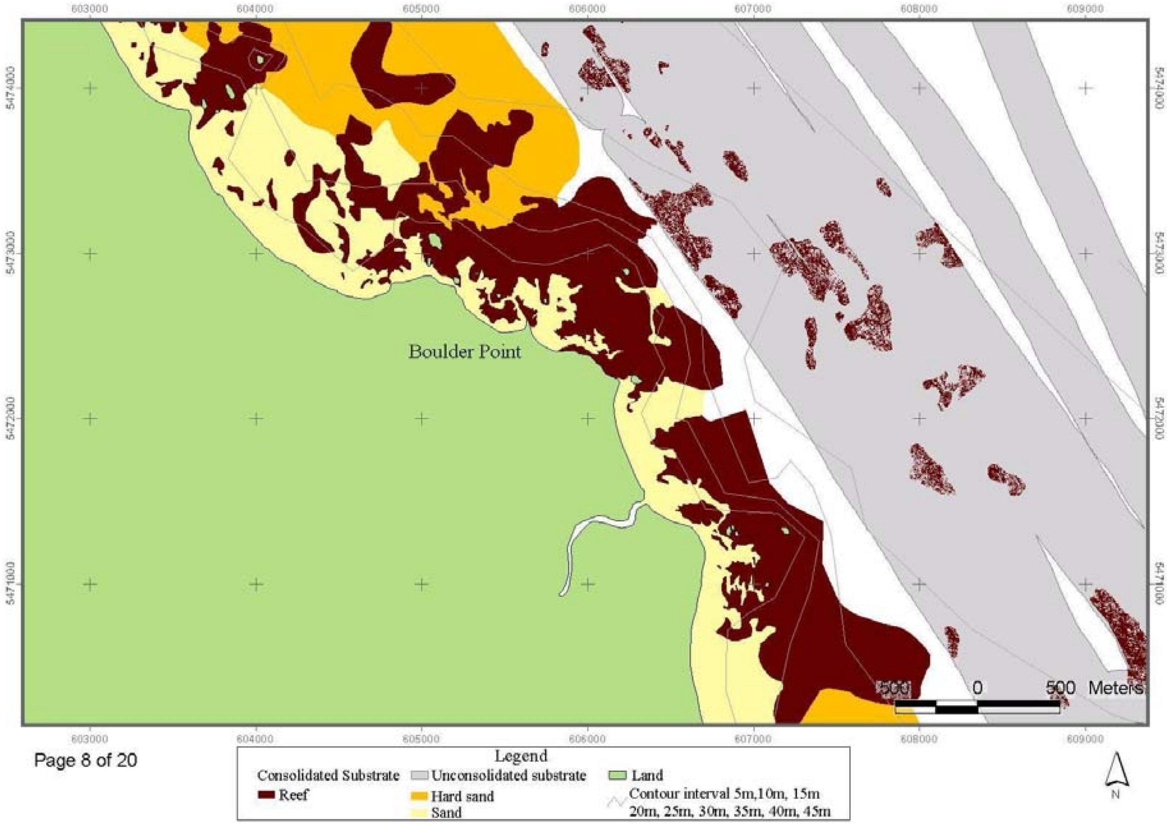

Fig. 19H. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 8.

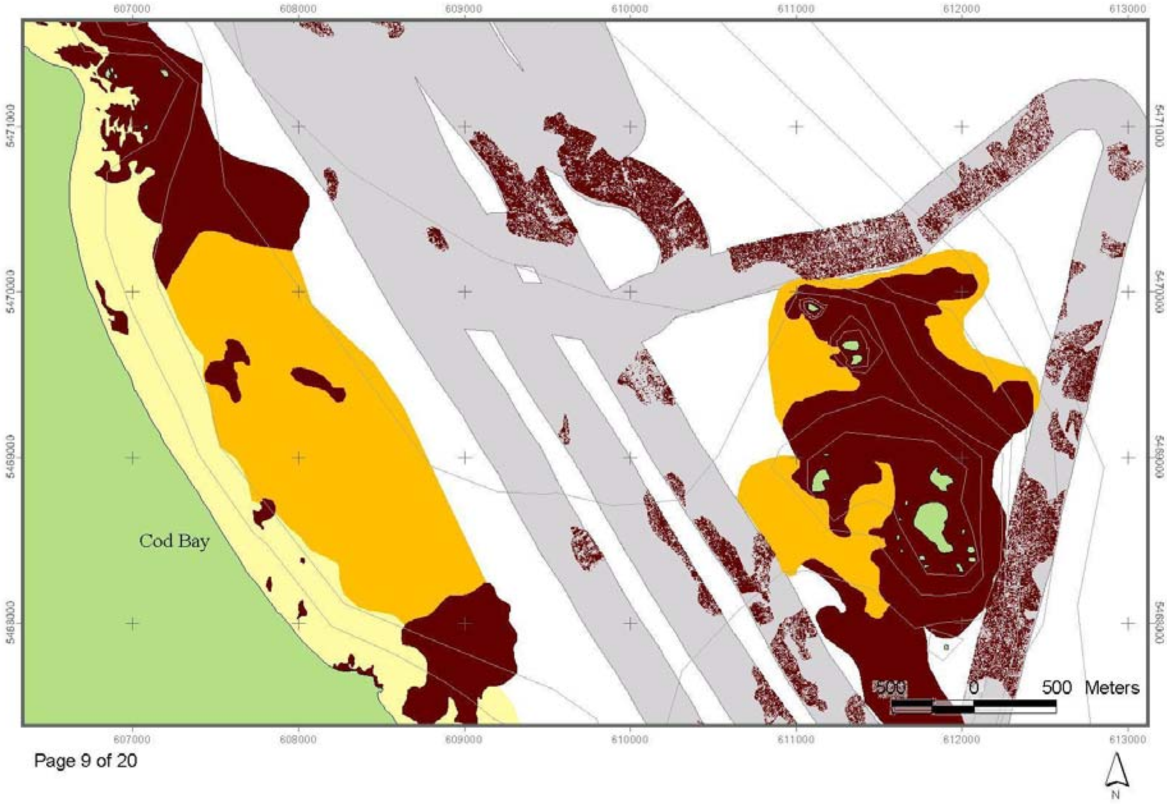

Fig. 19I. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 9.

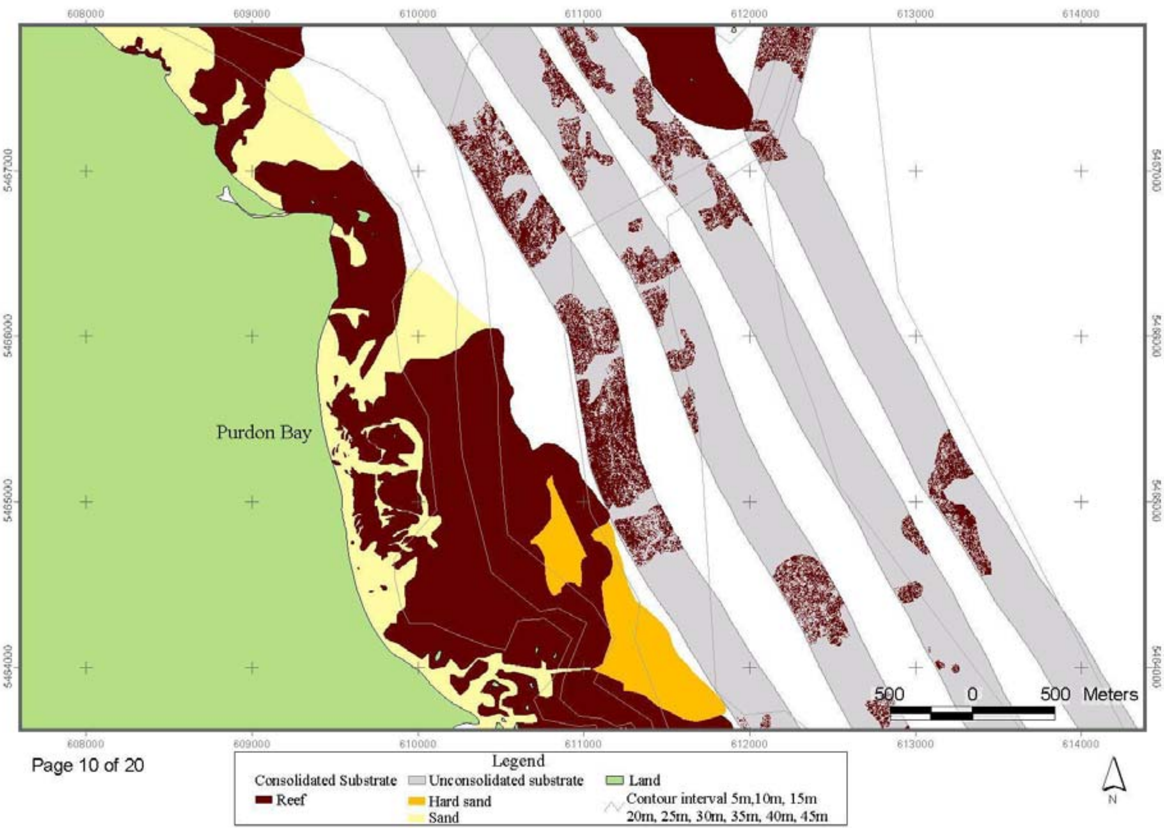

Fig. 19J. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 10.

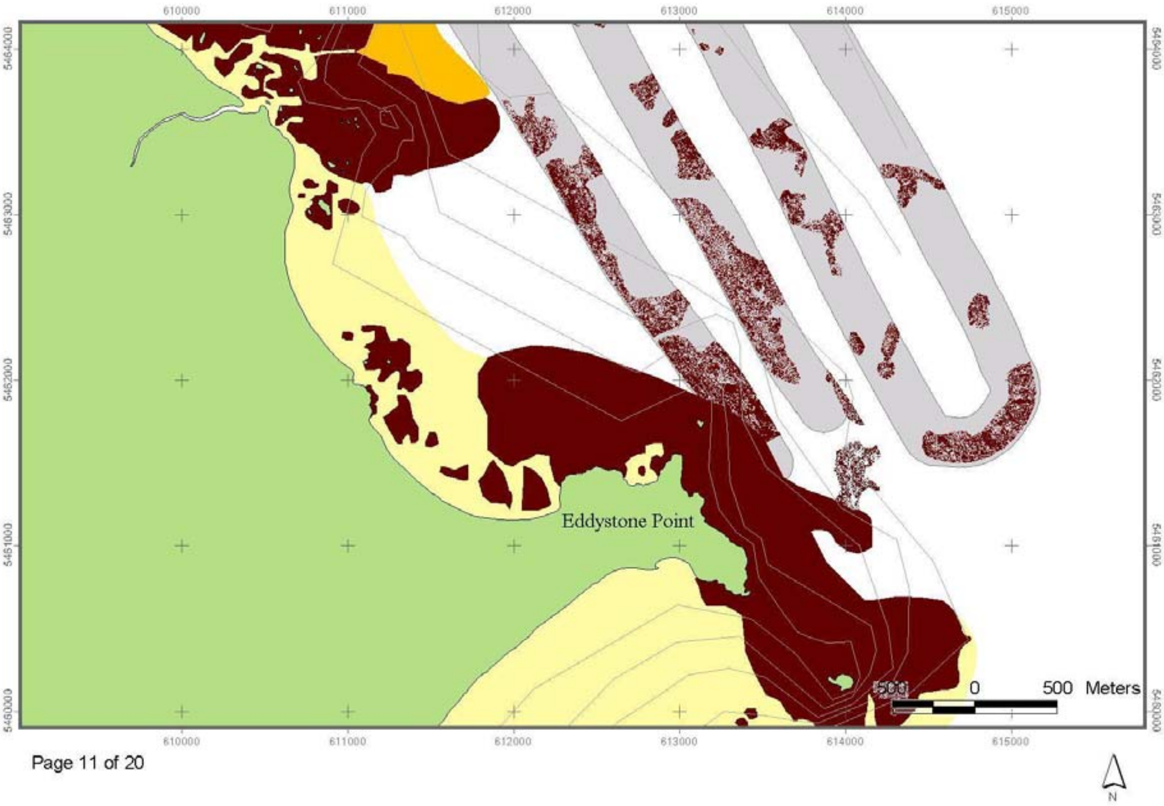

Fig. 19K. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 11

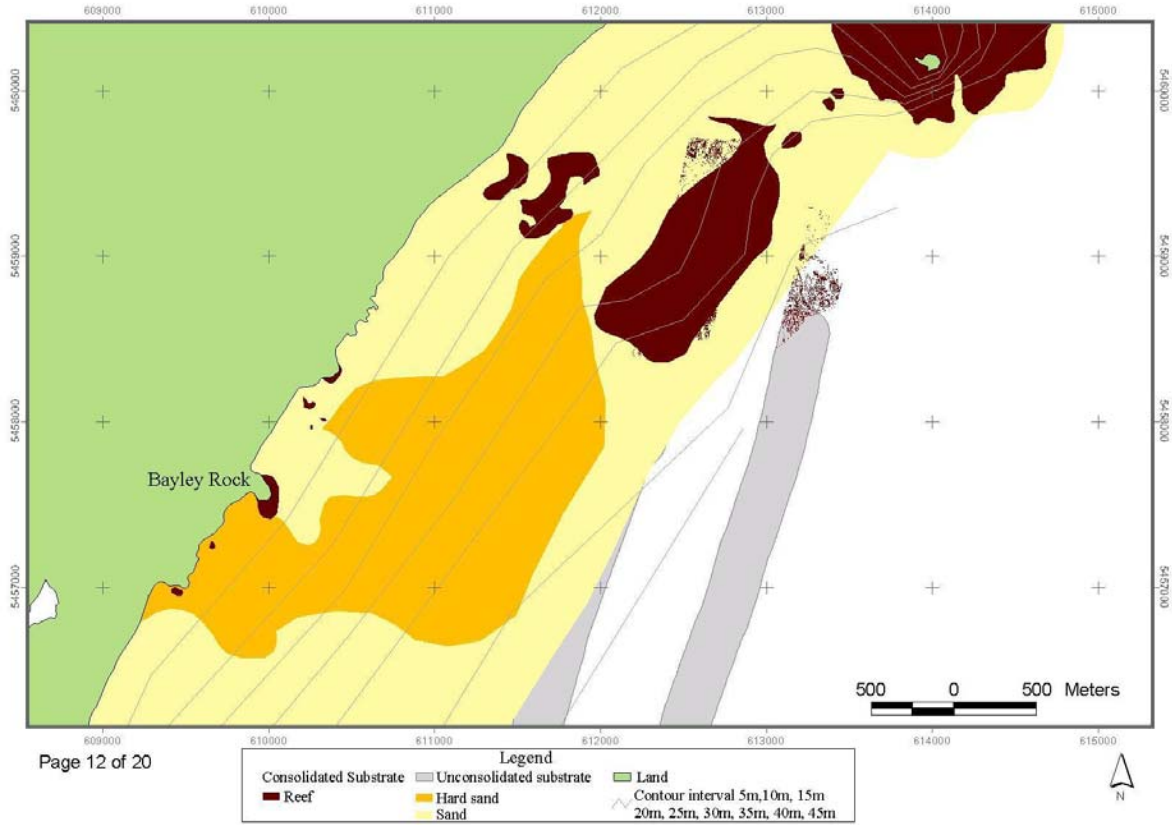

Fig. 19L. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 12

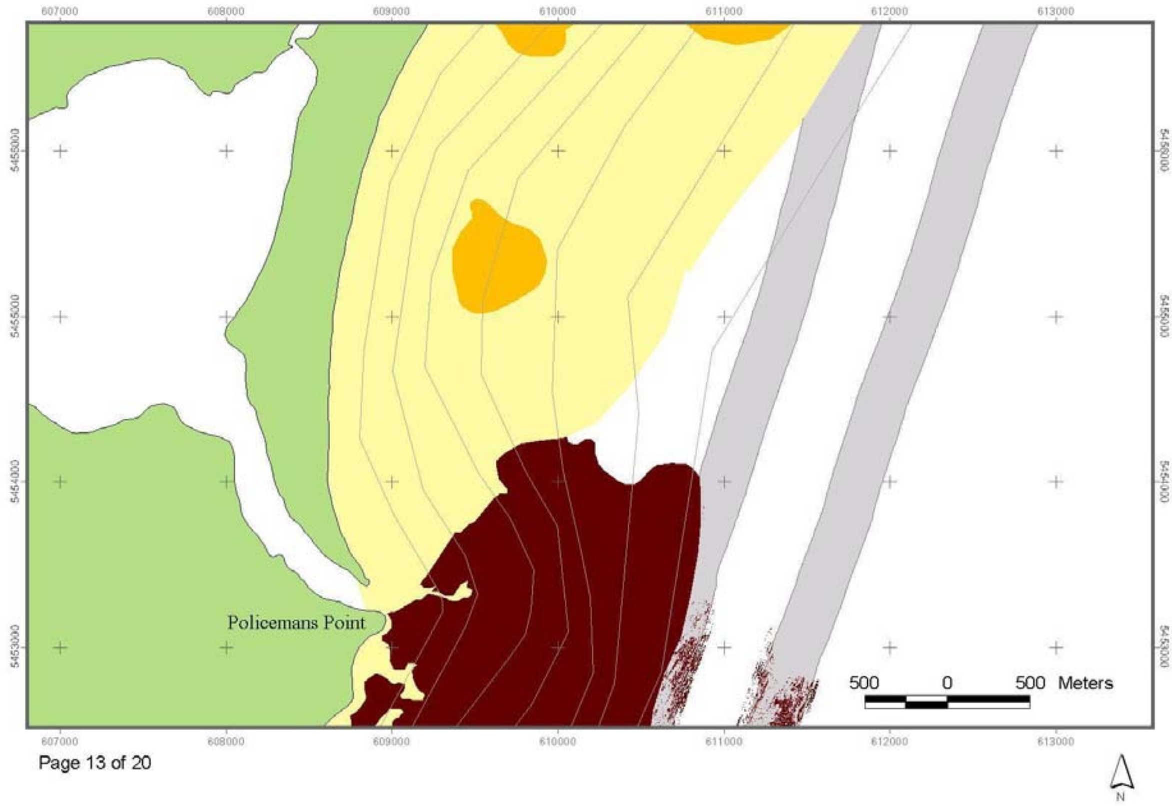

Fig. 19M. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 13

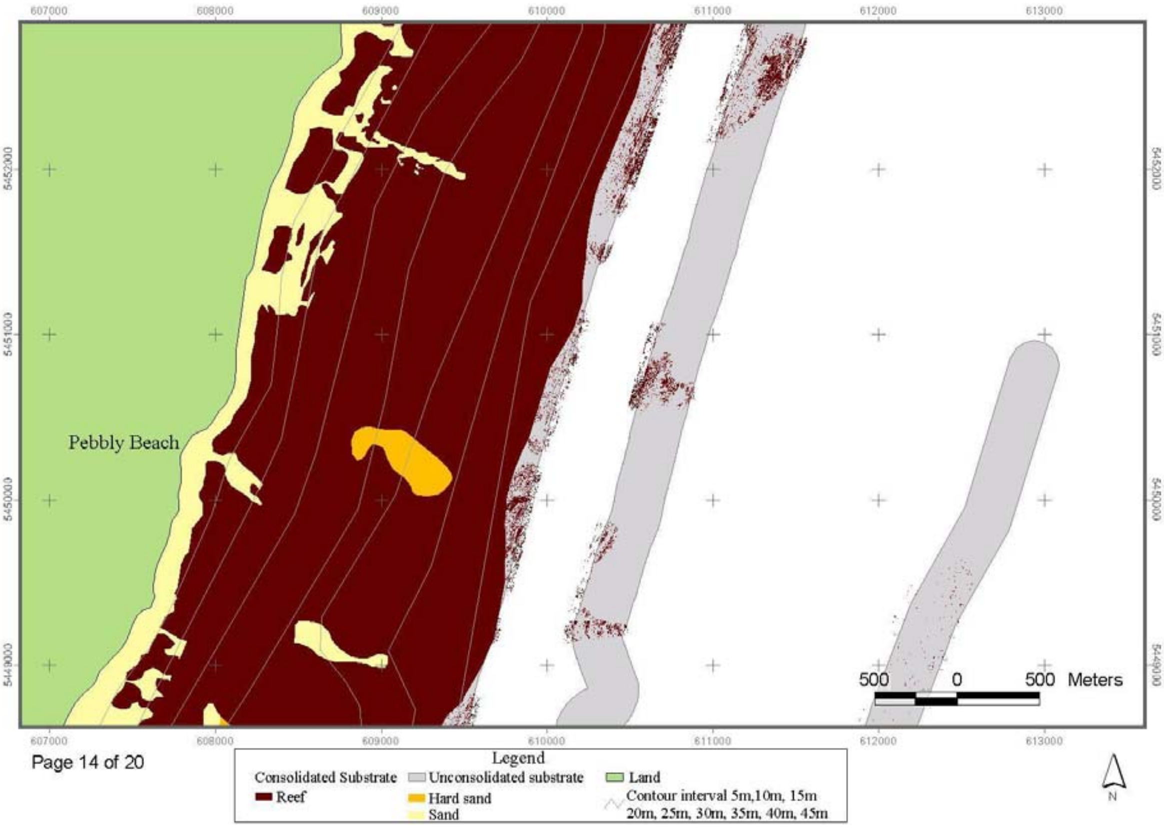

Fig. 19N. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 14

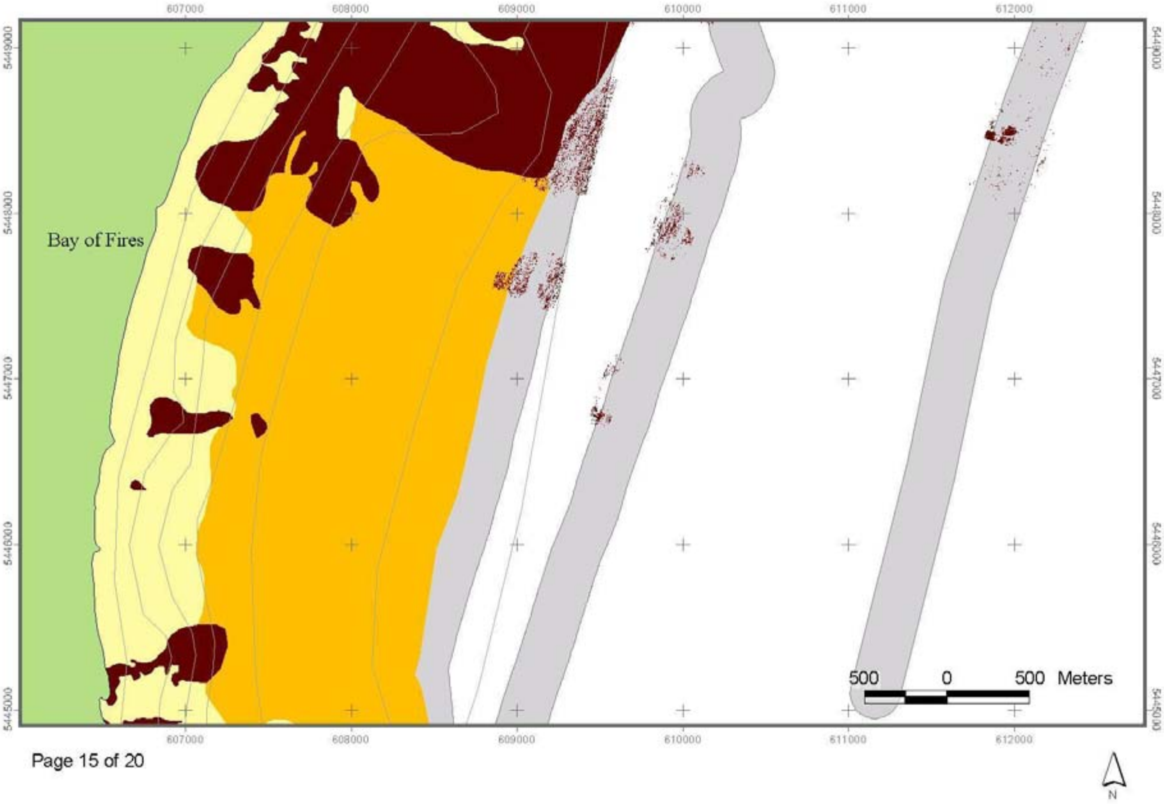

Fig. 19O. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 15

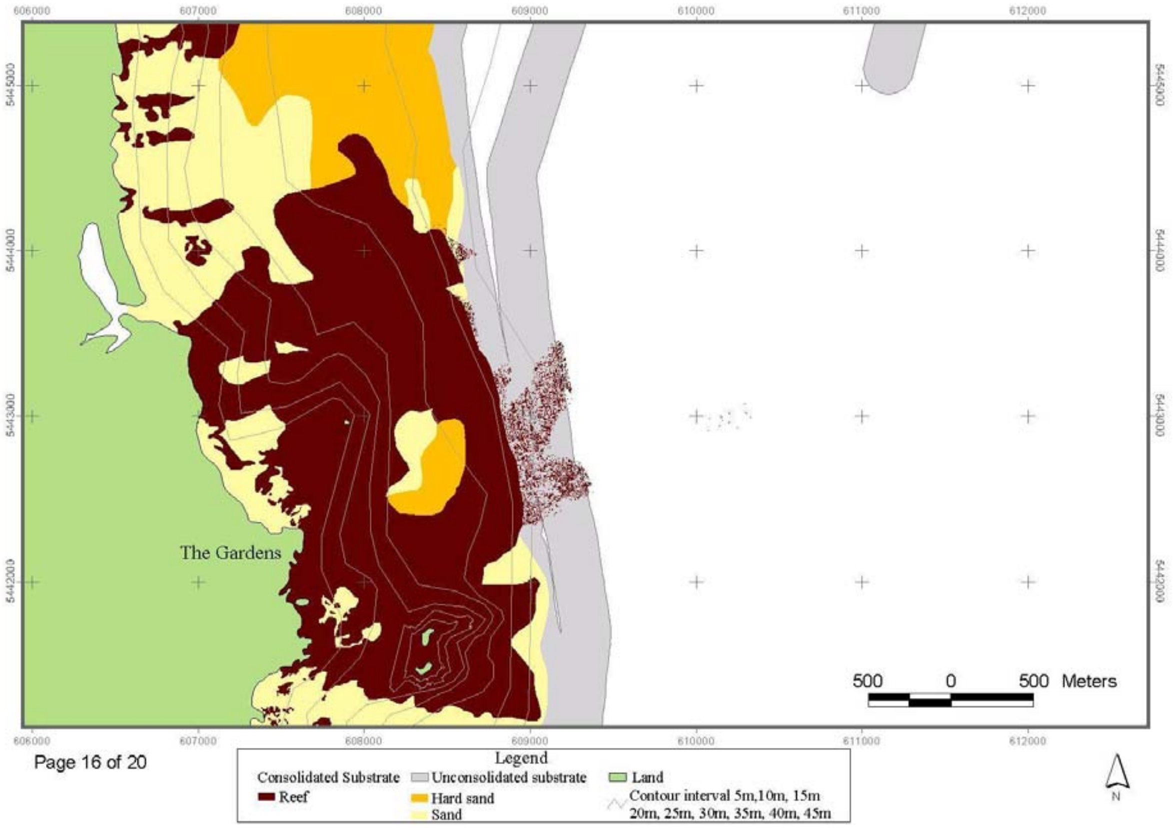

Fig. 19P. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 16

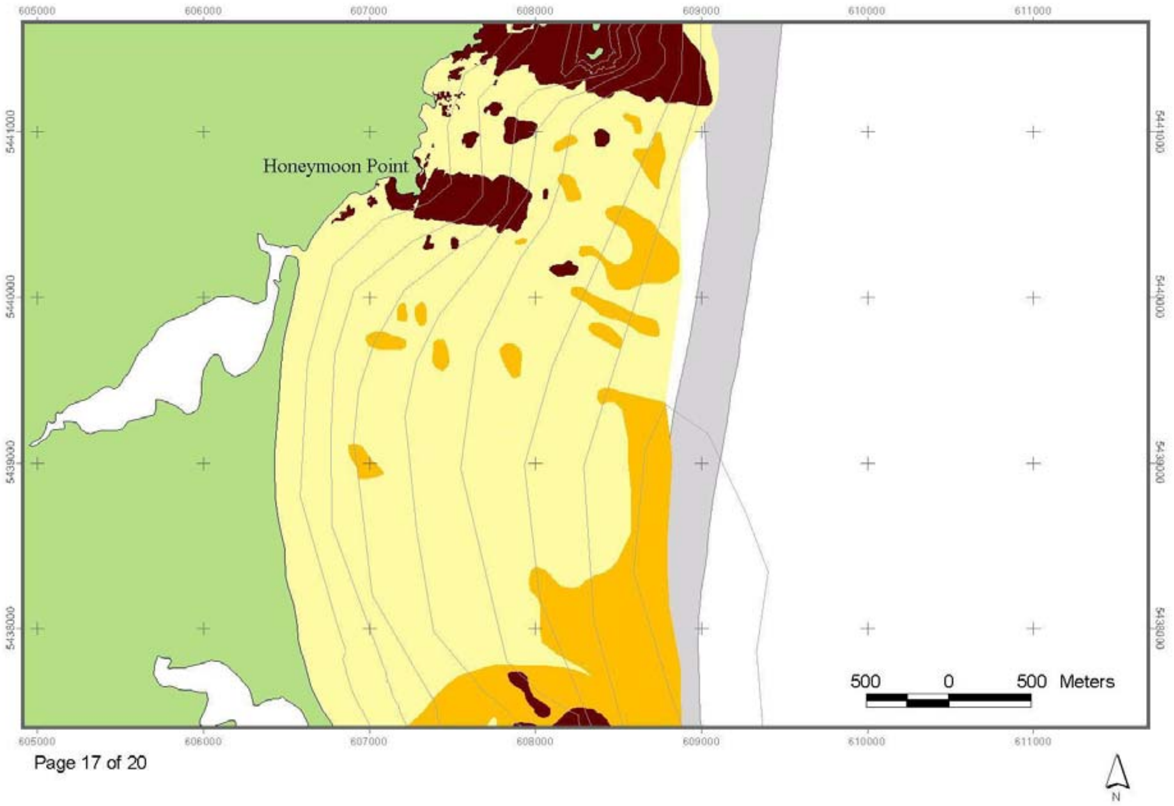

Fig. 19Q. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 17

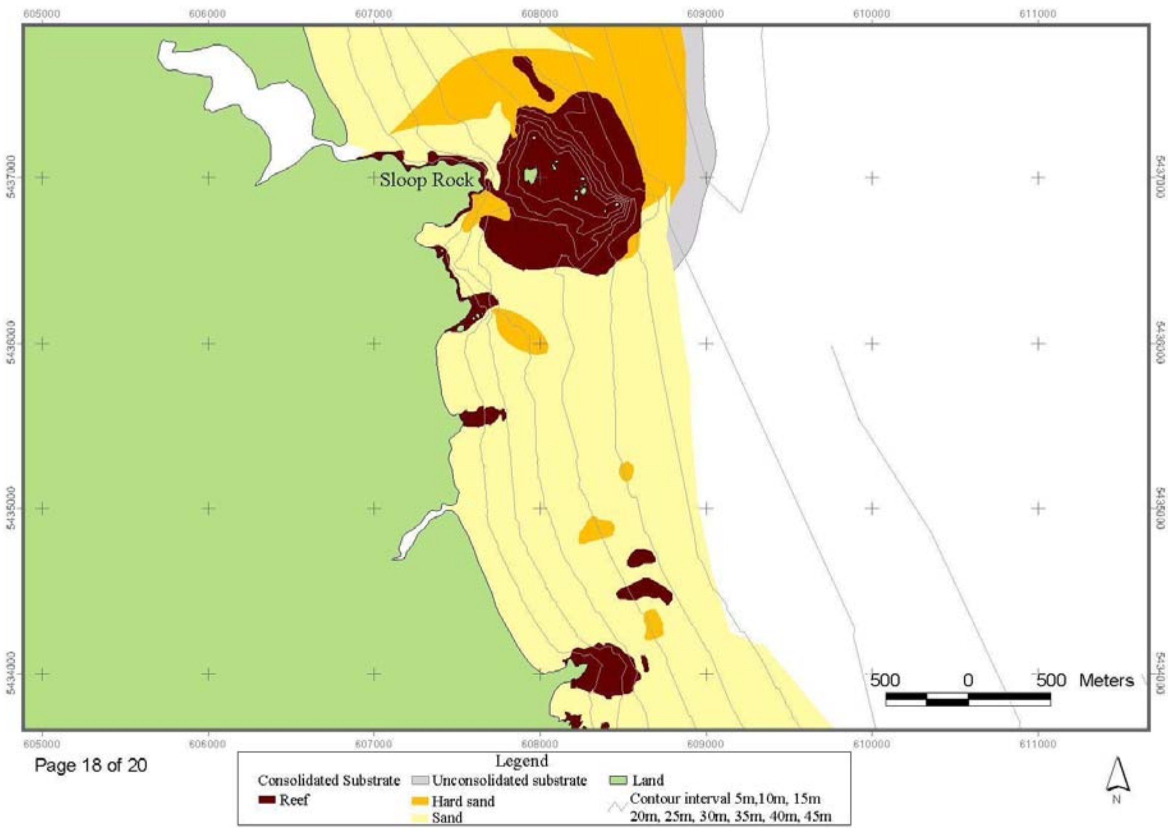

Fig. 19R. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 18

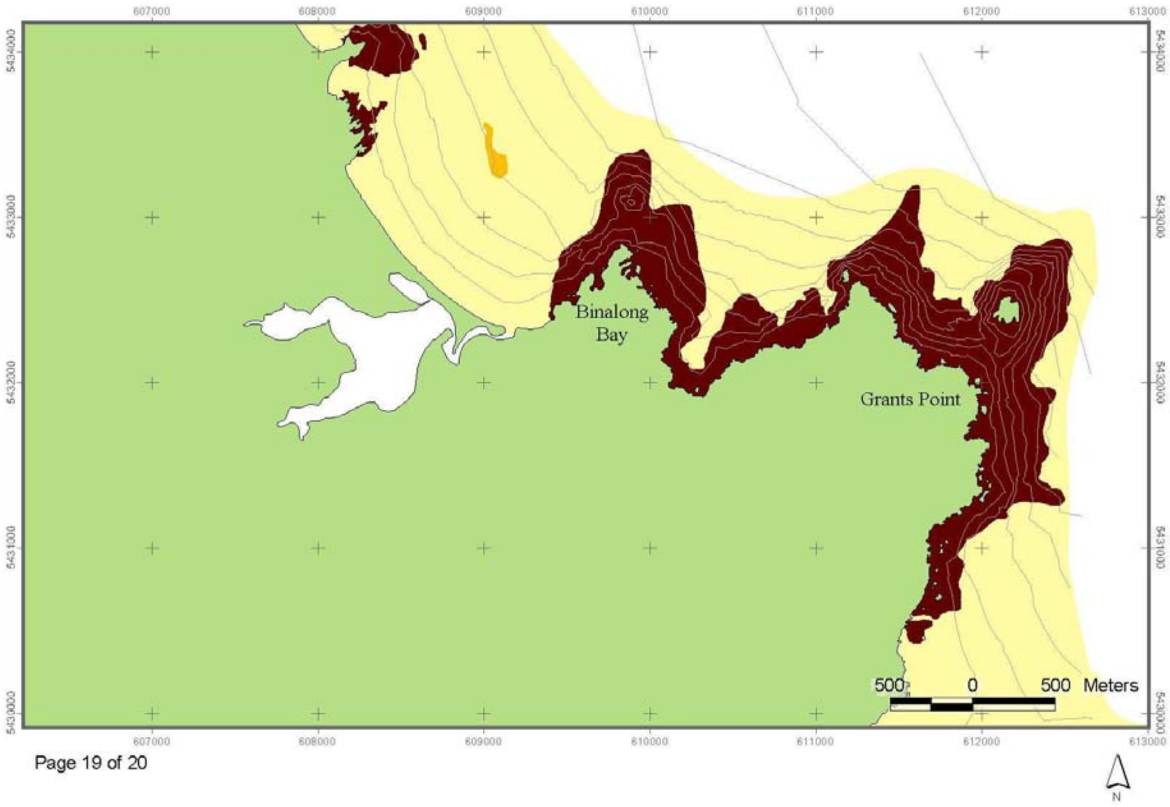

Fig. 19S. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 19

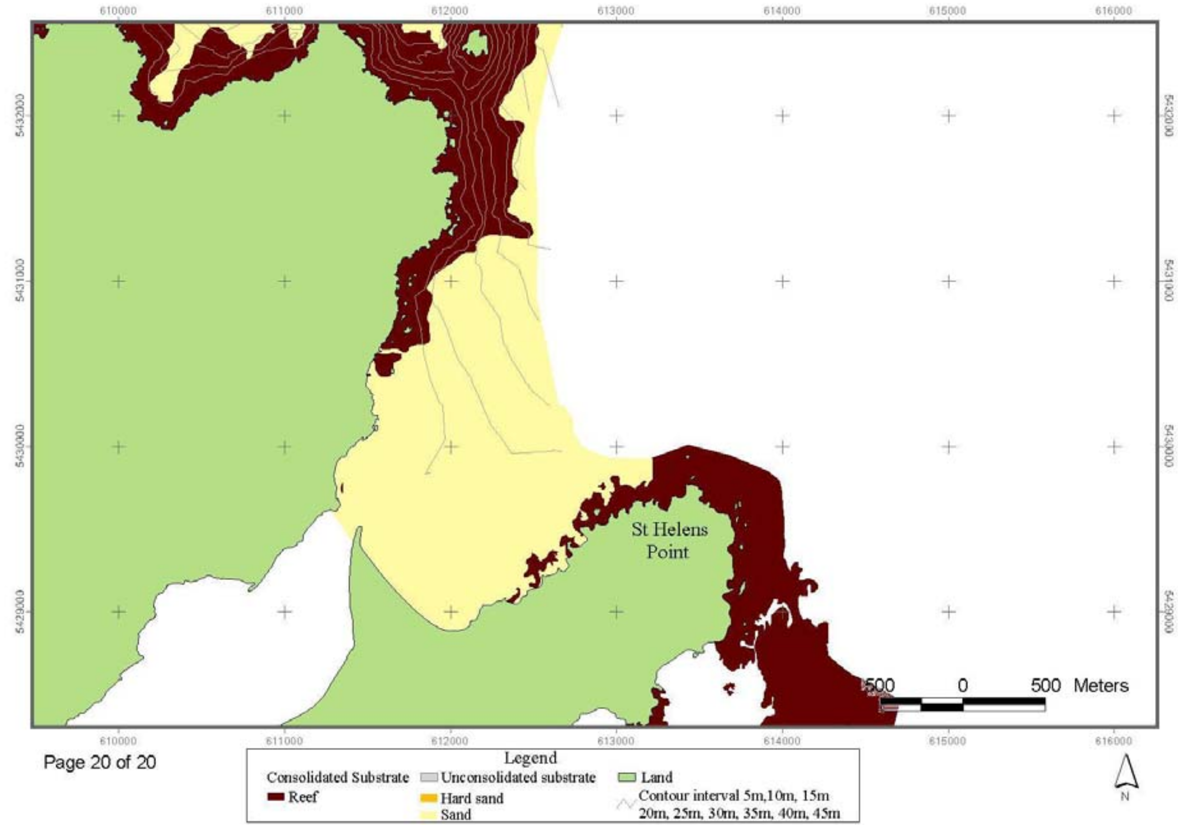

Fig. 19T. Distribution of seabed habitats in north-east Tasmania at a scale of 1:25,000 within area 20

Reef profile was determined at a series of transects throughout the north-east sub-blocks (see Fig. 10B, C) to examine the fine-scale structure of the reefs. Overall, all the sub-blocks are dominated by low profile reef (i.e. <1 m relief) with between 60-80% of reef with low profile, although there were some differences in specific depths (Fig. 20). These were specifically in the 0-10 m depth strata in sub-block 30B and 30-50 m strata in 31A, both of which had a higher proportion of medium profile reef. In sub-block 31A this specifically relates to deep reef on the eastern side of George III Rocks. The highest proportion of low profile reef occurred in sub-block 31B, which in the 0-10 m depth strata relates to reef on the northern side of Swan Island and the 10-20 m strata on reef adjacent to Musselroe Point.

While analysis over an entire sub-block provides a useful overview, consistent with that found within the south-east sub-blocks, transects in the north-east showed a high frequency of change between low and medium profile over small distance resulting in small-scale complexity that is very difficult to present as a continuous surface (see Appendix 5a-e). Generally, sections of reef that were consistently of a specific profile were >200 m long although it was common for profile to vary between low and medium over distances of <50 m. With transects spaced in most places at distances >200 m, this high variability along the transect means that knowledge based interpolation is not effective in representing this variability and therefore maps of reef were presented without profile defined. However, profile information is available along every acoustic transect, with those presented in Appendix 5 only to provide limited examples.

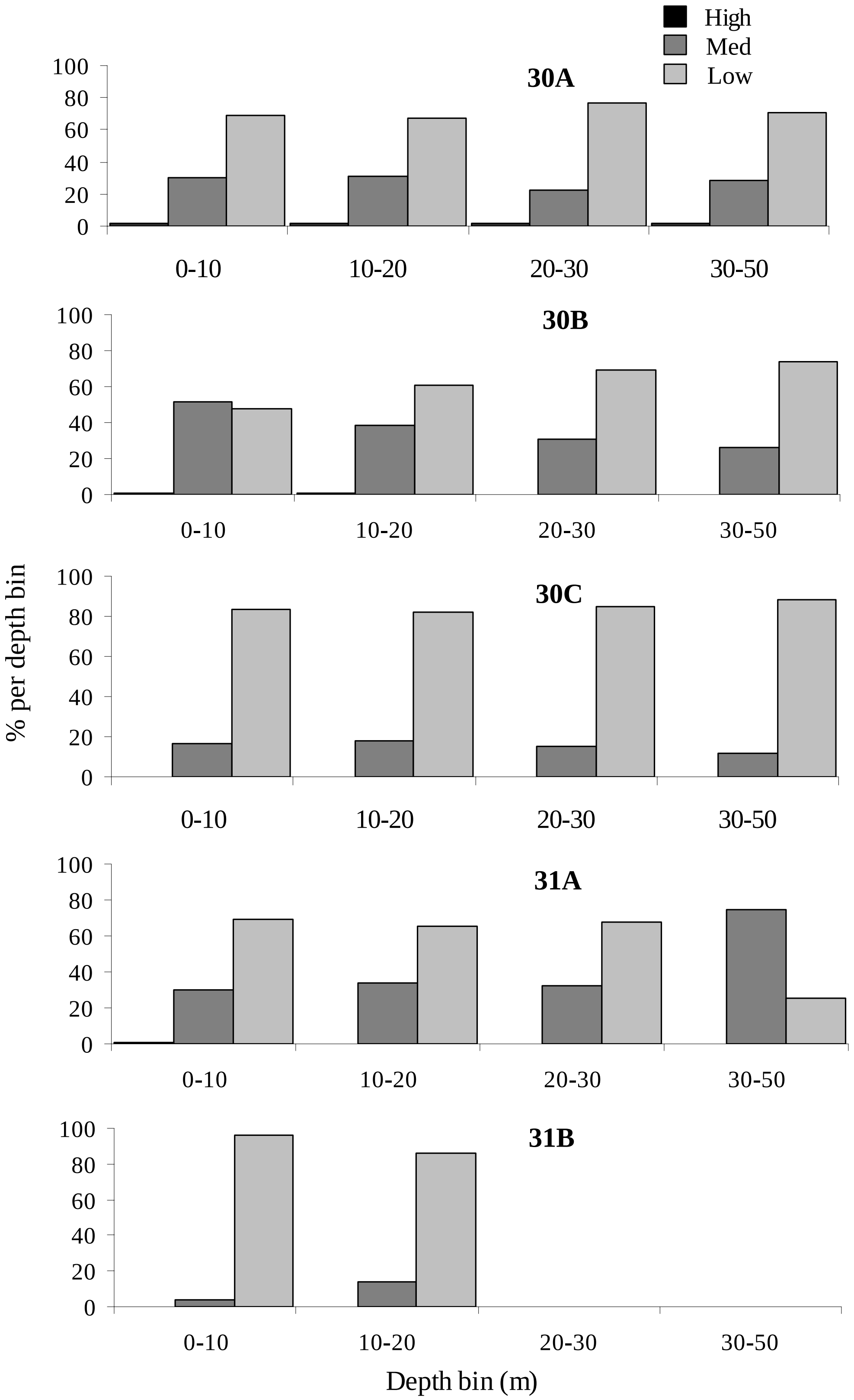

Fig. 20. Estimated proportion of low, medium and high profile reefs by depth strata in blocks 30 and 31 in north-east Tasmania.

Due to the acoustically defined minimum mapping unit of 15 m with the single-beam echosounder it is not possible to discriminate finer-scale habitat features and video analysis is required to assess the proportion of unconsolidated substrate with the reef defined polygon. While there was no obvious spatial trend in reef profile, the proportion of continuous reef decreased between sub-block 30A in the south to 31B in the north (Fig. 21). This was driven by an increase in both reef-sand complex and bare sand, with the higher proportion of sand identified from video within the northern sub-blocks indicating that the reef in this region is highly patchy at the fine-scale. This is consistent with the patterns of reefs determined from aerial photography where overall reef patchiness at a larger geographic scale increased in the northern sub-blocks. The data also indicate that much of the reef habitat in the more northern blocks defined using the single-beam acoustics is likely to be structured similarly to that defined from aerial photography (i.e. patchy at a range of scales). However, the nature of interpolation between acoustic transects results in many small patches being unrepresented in the maps. This conclusion is also supported by the sidescan sonar data that provided full coverage over a swath width of up to 200 m and revealed considerable fine-scale patchiness in the classification.

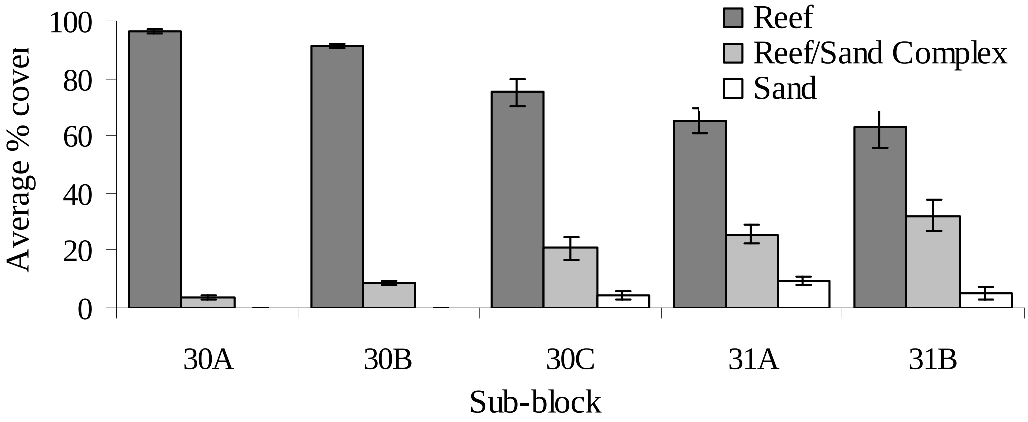

Fig. 21. Estimated proportion (± s.e.) of continuous reef, reef-sand complex and sand from video analysis in sub-blocks 30A-C and 31A, B.

6.2.2 Algal composition

Analysis of video transects revealed the broad pattern of distribution across depths of the dominant species in the macroalgal canopy (excluding *Macrocystis pyrifera*) and the understory assemblages of coralline and red algae and *Caulerpa* sp. Overall, the patterns were consistent with that previously identified for reef assemblages in north-eastern Tasmania (Barrett and Willcox, 2001), where depths from 0 to around 15 m were dominated by *Phyllospora comosa* and *Ecklonia radiata* (Fig. 22). The presence of *P. comosa* is generally indicative of a sub-maximally exposed coast, and this species is absent in locations without constant water movement, such as most of the Tasmanian north coast (Barrett and Willcox, 2001). Only a narrow fringe of *Durvillaea potatorum* (bull kelp) to around 2 m deep was identified in these video surveys, although this is an underestimate due to the logistics of conducting video drops on rocky reefs in depths of <2 m. The low abundance of *D. potatorum* reflects the absence of regular high-energy swells in this region as it is a conspicuous kelp on maximally exposed temperate coasts. Overall, there were few large-scale differences in algal assemblages apparent, reflecting the small variations in exposure to swell on the reefs between the sub-blocks. The only trend variation identified occurred in sub-blocks 30C and 31A, B in depths <20 m where *Caulerpa* sp. was either absent or at very low abundance compared to the sub-blocks immediately south (Fig. 22).

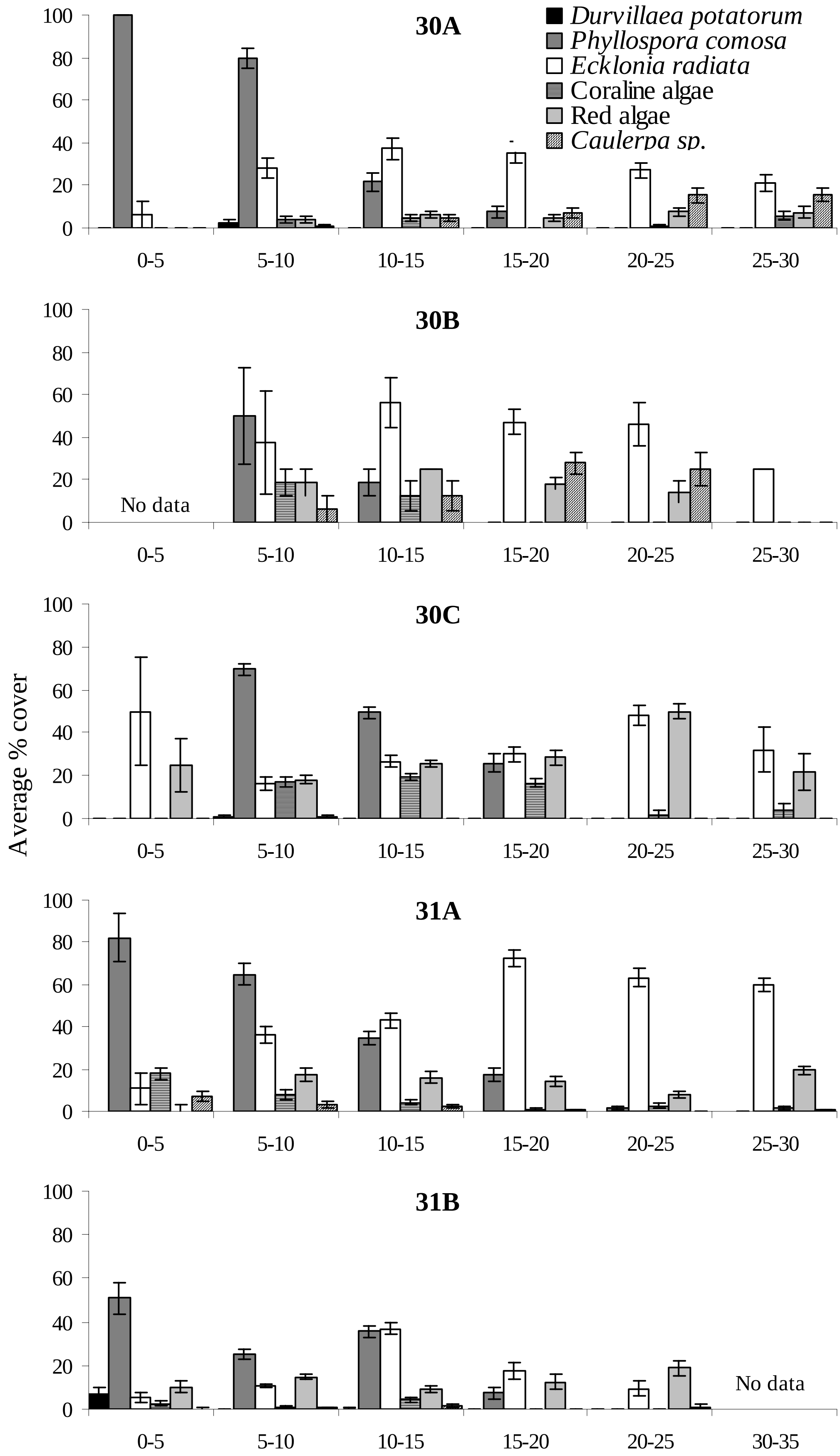

Fig. 22. Mean percentage cover (± s.e.) for dominant canopy macroalgae and understory algae associated with reef habitats in 5 m depth strata within the northeast Tasmanian blocks 30 and 31.

While species were found to dominate the macroalgal assemblage at any depth, there was generally a diverse range of species also present. Apart from those detailed earlier, the dominant species identified in this survey include *Cystophora* sp., *Acrocarpia paniculata*, *Ulva* sp., *Caulocystis uvifera*, *Sargassum* sp., *Carpoglossum confluens*, *Codium fragile*, turfing browns and a range of filamentous algae. There was little evidence of surface or sub-surface populations of *Macrocystis pyrifera* in the north-east blocks during the January and February survey period. Small surface populations were identified on reefs on the northern side of Musselroe Point and adjacent to Tree Point and Policemans Point, but were absent as either surface or sub-surface populations on all other reefs.

Due to an obvious difference in algal community composition, separate video analysis was conducted from transects on the reef immediately north of Swan Island (Fig. 19B, 23). This large area of low profile reef was dominated in the 0-10 m depth range by the seagrass *Ampbibolis antarctica*, which is know to occur on patchy reef where there is sufficient sand within the reef complex for plants to establish. The area was also characterised by the high abundance of *Cystophora* sp., *Acrocarpia paniculata* and a range of brown filamentous and turfing algae across most depths. This is the only section of reef in the north-east fishing blocks that this type of assemblage occurred and is likely to be related to its low exposure to swell and increased influence of Bass Strait hydrography.

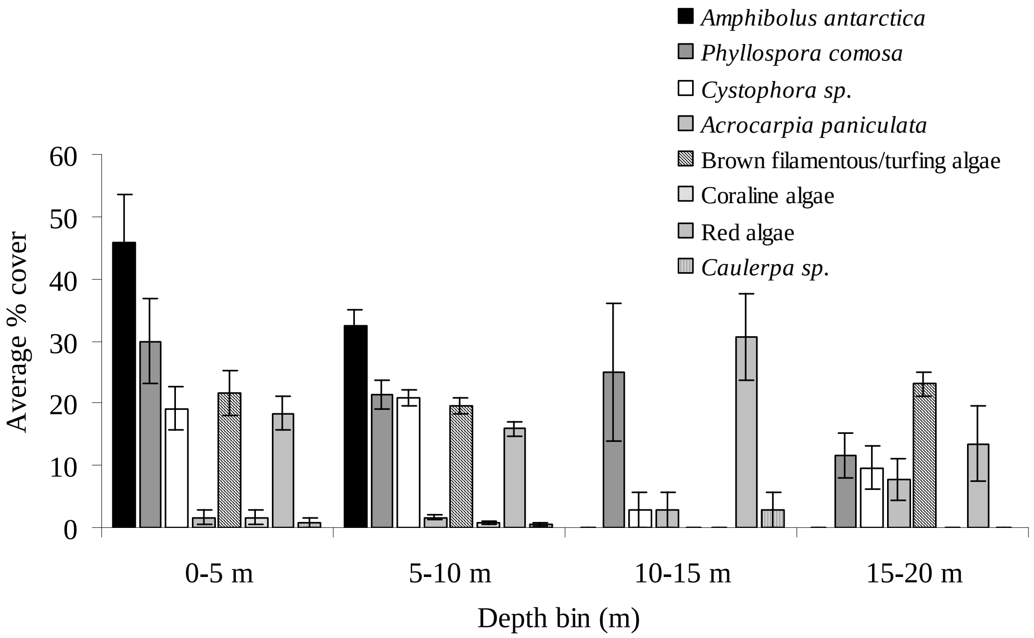

Fig. 23. Mean percentage cover (± s.e.) for dominant canopy macroalgae and understory algae associated with reef habitats in 5 m depth strata on the northern side of Swan Island (sub-block 31B).

The video surveys also revealed a large number of urchin barrens, which result from intense grazing by the long-spined urchin, *Centrostephanus rodgersii* (Fig. 24). Barrens constitute a distinct habitat of their own and are characterised by the almost complete absence of macroalgae and an enhanced presence of planktivorous fish. Barrens were found to extend from depths of 5 m to around 30 m with the highest cover occurring in the 15-25 m depth range. Barrens were most extensive in sub-block 30A where maximum barrens coverage was around 55% in the 15-20 m depth strata and only slightly less in the 10-15 m and 20-25 m strata. The majority of these barrens occurred on the rocky reef adjacent to Grants Point and Binalong Bay. The sub-block with the second highest urchin barrens coverage was 30B where they were most extensive (~ 26%) in the 15-20 m depth strata on the reef adjacent to The Gardens. There was little evidence of sub-block 30C despite there being extensive areas of deep reef adjacent to Pebbly Beach and Policeman Point. Most of the higher proportion of urchin barrens in sub-block 31A in the 15-30 m depth range were identified from video transects taken on reefs immediately north of Eddystone Point. There was no evidence of urchin barrens present any reefs in any depths north of this area.

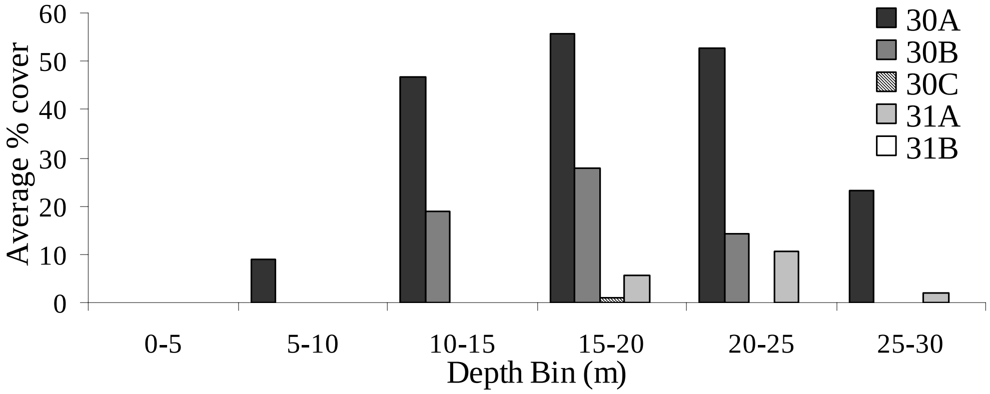

Fig. 24. Mean percentage cover (± s.e.) for urchin barrens across 5 m depth strata within the northeast Tasmanian blocks 30 and 31.

6.3 Assessment of track spacing and interpolation

In order to examine the influence of track spacing and the interpolation technique in determining habitat pattern and distribution from single beam acoustics, two aerial photographs were selected and rectified, one representing patchy composition of rocky reef and sand (consistent with that in block 31) and the other an area of continuous reef with few sand breaks (consistent with that in block 13). Transect lines were overlaid onto the photographs at different intervals beginning with 200 m from the edge of the study area, followed by 100 m, 50 m, and 50 m combined with 100 m horizontal transects from the shoreline to the outer edge of the photograph (Fig. 25, 26). The transects lines were converted into individual points 2.7 m apart, representing the same distance between points as collected using single beam acoustics at 5 knots. The points were attributed based on the habitat that they overlay within the photograph using the biogeomorphic levels of rocky reef and unvegetated unconsolidated substrate.

Beginning with only the 200 m attributed transect points and the aerial photograph removed, the reef and sand habitats were interpolated into continuous surfaces. This was repeated as each additional transect line (100 m, 50 m) were added for 4 simulations (Fig. 25, 26). The surfaces generated from using the 50 m, 100 m, 200 m and horizontal transect were based on the difference in areas of reef and the size and pattern of the polygons generated. These results were compared to the reef areas that were digitised from the aerial photograph.

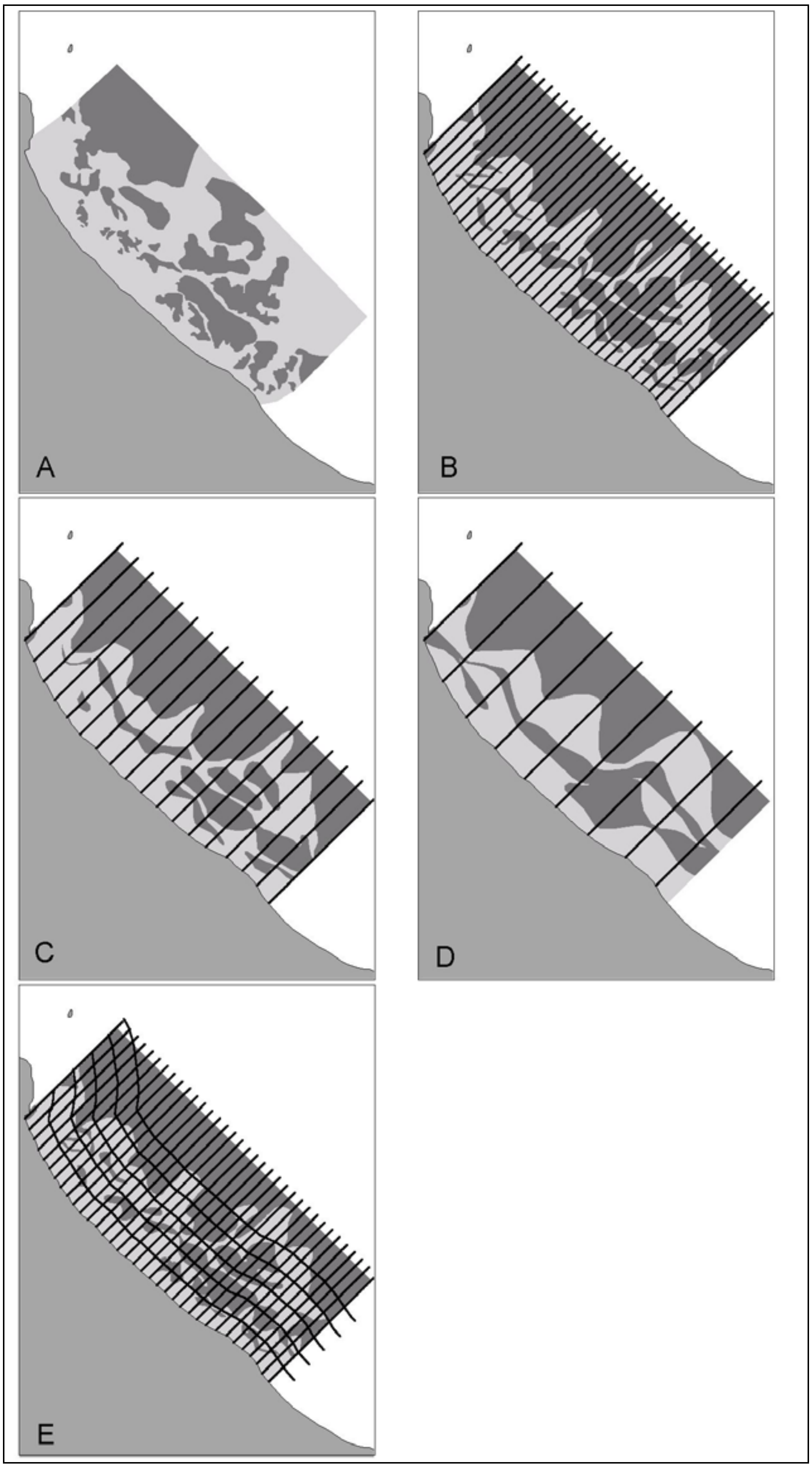

Fig. 25. (A) Aerial photography reef interpretation of patchy reef, (B) 50 m transect spacing reef interpolation, (C) 100 m transect spacing reef interpolation, (D) 200 m transect spacing reef interpolation, (E) 50 m perpendicular and 100 m horizontal transect spacing reef interpolation.

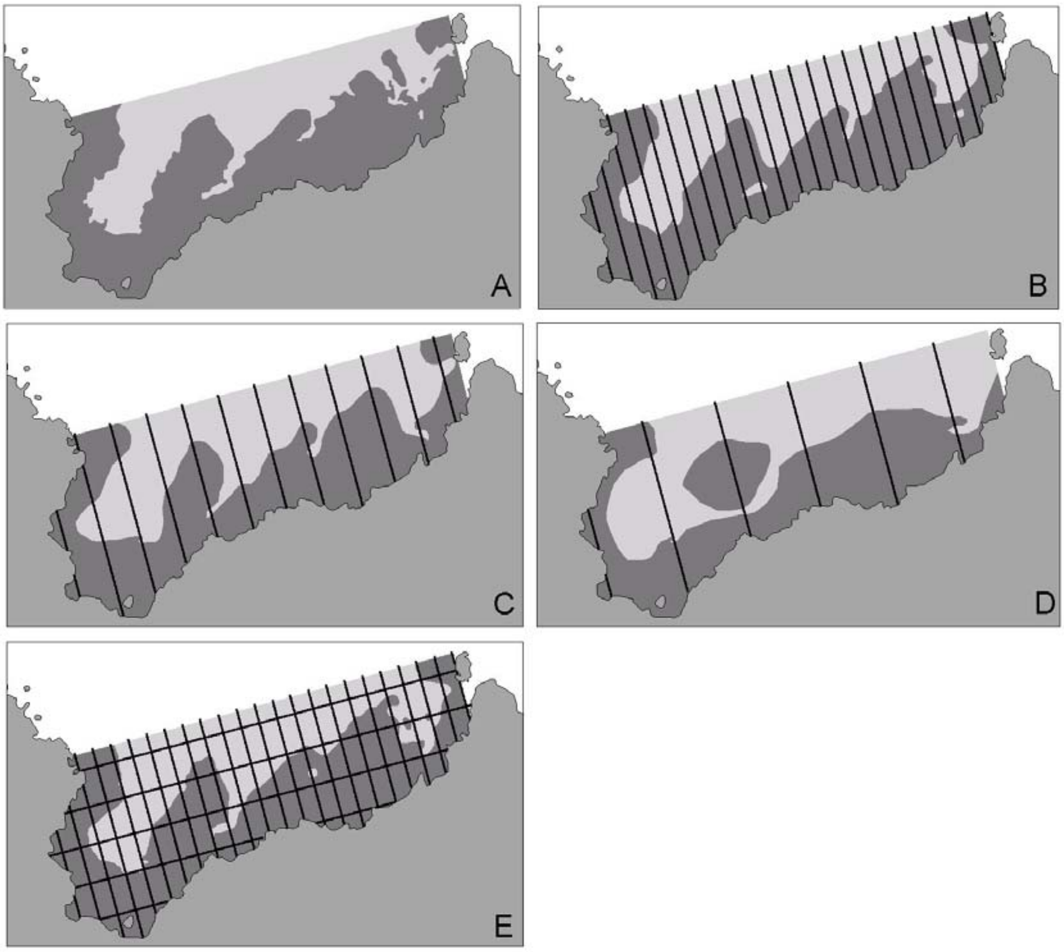

Fig. 26. (A) Aerial photography reef interpretation of continuous reef, (B) 50 m transect spacing reef interpolation, (C) 100 m transect spacing reef interpolation, (D) 200 m transect spacing reef interpolation, (E) 50 m perpendicular and 100m horizontal transect spacing reef interpolation.

The results indicate that the difference in reef area estimated between the various transect spacings on both types of reefs was minimal (Table 5). However, the representation of interpolated reef patterns were very different between the different transect spacings and this would be an important factor to consider if the reef distribution and pattern were important (Fig. 25, 26). If only the area of the reefs were required, the results indicate that broad transect spacings would offer the similar estimates as narrow transect spacing over both of these reef types.

Table 5. The differences in reef area (km^2) interpolated from (A) patchy reef and (B) continuous reef based on various transect spacings

A

Patchy reef	50m	100m	200m	50m with 100m horizontal
Study Area (km^2)	12045.4	12045.6	12045.5	12045.6
Area of reef digitised from photograph (km^2)	5169.2			
Number of habitat polygons	21	13	7	44
Average polygon area (m ^{2})	573.6	860.4	1505.7	273.7
Area of reef (km^2)	6919.0	7060.4	6888.6	6725.0
Area of sand (km^2)	5127.4	4985.2	5156.9	5285.6
Reef (% of total area)	57.4	58.6	57.20	55.8
Reef area compared to digitisation	1749.8	1891.2	1719.4	1555.8

B

Continuous reef	50m	100m	200m	50m with 100m horizontal
Study Area (km^2)	4202.9	4202.9	4202.9	4202.9
Area of reef digitised from photograph (km^2)	2566.3			
Number of habitat polygons	8	4	5	9
Average polygon area (m ^{2})	525.3	105.07	840.8	467.0
Area of reef (km^2)	2502.5	2397.3	2174.1	2499.6
Area of sand (km^2)	1700.4	1805.6	2028.8	1703.3
Reef (% of total area)	59.54	57.0	51.73	59.5
Reef area compared to digitisation	-63.8	-169.0	-392.2	-66.7

Foster-Smith (1999) found that a reduction in track spacing had a dramatic effect on the maps produced. It was found in this study that the data set with the most data point’s (50x100 m) did not produce the most accurate interpretation of reef habitats. The most accurate map was produced by the 50 m transect spacing followed by the 100 m, 200 m and 50x100 m, respectively. However, the results reveal that the areas were captured for these habitat types but the spatial pattern or position of the reefs were not captured accurately. This could affect survey design and planning because if only areal estimates of habitat the lower costs in both time and money to collect data from 200 m as opposed to 50 m transects would be considerable. Many biological studies require estimates of spatial structuring, minimum reef size and proximity to other types of habitat. However, for baseline assessment of habitat area, the results from this study indicate that 200 m spacing is sufficient.

7. General discussion

7.1. Comparison of reef extent, distribution and structure in relation to abalone landings

Mapping of the extent and distribution of rocky reefs in the north-east and south-east Tasmanian fishing blocks revealed considerable differences in the estimated area of habitat available for abalone. As the extent of offshore reef in depths >20 m in the north-east blocks were not fully mapped due to the size of the area, estimates are only presented out to 20 m. Because most abalone fishing occurs in depths <20 m, we considered that this effectively represents the reefs available to the fishery. Overall, the largest reef areas were identified in sub-blocks 31A, 13D and 13E, with 30A and 30B having the smallest areas (Fig. 26). These differences reflect a number of factors, primarily the length of coastline defined within the sub-block, local bathymetry, presence of offshore islands and large-scale geomorphology. While the length of coastline in the abalone fishing sub-blocks of 13C-E in south-east Tasmania is small, they contain a large area of continuous reef habitat that extends from intertidal waters to depths of over 50 m, including the dolerite offshore islands and reefs around the Acteaon and Sterile Islands. This reef system is an unusual subtidal feature of south-eastern and eastern Tasmania as much of the inshore reef in this region is limited to a narrow coastal fringe (Barrett *et al.*, 2001). However, much of the reef in these sub-blocks (particularly 13D, E) is in depths >20 m and therefore much of the abalone fishing occurs within a much smaller area than that presented.

The north-east blocks are characterised by extensive areas of rocky reef habitat, particularly in sub-blocks 30C, 31A and 31B, although the overall the extent of reefs indicates up to four times the area of reef in the 0-10 m depth range in block 31 compared to those in block 30 (Fig. 26). This pattern is not consistent in the 10-20 m depth range with sub-blocks 30C and 31A having up to five times the reef area than that estimated in sub-blocks 30A, 30B and 31B. In comparison, the area estimate for the 0-10 m depth indicates around twice the area in that depth range in block 31 than that present in the south-east sub-blocks of 13C-E.

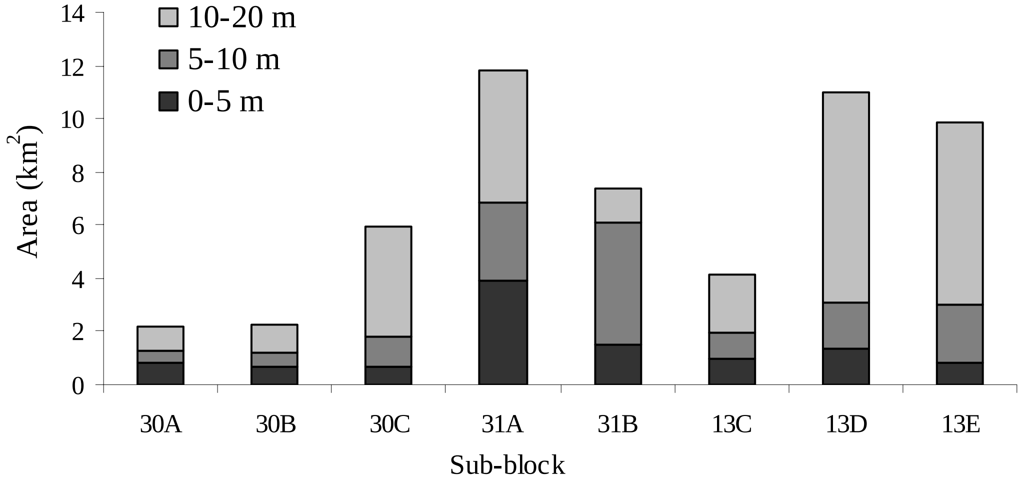

Fig. 26. Estimated area (km^2) of rocky reef habitat by selected depth strata in south-east (sub-blocks 13C-E) and north-east Tasmania (sub-blocks 30A-C and 31A, B).

A comparison between reef area and historical abalone catches at the fishing block scale indicates that there is no simple relationship between catch and available abalone habitat, and factors such as spatial structuring of reef, algal productivity and local hydrography are likely to be just as important. Firstly, annual commercial landings in block 13 averaged around 260 tonnes p.a. between 1975 and 1990, declined during the early 1990's to around 150 tonnes p.a., and have increased to average around 380 tonnes between 1993 and 2003 (Fig. 27). Within this region there is no direct relationship between sub-block catch (which have been available since 2000) and reef area, with 13E consistently producing considerably higher landings than 13D (Fig. 28), despite containing less reef habitat. Also, in 2002 and 2003 higher catches were taken in 13C than 13D despite the larger reef area <20 m deep in 13D. Some of these trends may be influenced by depth distribution of fishing effort, which if targeted at depths <10 m have similar amount of reef available in both 13C and 13D (Fig. 26). It may also be influenced by fine-scale reef structure as there was a much higher proportion of medium profile reef in 13C resulting in a more complex habitat.

The north-east blocks of 30 and 31 have shown a different historical trend in landings with an average blacklip abalone catch of around 160 tonnes p.a. per block in the mid 1980's (with a peak of 300 tonnes in block 30 in 1983 and 225 tonnes in block 31 in 1985). Landings decreased substantially to around 50 tonnes during the late 1980's and <30 tonnes in the 1990's. While effort also decreased at a similar rate during this period the evidence indicates that this resulted from a combination of high levels of fishing pressure and poor recruitment. Landings in recent years have remained at very low levels in block 30 (4 tonnes in 2003), but remained slightly higher in the adjacent block 31 (34 tonnes in 2003). So despite the presence of substantial reef habitat in the region, particularly in block 31, there is evidence that high fishing effort in the 1980s resulted in localised recruitment failure. The potential for further recruitment failure due to the shift in effort to block 31 has been highlighted by Tarbath *et al*. (2001, 2002). In this region there are many reefs that have in recent years become 'unproductive', with little evidence of abalone recruitment to these reefs (Tarbath *et al*. 2002).

There is no doubt that the high catches historically taken from all of these fishing blocks is due in large part to the extensive area of shallow reef habitat. In contrast to these two blocks, reef habitat along the southern east coast (e.g. blocks 20-23) consists of a narrow coastal fringe where the 20 m depth contour is often only 200 m from shore (Barrett *et al*. 2001). This is reflected in the long-term average landings of around 50 tonnes from these blocks. However, a comparison based solely on the area of shallow reef at the sub-block level to recent sub-block landings (Fig. 28) does not explain the differences in catch trends, with the decrease in landings in the late 1980's in blocks 30 and 31 indicating that these reefs have become considerably less 'productive' in terms of abalone that block 13, which has maintained high catches for a period of at least 30 years. Over recent years there is evidence of stock decline in sub-blocks 13C-E, but this has only affected the fishable biomass and recruitment appears to be unaffected (Tarbath *et al*., 2003).

It is likely that one of the key factors influencing abalone productivity between the two regions is the extent and large scale spatial structuring of the reefs and the influence this has on such things as recruitment, algal productivity and maintenance of egg production through protection of large individuals on deeper but continuous reefs. While there are a number of physical, biological and fishery related reasons for the differences in the sustainability of the catch levels between the two regions, the mapping has revealed considerable differences in the structuring of the reefs at a number of spatial scales between the north-east and south-east that may account for some of the trends.

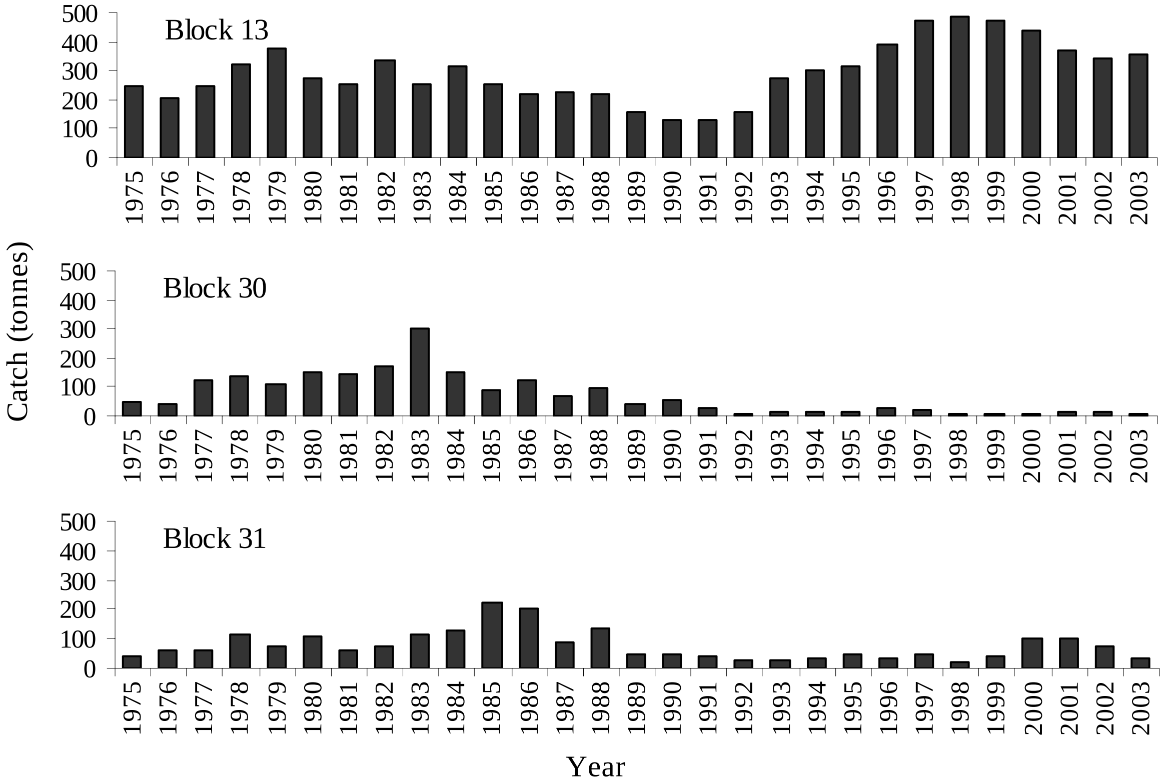

Fig. 27. Catch (tonnes) of blacklip abalone between 1975 and 2003 from blocks 13, 30 and 31.

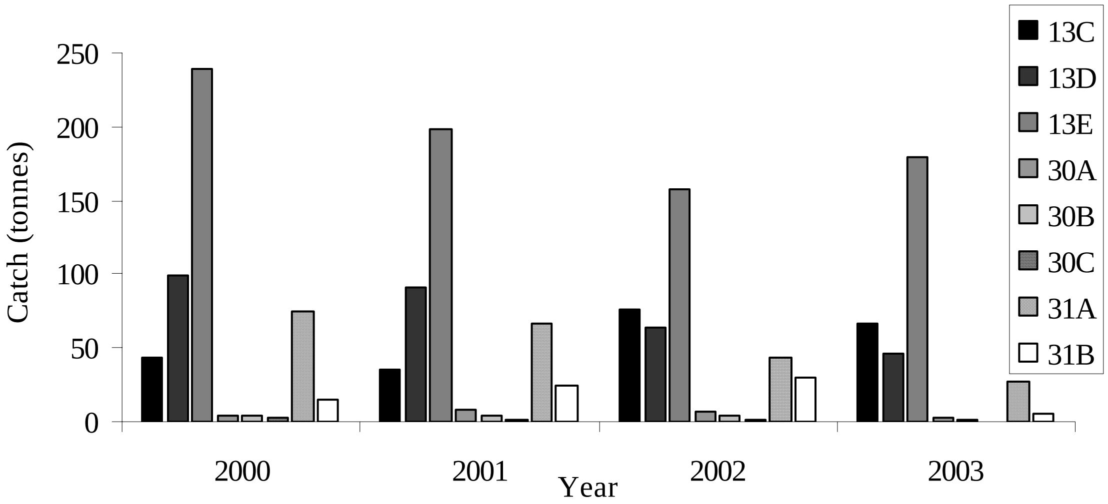

Fig. 28. Catch (tonnes) of blacklip abalone between 2000 and 2003 from sub-blocks 13C-E, 30A-C and 31A, B.

Firstly, the reefs within sub-blocks 13D, E are part of a section of dolerite that runs seaward from Eliza Point resulting in a large area of continuous reef that extends up to 8 km offshore in places. While this means that there is a large area of reef within the depths targeted by the fishery (mostly <20 m), there is also a considerable portion between 20 m and the edge of the reef in ~50 m. While not extending a significant distance offshore, sub-block 13C also has a considerable proportion of its overall reef area below 20 m deep. This results in a large area of continuous abalone habitat below the depths that the majority of the fishery operates resulting in the potential for significant protection for this component of the population. Such protection of abalone populations in deep water off the Californian coast has resulted in continued high yields in the fishery in adjacent shallow water by apparently protecting sufficient adults from harvest during protracted periods of low recruitment (Karpov *et al*., 1998).

The large extent of continuous reef habitat, combined with the potential for enhanced recruitment due to larvae being retained within an area of suitable settlement habitat, means there is likely to be a greater potential for consistent recruitment. This may also be influenced by the local hydrography, which due to the predominant northward flowing current encountering a large offshore shallow area of reef and islands is likely to produce eddies on the northern side of the system resulting in increased retention of larvae and consistent recruitment. There is evidence that such eddies have can influence the dispersal of abalone larve resulting in increased recruitment to parent reefs (McShane *et al*., 1988). While there is evidence in sub-block 13E of a decline in size composition of the fished abalone populations in recent years, much of the catch consists of new recruits. It is also possible that the large areas of more sheltered habitat, such as on the western side of reefs in sub-block 13D, results in reefs with the potential for higher recruitment, consistent with the findings of (McShane *et al*. 1988) in Victorian waters. The large area of continuous reef also results in a greater production of macroalgae that may be retained within the reef system, particularly red algae that becomes drift and may concentrate in certain areas due to local currents. Such drift algae have been shown to be a major component of the diet of abalone in southern Australia (Shepherd, 1973).

Given the large amount of available reef habitat within the north-east blocks of 30 and 31, the difference in historical tends in abalone landings compared to 13C-E may largely relate to differences in the habitat structure and its influence of the factors discussed above. At a fine-scale (~2-5 m) the reefs were found to often consist of a high proportion of reef-sand complex, which is more dominant in block 31 resulting in a large number of sand gutters. However, while sand patches at a large scale reduces available abalone habitat, this fine-scale structure may not have a large influence on population size as reef edge and sand gutters have been found to influence the post settlement and distribution of abalone and they often have a preference to aggregate in crevices or depressions at the base of reefs (Shepherd, 1973). Therefore, complex reef heavily dissected with gutters and crevices may contain more abalone than less complex continuous reef of the same total area, and may create hydrodynamic conditions at the local scale that enhance larval retention and settlement (McShane *et al*. 1988).

At a large geographic scale the reefs in the north-east consist of a granite substrate that forms a complex mosaic of reef habitat that is interspersed with large areas of sand, which is often not continuous to shore. This patchiness is particularly obvious in the shallow habitats defined from the aerial photographs due to the lack of need for interpolation, which in the single beam acoustics resulted in patchiness being underrepresented. It is likely that this large-scale patchiness has a strong influence on the long-term sustainability of catches as each ‘patch’ of reef contains an isolated abalone population that relies on recruitment to maintain population numbers, and high catch rates could be maintained at the block scale for several years through a process of serial depletion. It is also expected that the patchiness can reduce the likelihood of consistent recruitment as there is evidence to suggest that abalone recruit only over relatively small distances (possibly 100’s m) (Prince *et al*., 1987), and therefore many reefs are isolated and rely on localised recruitment. While modelling of abalone transport has also indicated potential dispersal over distance of km’s (McShane *et al*. 1988), this reduces the probability of larvae encountering suitable substrate on which to settle, particularly in patchy reef area such as in the north-east blocks. Once the spawning biomass has been substantially reduced, which is what occurred in the 1980’s in blocks 30 and 31, the subsequent long-term decline in productivity reflects that reduced capacity for stock rebuilding through recruitment. The lack of data on local hydrography in this region precludes any detailed assessment of how this relates to recruitment processes in this region, although further work on larval duration, behaviour and settlement preference is also needed.

Recent developments in multibeam echo-sounders have allowed the collection of bathymetric and backscatter soundings across a wide swath of seabed using a number of acoustic beams resulting in increased spatial resolution and coverage. These systems have resulted in the capability to map reef structure at the centimetre scale (depending on the acoustic configuration), and will allow considerably improved estimates of reef patchiness, rugosity and complexity. The detailed bathymetric data will also assist with the development of hydrodynamic models, which can be used to examine the connectivity of larval supply between reef habitats.

The significance of the likely expansion in urchin barrens in the north-east blocks on abalone productivity since the 1980’s is difficult to assess due to the absence of long-term data on barrens distribution. The long-spined urchin, *Centrostephanus rodgersii* was first recorded on the north-east coast of Tasmania in 1978 (Edgar, 1997), although it is unlikely that the densities were at a level to form substantial barrens. While little is known about the transition from macroalgal dominated reef to barrens habitat, there is evidence of a threshold density needed to initiate total removal of macroalgae by grazing (which is much higher than natural densities), and this is higher than the density required to maintain barrens (Hill *et al*. 2003). It is also unlikely that their formation was rapid enough to result in the substantial decrease in landings in the late 1980’s, particularly as similar trends occurred in block 31 where there was little evidence of urchin barrens. In addition, there was little evidence of barrens in depths <10 m and therefore little direct loss of abalone habitat in the depths targeted by much of the fishery. The less direct effect of a large loss of algal production on adjacent deeper reefs on the productivity of shallow reefs may be important, but would require considerable experimental work to determine.

While catch data indicates other sections of the mid and lower east coast have seen declines in abalone catches, and anectodal evidence indicates that there are areas of reef that have become ‘unproductive’ in terms of abalone, the north-east blocks have seen the largest decline and the longest period of reduced catches. While there has been some recovery in catches in block 31 in recent years, with much of that driven by landings from sub-block 31A, it is possible that this has resulted from divers finding isolated patches of recently unexploited reef which yield large but short-term catches. This results in a problem in relying on trends over several years in catch data and catch-rates and catches to examine stock status. Overall, it is clear that catch-rates alone fail to indicate abundance decline due loss of productive reef.

7.2 Attribution uncertainty

Some of the major uncertainties in seabed habitat mapping relates to the ability of optical and vessel-based remote sensing techniques to identify and classify habitats, particularly at the eco-unit level. Single-beam sounders have been commonly used to obtain information on the acoustic reflectance of the seabed where a single acoustic pulse is used to esonify an area of the seabed directly under the vessel. The various AGDS (i.e. RoxAnn, EchoPlus and QTC View) use parameters of the echo return to classify seabed substrates. In the case of RoxAnn and EchoPlus processing, the strength and intensity of the first echo, and the whole second echo are taken to be measures of roughness and hardness, respectively. The QTC View system uses a large number of parameters of the tail of the first echo to categorise habitats based on supervised (i.e. ground-truthed) or unsupervised classifications.

These methods have been well documented in the literature and many factors have been identified that influence attribution accuracy. These can be categorized as sounder configuration (e.g. beam width, frequency, ping rate, power output), survey design (depths, vessel speed, sea state, transect spacing) and analysis techniques (components of echo return, supervised and unsupervised classification, clustering techniques; interpolation procedures) (Magorrian *et al*. 1995; Greenstreet *et al*. 1997; Collins and McConnaughey, 1998; Pinn *et al.* 1998; Hamilton *et al*. 1999; Kloser *et al*. 2001; Foster-Smith and Sotheran, 2003; Wilding *et al*. 2003). All of these factors can introduce a component of uncertainty in habitat attribution, which to a large extent is determined by the level of habitat heterogeneity and similarity in acoustic properties between habitats.

Confusion in attribution due to acoustic similarity can occur when habitats are present over distances smaller than the area integrated from multiple echo returns, which varies according to depth. Also, uncertainties arise due to the often gradual change in unconsolidated habitats (e.g. sand to silty-sand) that results in fuzzy boundaries, and the fact that some physical factors cause acoustic uncertainties in substrates with similar particle size (e.g. ripples, sandwaves, holes and bioturbation). There are considerably less acoustic uncertainties between rocky reef and unconsolidated substrates and the boundaries are generally distinct, apart from when the habitat size is smaller than the integrated acoustic area. It is important that a clear linkage exists between the habitat categories and the acoustic technique and therefore not every category identified from video data can be mapped using acoustics. Overall, as the number of habitat categories increases and biological attributes become more important, usually at lower levels in the classification hierarchy, the ability to accurately discriminate between classes acoustically decreases. Therefore, it is essential that ground-truth data be incorporated into the analysis and production of habitat maps, particularly in the delineation of boundaries. The ground truth data can also be used to obtain further information on eco-unit modifiers (e.g. macroalgal species composition) and at this level much of the uncertainty is due to taxonomic resolution.

Uncertainty in habitat attribution in this project was minimised by combining real time boundary attribution in shallow areas (generally <10 m deep) with boundary position defined from aerial photographs and post-processed echogram analysis from deeper areas where the ES60 echograms are examined to remove any poor data due to signal attenuation. In shallow depths further discrimination of habitat type at the eco-unit level (e.g. *Zostera*, *Durvillea potatorum*) was possible through visual observation over the side of the vessel or using an underwater glass viewer. In addition to ground-truthing sites, a spatially referenced video camera was deployed during a subsequent field survey at further sites to verify echosounder classifications when confusion existed, confirm habitat boundaries, and obtain more detailed information on dominant macroalgal assemblages.

Links between acoustic data and habitat type are rarely sharply defined and existing AGDS apply a number of analysis methods to allocate acoustic data to discrete habitats. In principle, the acoustic data are linked to the habitat attributes by a set of conditions based on the clustering of components of the echo return supported by video and/or grabs taken on representative habitat types. The algorithms used in AGDS to attribute a habitat must contain the least amount of variation as possible so that the attributions are replicable, and considerable development in analysis procedures has occurred to minimize attribution error (Foster-Smith *et al*., 1999). Such attribution uncertainties are most common between unconsolidated habitats due to similarities in acoustic properties and it is these types of habitats that have been the focus of much of the application of AGDS (e.g. Morrison *et al*. 1995; Wilding *et al*. 2003; Forster-Smith *et al*. 2004). In contrast, the seabed mapping in this project has focused on defining the spatial extent and distribution of rocky reef habitats reflecting the fact that the majority of fisheries target species are reef associated (e.g. abalone, rock lobster, banded morwong). Given the considerable difference in roughness and hardness between consolidated and unconsolidated substrates there is minimal attribution error at this hierarchical level. As attribution of unconsolidated habitats with echogram visualisation at the substratum and eco-unit levels can have higher uncertainties these are often represented at the bio-geomorphic level, mostly in areas of high spatial heterogeneity.

Overall, uncertainty in acoustic attribution is minimised by maintaining standard sounder configuration and vessel speed; restricting acoustic surveys to minimal wind and swell conditions; removing poor echogram data due to signal attenuation; minimising the number of habitat categories defined acoustically; complementing acoustics with aerial photography and real-time boundary attribution in shallow water; and using clearly defined contextual decision rules for habitat classification.

8. Benefits and adoption

Both the abalone industry and researchers will benefit from the findings of this study by having an improved knowledge of the spatial extent and distribution of rocky reef habitats in several key abalone fishing grounds. Overall, such information provides a better understanding of the fact that the structure and distribution of rocky reef habitat varies considerably between fishing blocks within Tasmania and that this strongly influences the productivity and long-term sustainability of abalone fishing. The historical trends in abalone landings between the north-east and south-east blocks indicates a substantially higher risk of stock collapse associated with high levels of fishing pressure within fishing blocks where reef is patchy at a range of spatial scales. Such patchiness is likely to strongly influence factors such as recruitment and detection of stock decline due to serial depletion of isolated reefs. Such information should be incorporated into a more formal risk assessment conducted as part of the ongoing fishery assessment process and any future reviews of management arrangements.

The spatial data will also provide an important benefit to abalone abundance survey design at several spatial scales relevant to abalone assessments, including the sub-block and site scale. Firstly, within sub-blocks the identification of isolated patch reefs in the north-east will be useful when planning manipulative experimental work in the region. Secondly, maps of high resolution available at a large-scale will assist the identification of abalone habitats where appropriate relative indexes of abundance could be established. The maps presented here will allow a more representative range of sites to be selected.

An important aspect of the maps for establishing survey sites is the bathymetry, which is now available in many areas in much greater detail than what is available with existing bathymetric charts. Information on relief and macroalgal community structure will also provide an additional insight into the factors influencing abalone abundance on reefs. The classification of reef profile and proportion of sand habitat within the reefs at the 1-10 m scale would be of secondary importance as these are not clear indicators of abalone presence or absence, but may of some use in conjunction with other knowledge (e.g. the level of exposure, dominant algal species etc) which can often be obtained from the maps and spatially referenced video clips.

One of the limitations for the maps is in identifying broad scale extent of fine-scale (10 cm – 1 m) habitat complexity (abalone cryptic habitat), which are really just cracks and crevices where abalone (juveniles and adults) are often found. As the amount of 'cryptic habitat' is often seen as a good indicator of abalone abundance there is a need to identify this spatially, but it is only information that can be obtained from video transects over limited geographic extent. This information is, however, provided on the accompanying CD-ROM that provides considerable additional information on specific habitat attributes such as reef structure (i.e. profile and patchiness), macroalgal assemblages and spatially referenced video footage. This CD will be of considerable benefit to industry and researchers in obtaining detailed fine-scale information on rocky reef habitats within the relevant fishing blocks.

The habitat maps will also provide significant benefit to the detailed assessment of spatial patterns of fishing effort through the use of GPS data loggers on commercial vessels. The use of the maps in conjunction with positional data of fishing catch and effort (from fishers collecting GPS data) will be very useful for examining those physical characteristics that make some abalone habitat more productive than another, such as local hydrodynamics, algal production and fine-scale reef structure. This information can be examined at a spatial scale that has never before been available and will provide considerable benefits to the understanding of fleet dynamics, spatial patterns of abalone distribution and catch/effort data.

As well as being available on CD-ROM, the habitat and bathymetric maps generated from this project are available on the Tasmanian node of the Australian Oil Spill Response Atlas and the SEAMAP Tasmania web site (www.utas.edu.au/tafi/seamap) therefore making the information available to a range of industry and government sectors and the wider community.

The component of the project to further develop cost-effective techniques for fine-scale habitat mapping and classification has provided considerable benefit to other research groups conducting seabed mapping. Firstly, developments in the processing of the sidescan sonar backscatter collected during this project will assist others conducting similar analysis, particularly those groups within the Coastal CRC. The further development of protocols for single-beam acoustic surveys will also benefit groups using similar techniques, and issues of minimising uncertainty in acoustic attribution is detailed in relation to sounder configuration and vessel speed, echogram analysis and real-time boundary attribution. Aspects of transect design were also examined which will benefit others research groups aiming to ensure such surveys are cost-effective in relation to the project objectives. Much of the acoustic techniques and habitat classifications have been standarised with research groups in Victoria conducting similar rocky reef surveys. While recognizing the use of various remote sensing platforms for seabed mapping throughout Australia, this project has provided an important contribution towards developing a framework for a national seabed habitat classification scheme and a national meeting was held in December 2004 to further progress this issue.

9. Further development

There are several key areas where steps can be taken to further utilise the results of this research to improve abalone assessments. Firstly, while detailed spatial information is now available on the spatial structuring of reef habitats in several fishing blocks there is clear need to further develop our understanding of how this influences factors such as recruitment and abundance of available drift algae through targeted studies on algal productivity, larval duration, behaviour and settlement preference. All of this should also be supported by further studies on hydrodynamics at a range of spatial scale in order to progress more quantitative modeling of such things as larval distribution.

There is also a need to further detail abalone fishing distribution at a fine-scale through the use of vessel based GPS monitoring systems that provide detailed spatial data on the distribution of fishing catch and effort. The increased number of vessels using this system would allow more spatial coverage around the state and more comprehensive data with individual fishing blocks and sub-blocks and result in the capacity to better quantify catch and effort at the scale of individual reefs.

The use of multibeam echo-sounders will allow the collection of high resolution bathymetric and backscatter data across a wide swath of seabed resulting in the capability to map reef structure at the metre scale (depending on the acoustic configuration).. Multibeam acoustic data was collected on shallow reefs on the east coast of Tasmania in March 2005, which will allow an assessment of this technology for improving estimates of reef patchiness, rugosity and complexity.

10. Planned outcomes

The planned outcomes of this project were successfully met, although much of the process of fishery independent abalone surveys, population parameter estimation and overall stock assessment is ongoing and will continue to rely on the outputs of this project for some time. The primary output of detailed maps of rocky reef habitat in key fishing blocks has provided researchers, industry and fisheries managers a much improved knowledge of the significant variation in the extent, distribution and structure of abalone habitat within Tasmania and the likely influence this has on stock productivity and long-term sustainability. It is now important to determine mechanisms for incorporating this information into a structured risk assessment process that recognises that sustainability is likely to differ considerably between fishing blocks and sub-blocks. The baseline information of the distribution of urchin barrens in the north-east abalone fishing blocks will also be an important component of this process as considerable components of reef have become barren in particular sub-blocks therefore reducing the available productive abalone habitat. The extent of barrens determined during this study will also provide an important reference point in which to monitor future patterns of distribution in north-east Tasmania.

Continued implementation of fishery independent abundance surveys and examination of spatial variations in population parameters is a key component of the stock assessment process and the outputs of this study will provide important data for improved criteria on which to select representative survey sites. The information on spatial variations of macroalgal assemblages will also provide an improved capacity to examine the relationship between algal structure and abundance and abalone abundance, growth, size-at-maturity etc.

The planned outcome to further develop cost-effective techniques for fine-scale habitat mapping and classification has been achieved. The single-beam acoustic methodology has been further developed in terms of field surveys design and data post-processing and procedures for spatial interpolation from acoustic transects. The detailing of acoustic decision rules used for defining seabed habitats and contextual decision rules for final attribution and cartography as well as the framework for a seabed habitat classification scheme will contribute to further standardisation between research groups conducting seabed habitat mapping throughout Australia.

11. Conclusion

The combined use of existing aerial photography and structured single-beam and sidescan sonar surveys resulted in the detailed mapping of seabed habitats at a number of scales in order to determine the overall amount of reef, spatial patterns of reef systems, fine-scale (~1-10 m) structuring (i.e. profile, proportion of sand), patterns of macroalgal assemblages and extent of urchin barrens. Overall, approximately 344 km^2 of seabed was mapped during the project, with video surveys covering a total of around 50.6 km of reef habitat in the south-east and 20.9 km of reef in the north-east. Mapping revealed considerable differences in the estimated area of rocky reef habitat between the various abalone blocks reflecting a number of factors; primarily the length of coastline within the sub-block, local bathymetry, presence of offshore islands and large-scale geomorphology. The largest reef areas were identified in sub-blocks 31A, 13D and 13E, with 30A and 30B having the smallest areas. Sub-blocks 13C-E contain a large area of continuous dolerite reef habitat that extends from intertidal waters to depths of over 50 m, including the offshore islands and reefs around the Acteaon and Sterile Islands.

The north-east blocks contain extensive areas of granite dominated rocky reef habitat, particularly in sub-blocks 30C, 31A and 31B that are characterised by a highly patchy structure often containing a broad area of sand between the intertidal zone and the inner edge of the reef. The overall the extent of reefs indicates up to four times the area of reef in the 0-10 m depth range in block 31 compared to those in block 30, although this pattern is not consistent in the 10-20 m depth range. In comparison, the area estimate for the 0-10 m depth indicates around twice the area in that depth range in block 31 than that present in the south-east sub-blocks of 13C-E.

A comparison between reef area and historical abalone catches at the fishing block scale indicates that while it is clear that the high catches historically taken from all of these blocks is due in large part to the extensive area of shallow reef habitat, there is no simple relationship between abalone abundance (reflected as catch) and available abalone habitat. It is likely that factors such as spatial structuring of reef, algal productivity and local hydrography are likely to be just as important in determining abalone productivity and the influence these have on such things as recruitment and maintenance of egg production through protection of large individuals on deeper but continuous reefs. The mapping has revealed considerable differences in the structuring of the reefs at a number of spatial scales between the north-east and south-east that may account for some of the historical catch trends. Even over recent years there is evidence of stock decline in sub-blocks 13C-E, but this has only affected the fishable biomass and recruitment appears to be unaffected.

In addition, urchin barrens were most extensive in sub-block 30A where maximum barrens coverage was around 55% in the 15-20 m depth strata and only slightly less in the 10-15 m and 20-25 m strata. As there was little evidence of barrens in depths <10 m there appears to be little overall loss of abalone habitat in the depths targeted by much of the fishery, although there may be a large loss of algal production on adjacent deeper reefs reducing the productivity of shallow reefs.

Overall, such information provides a better understanding that the structure and distribution of rocky reef habitat varies considerably between fishing blocks within Tasmania and that this strongly influences the productivity and long-term sustainability of abalone fishing at this geographic scale. The historical trends in abalone landings between the north-east and south-east blocks indicates a substantially higher risk of stock collapse associated with high levels of fishing pressure within blocks where reef is patchy at a range of spatial scales. Such patchiness is likely to strongly influence factors such as recruitment, abundance of available drift algae and detection of stock decline due to serial depletion of isolated reefs.

Such information should be incorporated into a more formal risk assessment conducted as part of the ongoing fishery assessment process and related management arrangements.

The spatial data will also provide an important benefit to abalone abundance survey design at several spatial scales relevant to abalone assessments, including the sub-block and site scale. Firstly, within sub-blocks the identification of isolated patch reefs in the north-east will be useful when planning manipulative experimental work in the region. Secondly, maps of high resolution available at a large-scale will assist the identification of abalone habitats where appropriate relative indexes of abundance could be established. The habitat maps will also provide significant benefit to the detailed assessment of spatial patterns of fishing effort through the use of GPS data loggers on commercial vessels. It has also provided an important reference point of the extent of urchin barrens in which to monitor future patterns of distribution in north-east Tasmania.

Developments in the processing of the sidescan sonar backscatter collected during this project and protocols for single-beam acoustic surveys will assist others conducting similar analysis. While recognizing the use of various remote sensing platforms for seabed mapping throughout Australia, this project has provided an important contribution towards developing a framework for a national seabed habitat classification scheme. The development of cost-effective methods to quantify the extent, distribution and structure of reef will provide scientists and fisheries managers with the tools to examine information on reef habitat structure that is an important component of the overall data needed to improve the research and management of abalone stocks. It is anticipaed that this will ultimately result in an assessment of risk associated with fishing abalone in blocks with very different habitat extent, structure and overall productivity.

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Appendix 1: Intellectual Property

There are no intellectual property issues relating to this project.

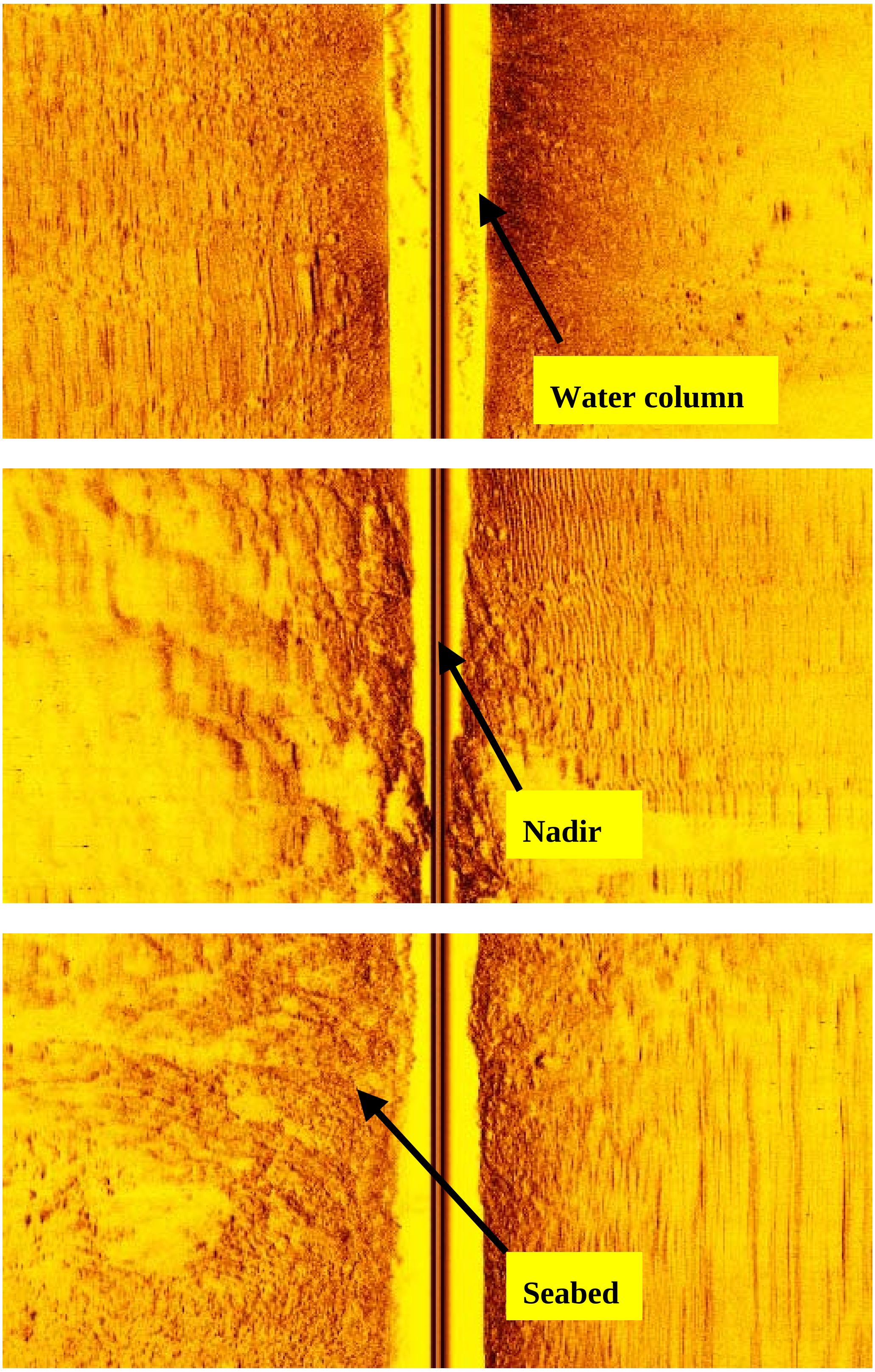
Appendix 2: Staff

All staff on this project were employed by the Tasmanian Aquaculture and Fisheries Institute, University of Tasmania. However, additional assistance was provided by Mr Andy Bickers of the University of Western Australia and Coastal CRC.

Dr Alan Jordan* – Principal Investigator
Ms Vanessa Lucieer – Research Assistant
Mr Miles Lawler – Research Assistant
Ms Taina Honkalehto – Casual Research Assistant

*Present address:
Senior Environmental Scientist (Marine Parks)
NSW Department of Environment and Conservation
c/o Port Stephens Fisheries Centre
Locked Bag 1, Nelson Bay, 2315, NSW

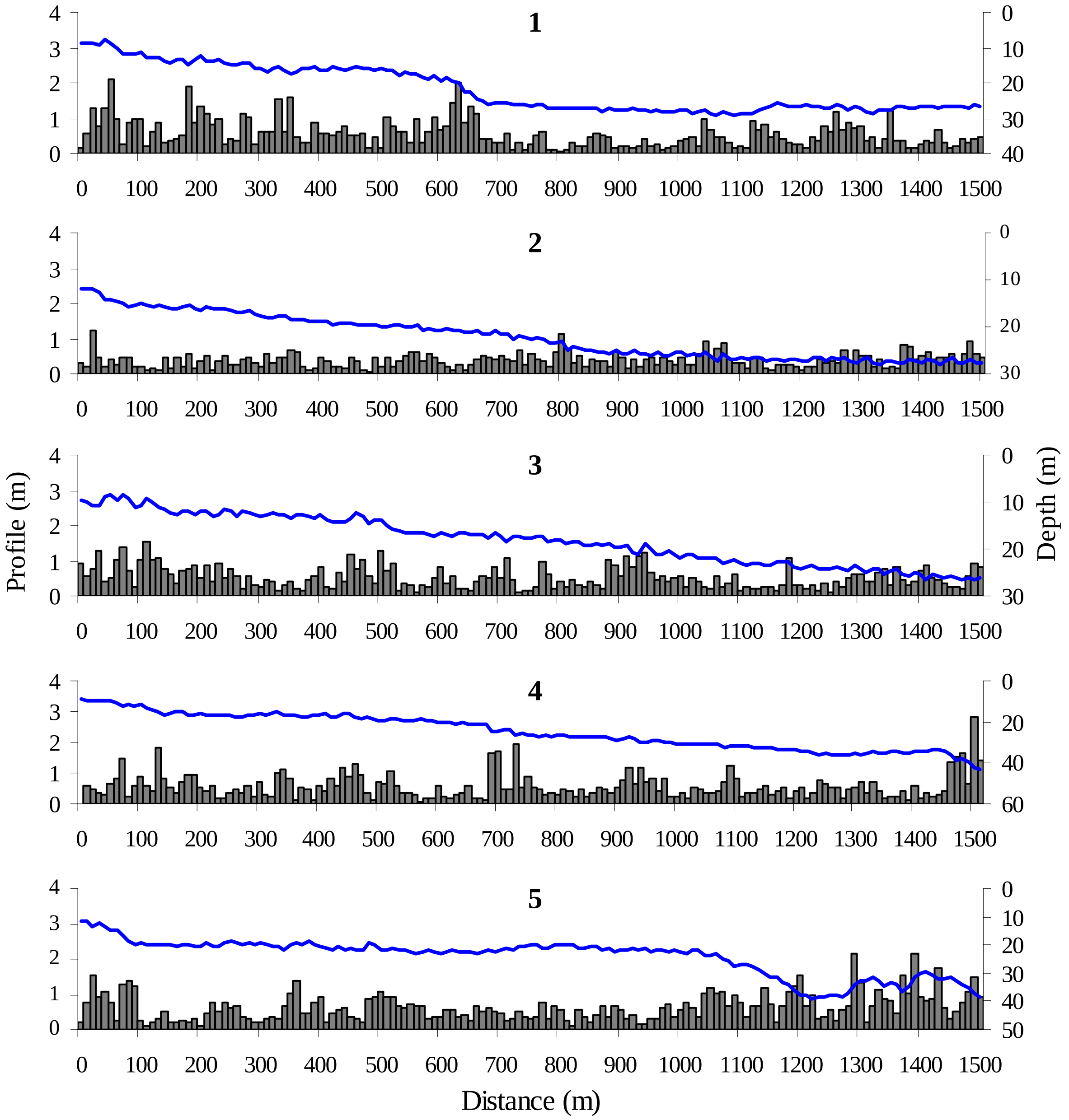
Appendix 3: Selected sidescan sonar images from north-east Tasmania



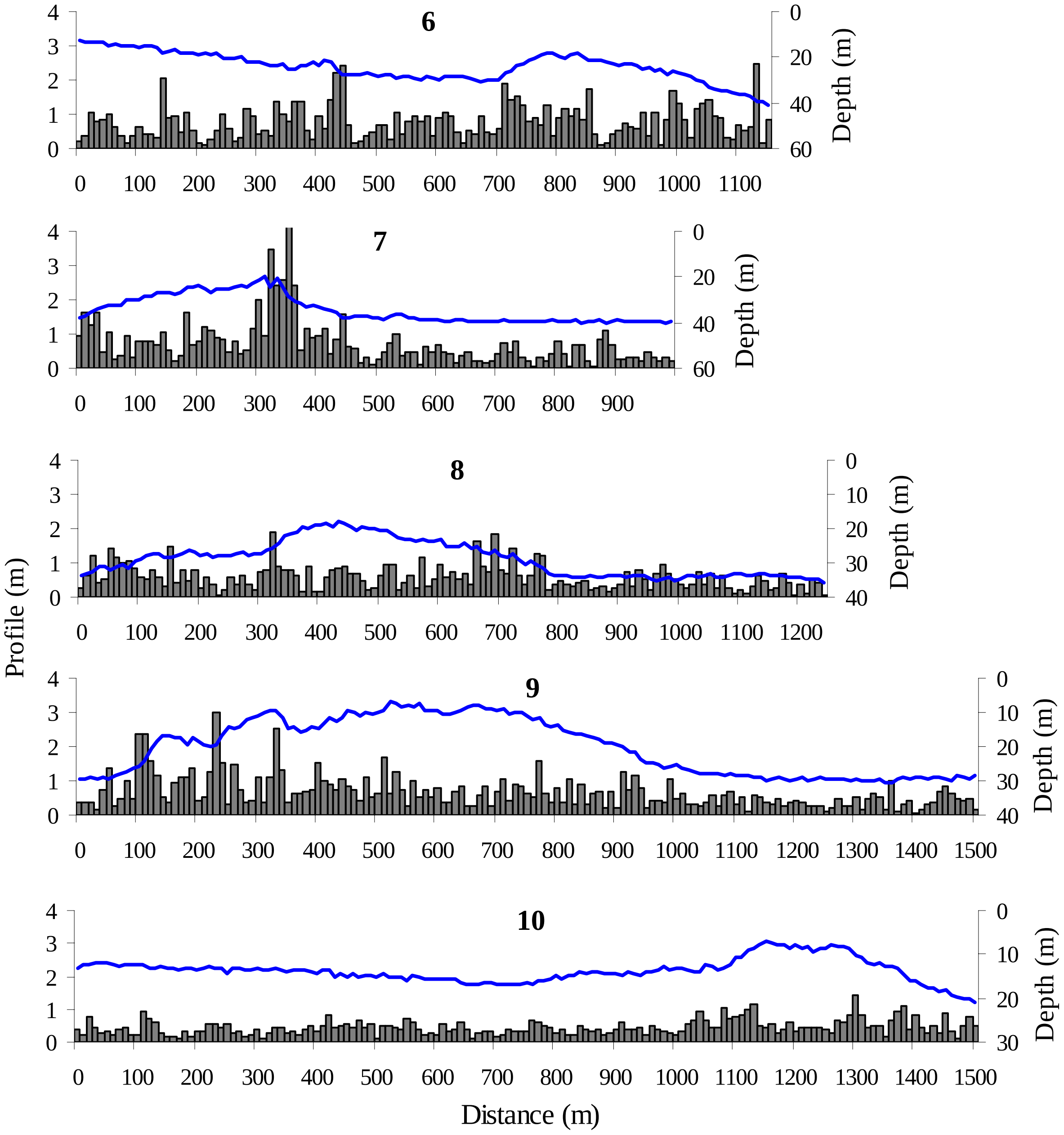
Appendix 3a. Example of raw sidescan sonar image of seabed in north-east Tasmania

Appendix 3b. Example of sidescan sonar mosaic of seabed in north-east Tasmania

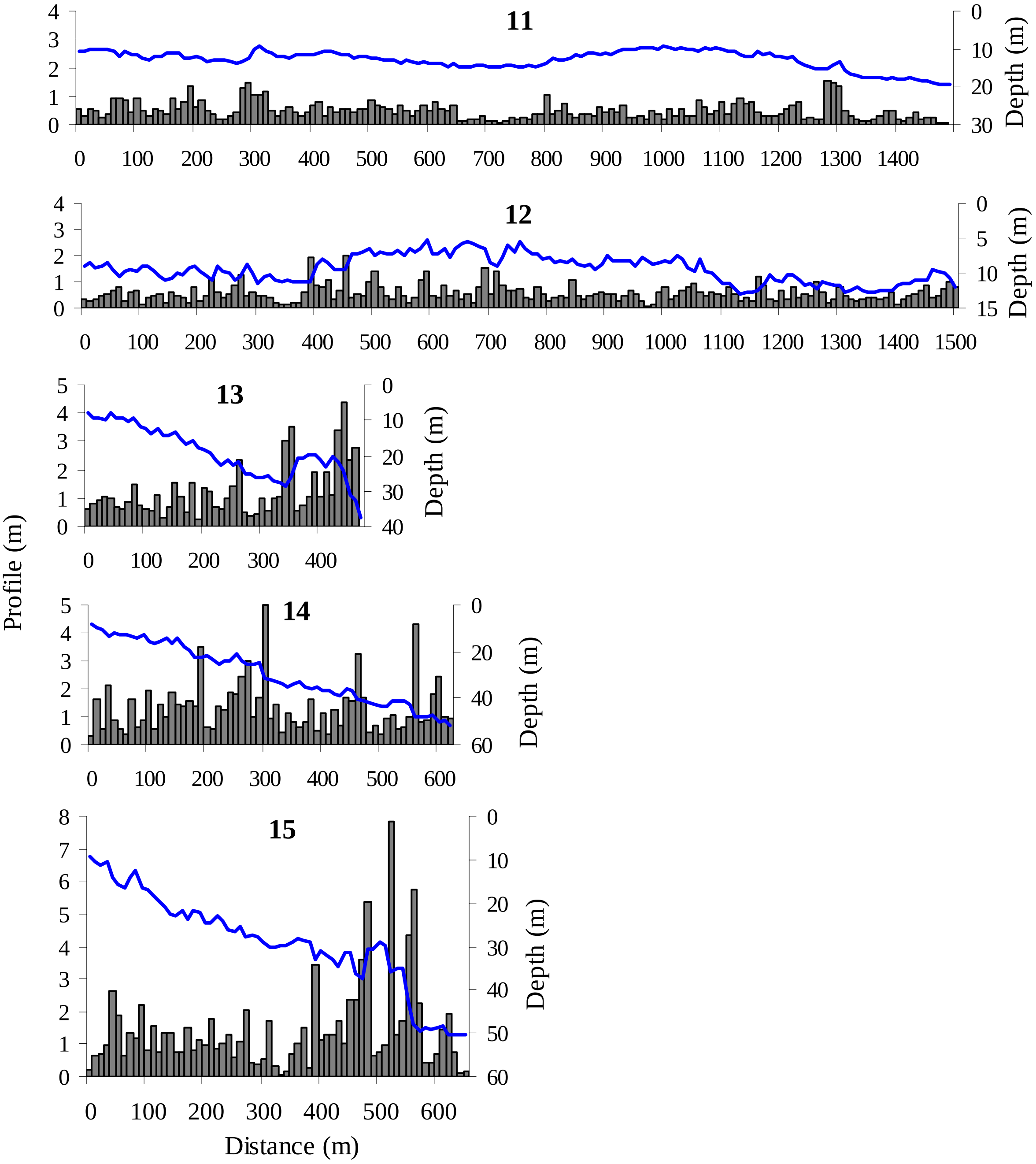
Appendix 4: Details of reef profile in sub-blocks 13C-E



Appendix 4a. Distribution of rocky reef profile (m) at 10 m intervals and depth (m) along acoustic transects 1-5 in sub-block 13E (see Fig. 10).

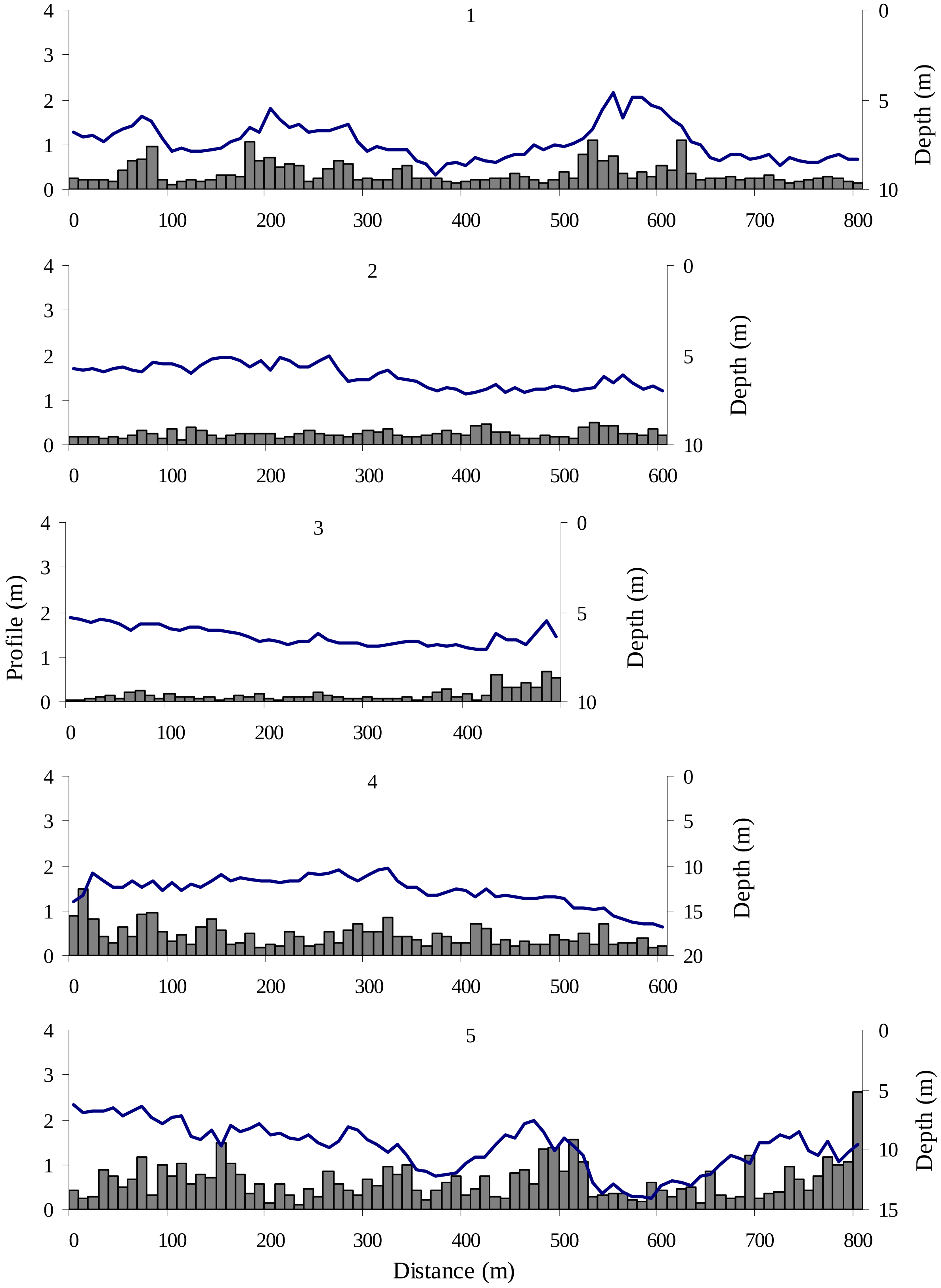


Appendix 4b. Distribution of rocky reef profile (m) at 10 m intervals and depth (m) along acoustic transects 6-10 in sub-blocks 13D and E (see Fig. 10).

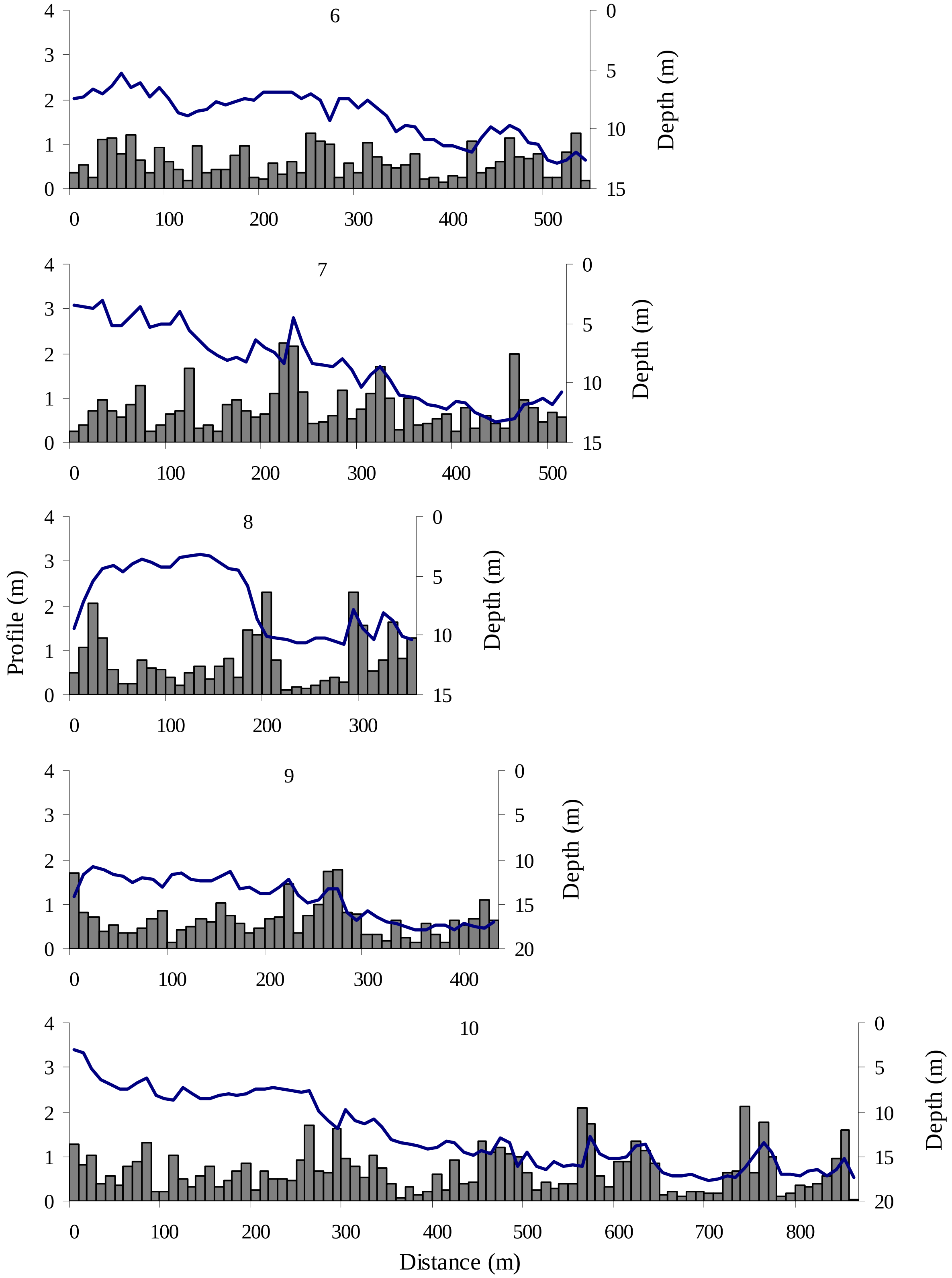


Appendix 4c. Distribution of rocky reef profile (m) at 10 m intervals and depth (m) along acoustic transects 11-15 in sub-blocks 13C and D (see Fig. 10).

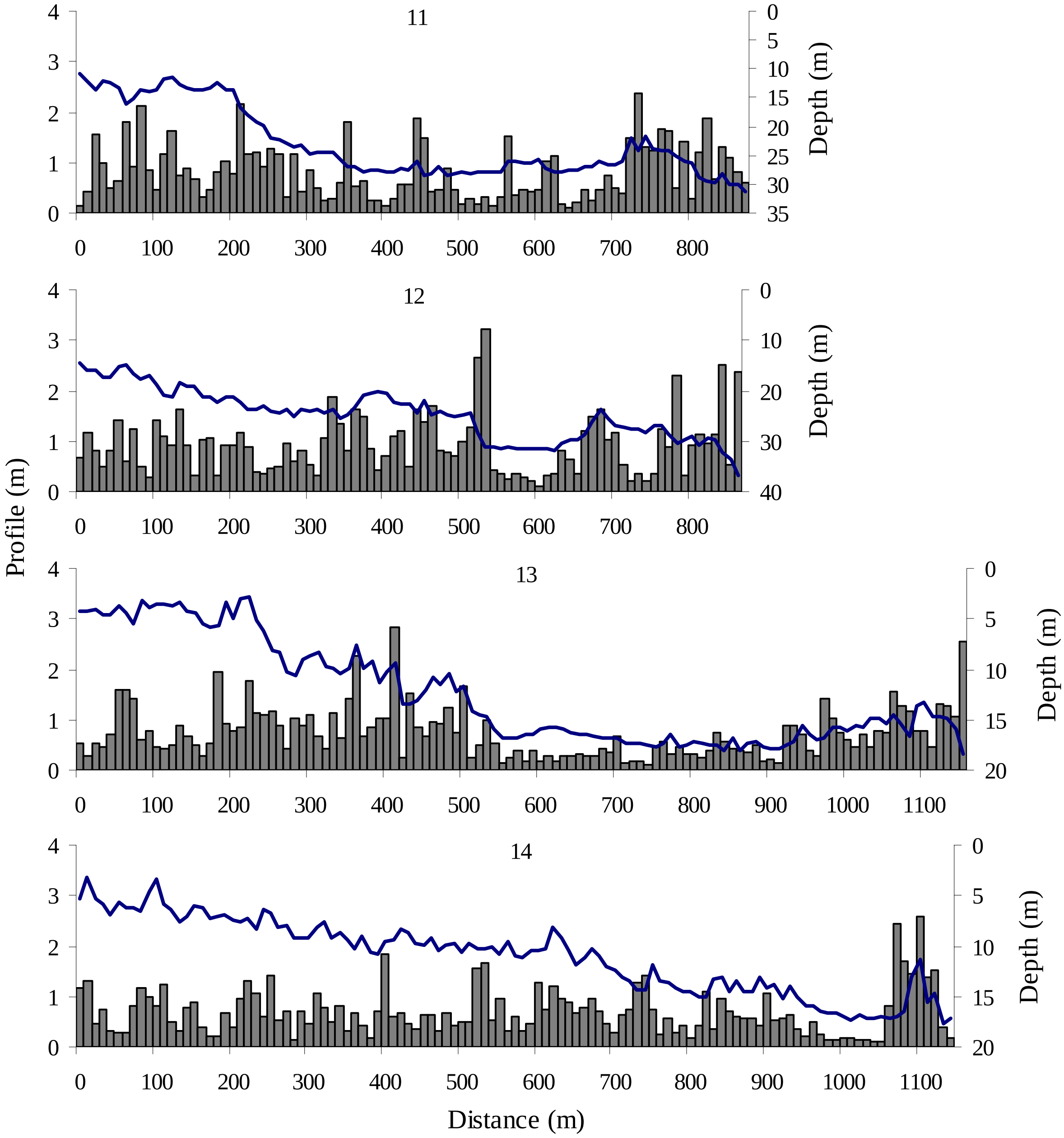
Appendix 5: Details of reef profile in blocks 30 and 31



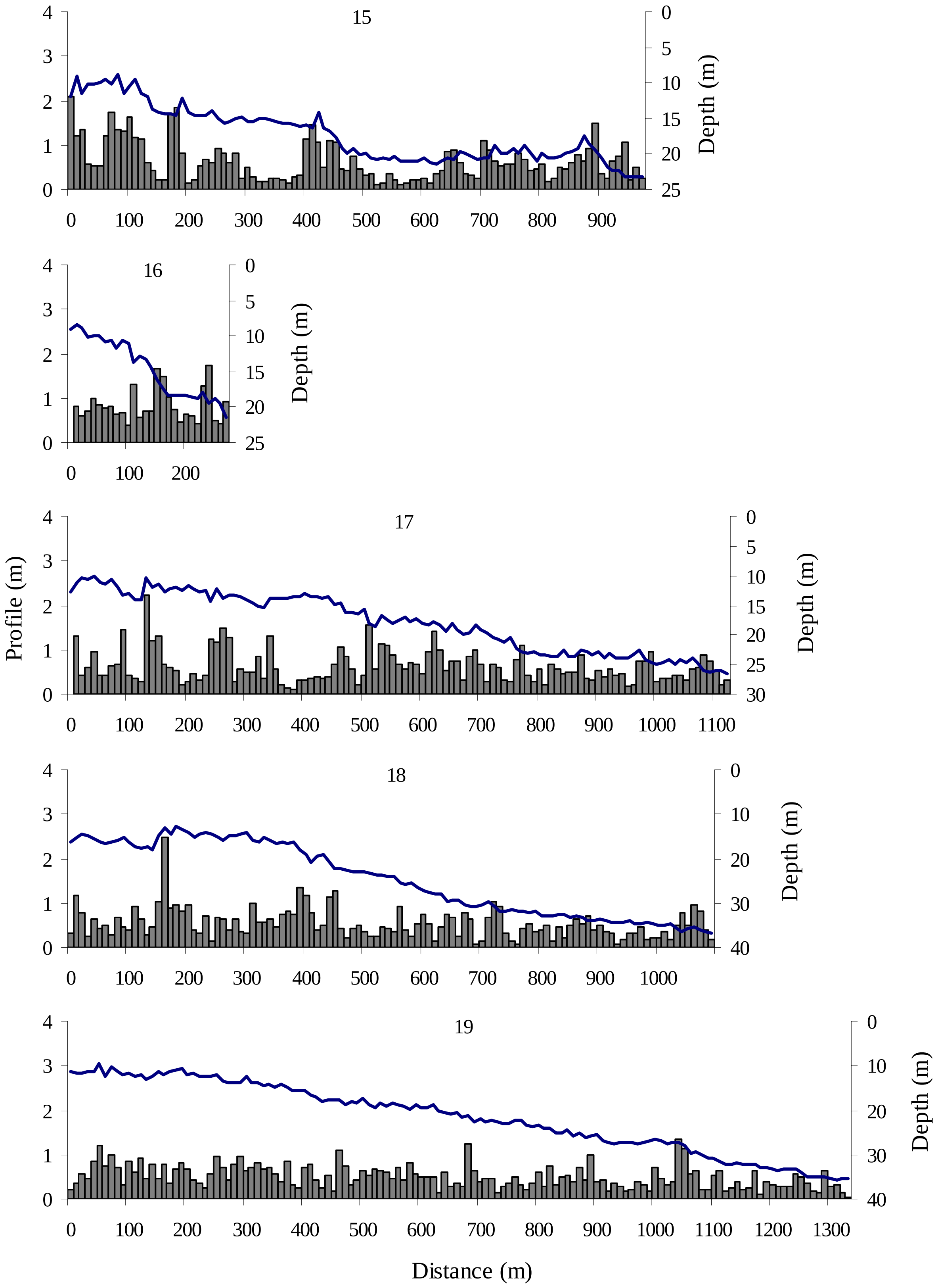
Appendix 5a. Distribution of rocky reef profile (m) at 10 m intervals and depth (m) along acoustic transects 1-5 in sub-block 31B (see Fig. 10).



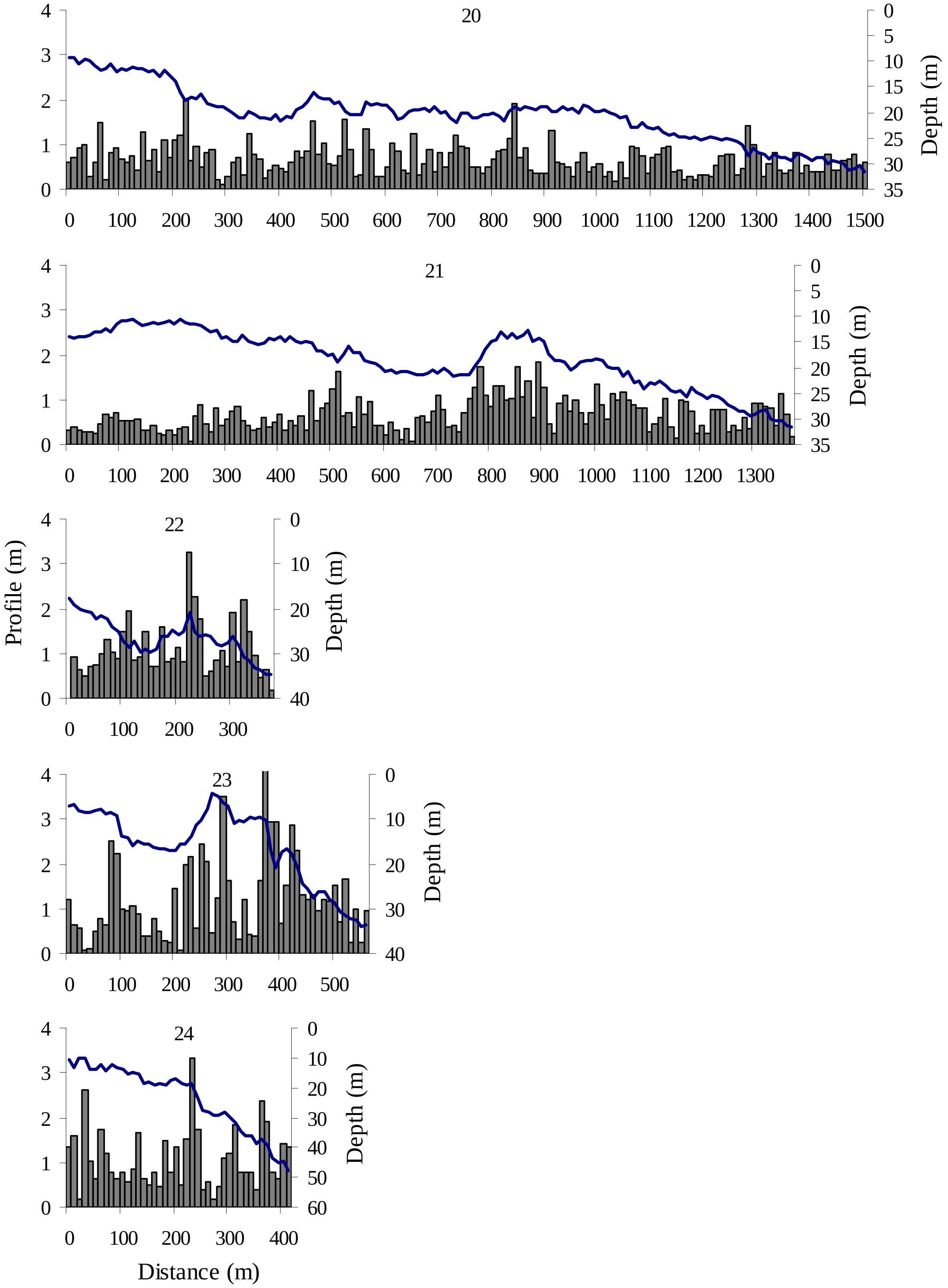
Appendix 5b. Distribution of rocky reef profile (m) at 10 m intervals and depth (m) along acoustic transects 6-10 in sub-blocks 31A and B (see Fig. 10).



Appendix 5c. Distribution of rocky reef profile (m) at 10 m intervals and depth (m) along acoustic transects 11-14 in sub-blocks 31A and B (see Fig. 10).



Appendix 5d. Distribution of rocky reef profile (m) at 10 m intervals and depth (m) along acoustic transects 15-19 in sub-blocks 31B and 30C (see Fig. 10).



Appendix 5e. Distribution of rocky reef profile (m) at 10 m intervals and depth (m) along acoustic transects 20-24 in sub-blocks 30A-C (see Fig. 10).

Appendix 6: CD-ROM of maps of fishing blocks 13C-E, 30 and 31 at various scales showing benthic substrate, sidescan sonar images, selected video images and depth contours