Autonomous Underwater Vehicle (AUV) for mapping marine biodiversity in coastal and shelf waters: Implications for Marine Management

Neville Barrett[*], Jan Seiler[*], Tara Anderson[#], Stefan Williams[**], Scott Nichol[#], S., Nicole Hill[*]
[*]University of Tasmania, [#]Geoscience Australia, [**]University of Sydney
neville.barrett@utas.edu.au, tara.anderson@ga.gov.au

Abstract- **Autonomous Underwater Vehicles (AUVs) have only recently become available as a tool to investigate the biological and physical composition of the seabed utilizing a suite of image capture and high-resolution geophysical tools. In this study we trialled the application of an AUV, integrating AUV image capture with ship-based high resolution multibeam bathymetry, to map benthic habitats and biodiversity in coastal and offshore waters of SE Tasmania. The AUV successfully surveyed a plethora of marine habitats and organisms, including high-relief kelp-dominated rocky reefs to deep mid-shelf reef and sediments that are otherwise difficult to access. To determine the spatial extent of these habitats within a broader-scale context, the AUV surveys were integrated with larger scale multibeam mapping surveys. The data collected using the AUV significantly improved our understanding of the distribution of benthic habitats and marine organisms in this region, with direct application to the management and conservation of these environments. For example, preliminary results identified the distributional extent of an introduced invasive marine pest, the screw-shell *Maoricolpeus roseus*, which was recorded adjacent to rocky reefs but is now known to also extend in high abundance across the SE shelf. Integrating the AUV data with the large-scale mapping data provided the opportunity to quantify the relationships between the biological and physical variables, and to use thise data to develop predictive models of biodiversity across the region. The effectiveness of the AUV as a pioneering tool for undertaking spatially repeatable surveys makes it a highly versatile technique for future use in surveying remote environments, particularly with respect to surveying and monitoring biodiversity in newly established Commonwealth MPA's. It also has application in the context of climate change, the study of invasive species, impacts of fishing activities and determining the relative uniqueness and/or representativeness of these marine environments.**

I. Introduction

Until recently, very little quantitative information, other than those collected by spatially coarse methods such as trawls, has existed about the benthic fauna on deep reef and their adjacent shelf sediment habitats [1]. This is despite these areas often being core habitats for important fishery species such as rock lobsters, striped trumpeter and banded morwong on reefs, and scallops and flathead on the sediments [2], and with the requirement to understand and maintain habitat health being the focus of Ecosystem Based Management (EBM), an integral part of current fisheries management. In addition, an extensive offshore MPA network is currently being developed around Australia [3], and appropriate non-destructive tools are urgently needed to describe and monitor the range of habitats and biodiversity these MPAs are intended to protect. Monitoring of these MPA's may include evaluating the effectiveness of MPAs in protecting habitats from the effects of fishing (eg. trawling) and their resilience to climate change and introduced marine pests.

In this paper we describe a multi-scale seabed mapping approach that highlights the importance of the IMOS (Integrated Marine Observing System) Autonomous Underwater Vehicle (AUV) in examining bio-physical relationships in benthos off South-eastern Tasmania. Biological data derived from AUV acquired imagery was coupled with multibeam sonar derived from ship-borne instruments to assess the ability of these emerging technologies to fill this information gap. Specific aims of the study were to 1) test the effectiveness of multibeam products as surrogates for the habitats and biology by matching habitat information and biological assemblage data derived from AUV imagery with mapped patterns in multibeam sonar bathymetry and acoustic backscatter, 2) map and describe seabed features non-destructively, 3) develop cost-effective techniques for future biodiversity description and monitoring in deep shelf environments. This research was undertaken within the CERF (Commonwealth Environment Research Facility) Marine Biodiversity Hub - a commonwealth funded collaborative venture between leading Australian marine research groups, aimed at developing best methods to describe and predict the patterns of biodiversity in Australian waters for resource management and planning [4] and supported by the IMOS national facility support program, through the provision of the AUV. Data presented here on the south-eastern coast of Tasmania were collected as part of a collaboration between the Tasmanian Aquaculture and Fisheries Institute (TAFI; University of Tasmania) and Geoscience Australia (GA), and was completed in two stages during 2008/09 [5].

II. Methods

Seven study areas were selected to reflect a representative range of environments in coastal and shelf waters of SE Tasmania, with a particular focus on deep reef features of the

978-1-4244-5222-4/10/$26.00 ©2010 IEEE

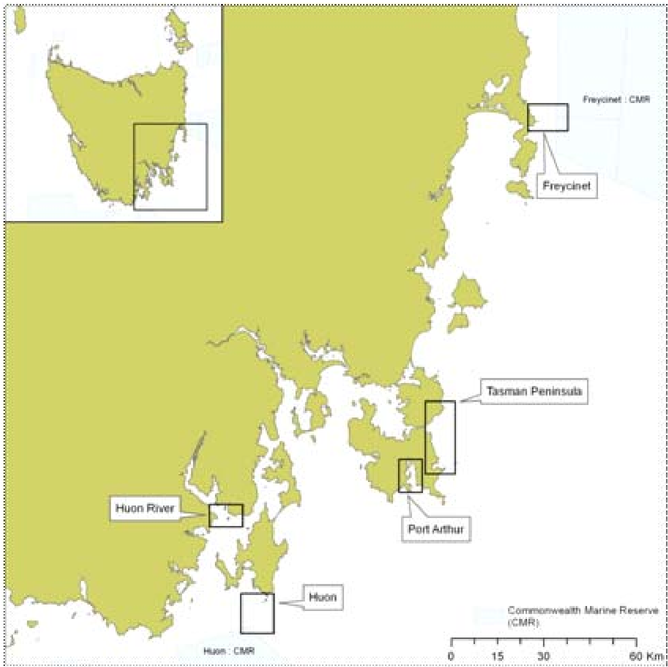

Figure 1. Location of survey areas mapped during the 2008/09 multibeam surveys, including boundaries of the Huon and Freycinet Commonwealth Marine Reserves.

Tasman Peninsula and reefs within two newly proclaimed Commonwealth Marine Reserves (CMR's, Freycinet CMR and Huon CMR, Fig. 1). Study areas were mapped in 2008 and 2009 using Geoscience Australia's Konsberg EM3002 multibeam sonar system, to determine the extent of habitat variability within and between these areas, and provide detailed seabed information to assist the design of the AUV and towed video surveys (Fig. 2). The seven study areas included representative habitats from a range of marine environments, water depths (18-120 m), and exposure to oceanic swells. These primarily included coastal reefs and adjacent shelf sediments, but more sheltered embayment's and river channels were also mapped. To examine the relationship between the physical structure of the seabed and the associated biological assemblages, a range of physical characteristics of the seabed were derived from the multibeam bathymetry (e.g. slope, rugosity) and backscatter (hardness, and smoothness) for testing of correlations with the AUV derived imagery.

The high-resolution multibeam bathymetry revealed many interesting geomorphic seafloor features, including ancient coastlines, high relief fractured rocky reefs, drowned river valleys in the Huon River valley and Port Arthur, and dense nests of 30 m wide circular depressions at the mouth of the Huon River (Fig. 3). To characterise the finer-scale abiotic and biotic structure and complexity of the seabed, we first undertook two surveys: a meso-scale towed-video survey, followed by a finer-scale AUV survey.

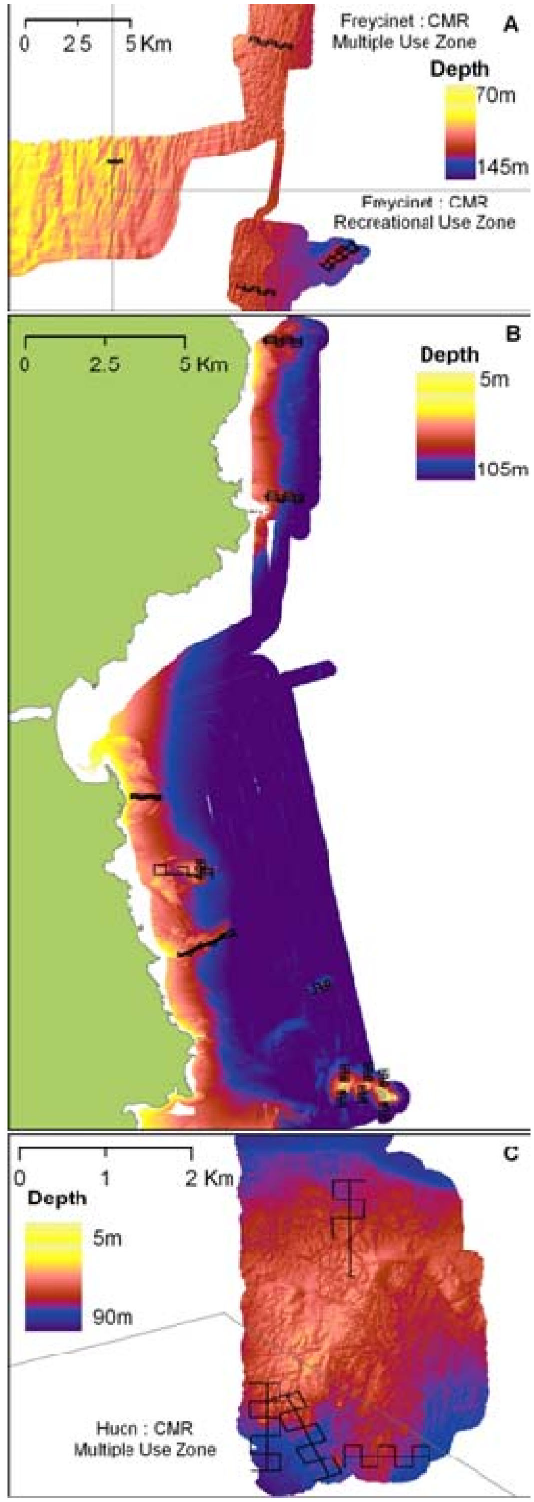

Figure 2. Representative example of areas mapped during the initial multibeam survey showing subsequent tracks of the AUV deployments. (A) Freycinet Commonwealth Marine Reserve, (B) Tasman Peninsula, (C) Huon Commonwealth Marine Reserve. Multibeam data courtesy of Geoscience Australia.

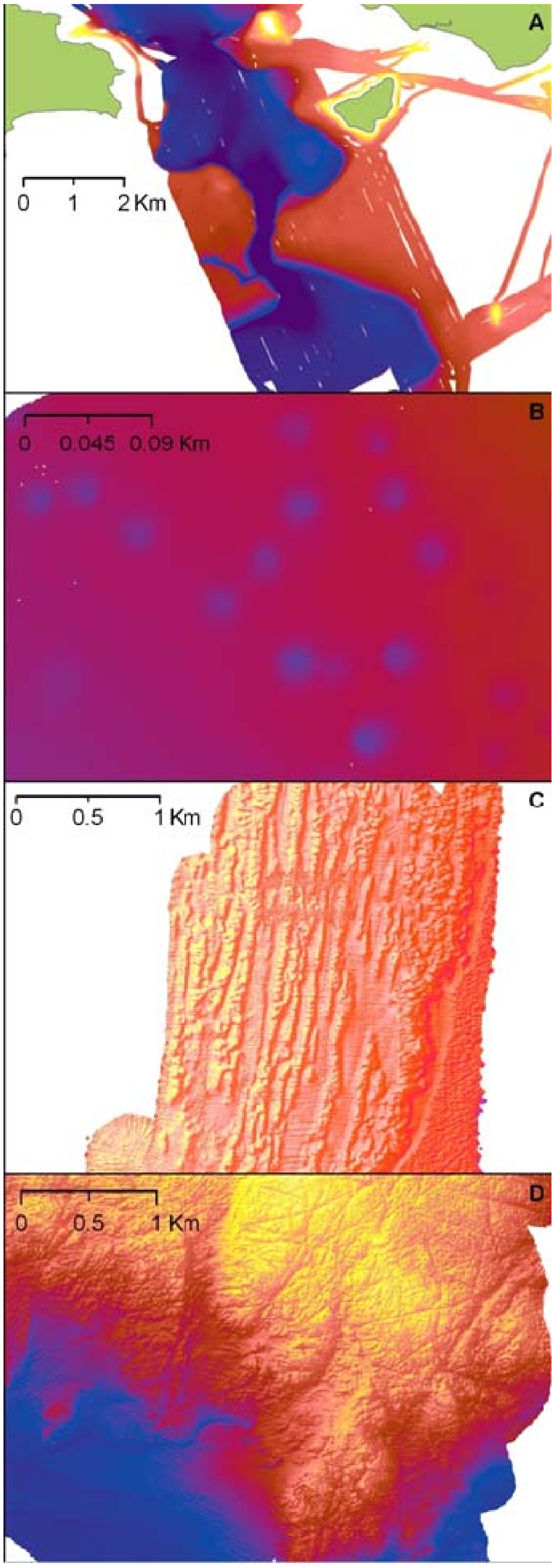

Figure 3. Representative array of seabed features revealed by multibeam mapping and subsequently ground-truthed by AUV surveys. (A) Drowned River Valley at the mouth of the Huon River, (B) nest of slump features in sediments within the D'Entrecasteaux Channel, (C) mid-shelf ancient coastline in 90-105 m depth in the Freycinet Commonwealth Marine Reserve, (D) mid-shelf dissected dolerite reef in the Huon Commonwealth Marine Reserve. Multibeam data courtesy of Geoscience Australia.

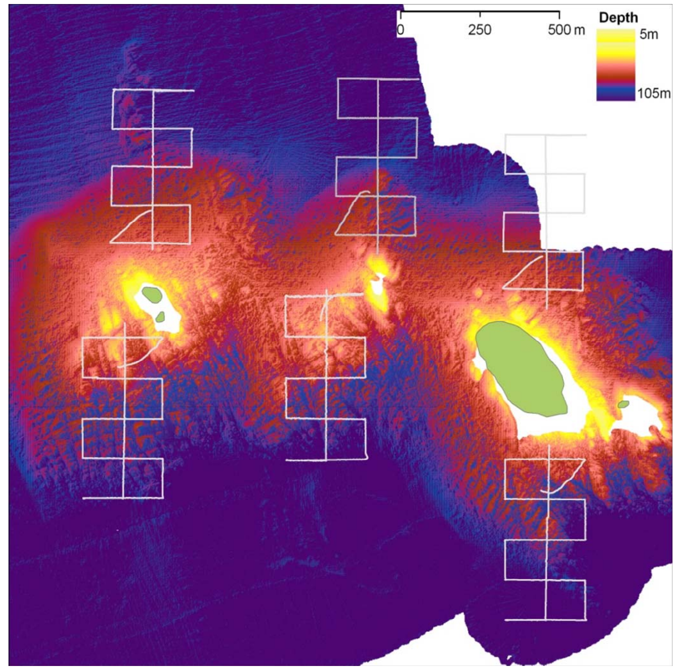

Figure 4. Example of the grid pattern used in AUV deployments during the SE Tasmanian surveys. The mission tracks shown here are overlying a multibeam sonar map of the Hippolyte Rock, a mid-shelf offshore island, with AUV missions typically extending from 15 m depth to 90 m depth. Multibeam data courtesy of Geoscience Australia.

In Feb-Mar 2009 we collected towed-video footage of the seabed over broad spatial scales that covered the depth range, habitat types, and spatial extent mapped by the multibeam sonar (Nichols et al., 2009). Substrata, geomorphology, biota presence and % cover of key taxa were classified in real-time from the towed-video footage. A USBL system attached to the towed-video and AUV systems was used to accurately record the geographic position of acquired imagery relative to the multibeam maps. Habitat types and distributions of biota obtained from towed-video survey were then plotted in ArcGIS to assist in the planning of the AUV survey. The AUV *Sirius* was then deployed in May and October 2009 to collect finer-scale imagery of the seabed over representative, but more discrete spatial areas (deployment locations shown in Fig. 2) to depths of 120 m.

The AUV is a robotic submarine, managed by the IMOS Autonomous Underwater Vehicle facility operated out of the University of Sydney, that navigates a pre-determined course (mission) at set height over the seabed while taking a continuous series of stereo photographs. The mission course is programmed into the AUV prior to each deployment, and incorporated a crossover grid pattern (e.g. Fig. 4) that enable the AUV to cross-reference and correct its actual position along the trackline via image recognition at crossover points. Course direction was usually oriented up and down the slope of a seabed feature with the length and width of the grid determined by the size and depth range of each feature surveyed. AUV tracks were generally 1 km in length, and typically traversed a coastal reef from a minimum safe depth of 15 m (to avoid adverse swell related motion in shallower water and entanglement in giant-kelp) to beyond the reef/sediment margin. Multiple tracklines were surveyed alongshore to provide replication of imagery at each depth within each feature type. This multiscaled approach, enabled us to examine natural variability at multiple scales, form (e.g. metre scale for variability between adjacent images, 100 m scale for variation between adjacent tracks). During each AUV mission, fine-scale multibeam bathymetry was recorded continuously (2 x 2 m footprint) and a still camera captured stereo images every second along each trackline. Each AUV stereo image covered an area of 1.2 x 1.6 m at a resolution of 1360 x 1024 pixels. The sequence of 1-second stereo images provided sequential overlap of the seabed images. This overlap meant that while stereo images could be examined individually, they could also be stitched together to form a continuous three-dimensional photo-mosaic that permits a full visualisation of the seabed along the AUV tracklineThe collected stereo images can be examined individually, or the overlapping images can be stitched together to form a continuous three-dimensional photo-mosaic that permits a full visualisation of the seabed along the AUV trackline. For example, Fig. 5 shows a small photo-mosaic produced by stitching together images taken in 50 m water depth off the Tasman Peninsula.

To quantify substratum type, geomorphology and biota % cover and abundance, individual AUV images were post-processed using the CPCe (Coral Point Count with Excel extensions; [6]) freeware software package, but modified slightly to suit a temperate, rather than tropical, ecosystem. Initial scoring focussed on scoring every 100th image (approximately 50 m spacing), with subsequent scoring infilling areas of specific focus to increase replication as needed. Each image was scored using 50 point counts, whereby habitat and species categories were counted for each point. The pixel resolution of images, however, meant that many benthic fishes, large macroaglae, mobile invertebrates and large sessile invertebrates could only be identified to genus or morph type. Some key ecological taxa (e.g. scallops, sea-urchins, screw shells, and crayfish) were identifiable to species. These key taxa were counted within each image, and sized where possible. The sizes of key taxa were estimated using SeaGis PhotoMeasure™ system software. All seabed images were spatially geo-referenced and subsequently integrated with the multibeam sonar parameters to examine their relative contributions in explaining and predicting seabed complexity and diversity.

III. Results and discussion

Overall, the AUV was highly effective at operating both in the coastal and shelf environments and over the potentially hazardous rocky terrain of the deep rocky habitats. Twenty successful missions were conducted, capturing valuable co-located digital images and physical data.

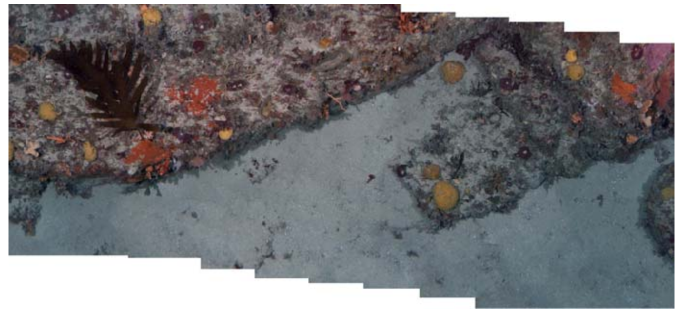

Figure 5. Mosaic of AUV imagery collected at the reef/sand interface in 60 m water depth offshore from Waterfall Bluff, Tasman Peninsula.

Although the AUV imagery has yet to be fully analysed, or correlated with multibeam-derived variables, several important management related patterns are already emerging. For example, the long-spined urchin (*Centrostephanus rodgersii*) is a species that can drastically modify its environment by completely denuding kelp from rocky reefs (referred to as urchin barrens) [7], [8]. Previously, *C. rodgersii* was thought to have a broad depth range extending from the shallow to deep reef habitats. This study showed that *C. rodgersii* is far less abundant on deep sponge-covered reefs than algal covered shallower reefs, identifying a more depth-restricted threat on these temperate reef systems by *C. rodgersii* than previously thought. This has positive management implications such that future actions toward minimising barren formation through restoration of natural urchin predators can now be more confidently targeted toward shallow water ecosystems. In contrast, we identified a significantly greater distribution and abundance of New Zealand screw shells, *Maoricolpeus roseus,* than had previously been assumed. *M. roseus* was introduced to Tasmania in the early 1900's, and has become widespread in eastern Tasmanian waters. This study, however, highlighted that *M. roseus* is not only widespread along the coast, but is present in very high densities in many soft-sediment habitats (Fig. 6) and now has an extended distribution out across the eastern Tasmanian shelf (e.g., shown in AUV tracks in Fig. 7) essentially producing its own biogenic habitat through the physical structure that the dense shell beds form. This habitat is subsequently colonised by sponges and other sessile invertebrates, creating a biological assemblage that is quite distinct from that likely to have been present prior to the screw shell beds forming.

The ability to identify, count, and measure important fishery species both on rocky reefs (e.g. reef fish, lobsters) and soft-sediment areas (e.g. scallops and flathead) also makes the AUV a potentially valuable fishery tool. The more exposed southern reefs around the Friars, for example, were found to support large numbers of the southern rock lobster, *Jasus edwardsii*, than more northern reefs. Scallops (*Pecten fumatus*) were also readily apparent in many images (fig. 6), particularly in areas traditionally dredged for scallops, and were sufficiently abundant in the imagery to yield informative size frequency distributions as well as density estimates. Fishery-applied application of the AUV may also be improved for some species by using night time AUV deployments, as our night time trials proved particularly valuable for estimating lobster or sea-urchin abundances - as lobsters tend to emerge from hidden dens at night to forage (Fig. 6), while sea-urchins are more active at night.

The application of the *Sirius* AUV system also identified some limitations that will be examined and improved, wherever possible, for future surveys. For example, coastal currents stronger than 1 knot impeded the ability of the AUV to maintain course heading or speed over the seafloor. While future power modifications may improve mobility in higher current environments, at present AUV surveys are limited to moderate or low current environments. Stereo imagery is substantially reduced in high turbidity environments. It has yet to be determined whether turbidity problems experienced during this study (i.e. Huon River) were the result of naturally turbid conditions or was the result of the AUV re-suspending fine silts into the water column. Further trials are required to resolve this potential problem. Current memory limitations, coupled with necessary download time between missions, meant a trade off was required between the number of stereo images that can be collected and the resolution/size of each image. In these surveys, stereos images were collected every second at 1.4 Mb resolution per image. Although these images clearly differentiated benthic habitats and many biota to species or morphotypes (examples in Fig. 6), resolution was often insufficient to differentiate characteristics required to separate other species. While some species will never be resolved from photographic imagery alone, a tenfold increase in resolution was estimated by our image scoring experts to be sufficient to overcome most of our identification questions. To resolve this issue in future deployments, an additional single camera could be mounted to the AUV to take less frequent (e.g. every ten seconds) but higher resolution imagery (10 mb) with a narrower field of view (1x1 m).

Another current opportunity and limitation was in the use of the stereo-image pairs to estimate an objects size using available software such as the SeaGis PhotoMeasure™ system [9]. At present the stereo cameras are positioned 80 mm apart, a spacing that is insufficient to optimal estimation error in calculating an objects size [10] but may readily be addressed in future AUV surveys where size information was an important survey requirement. The improvements suggested here would greatly enhance the value of the AUV as a tool for ecologists. While these modifications are within the current capacity of the system, it is also important to identify that ongoing technological advancements and innovation in AUV engineering and software development means that many more features and capabilities may soon be available.

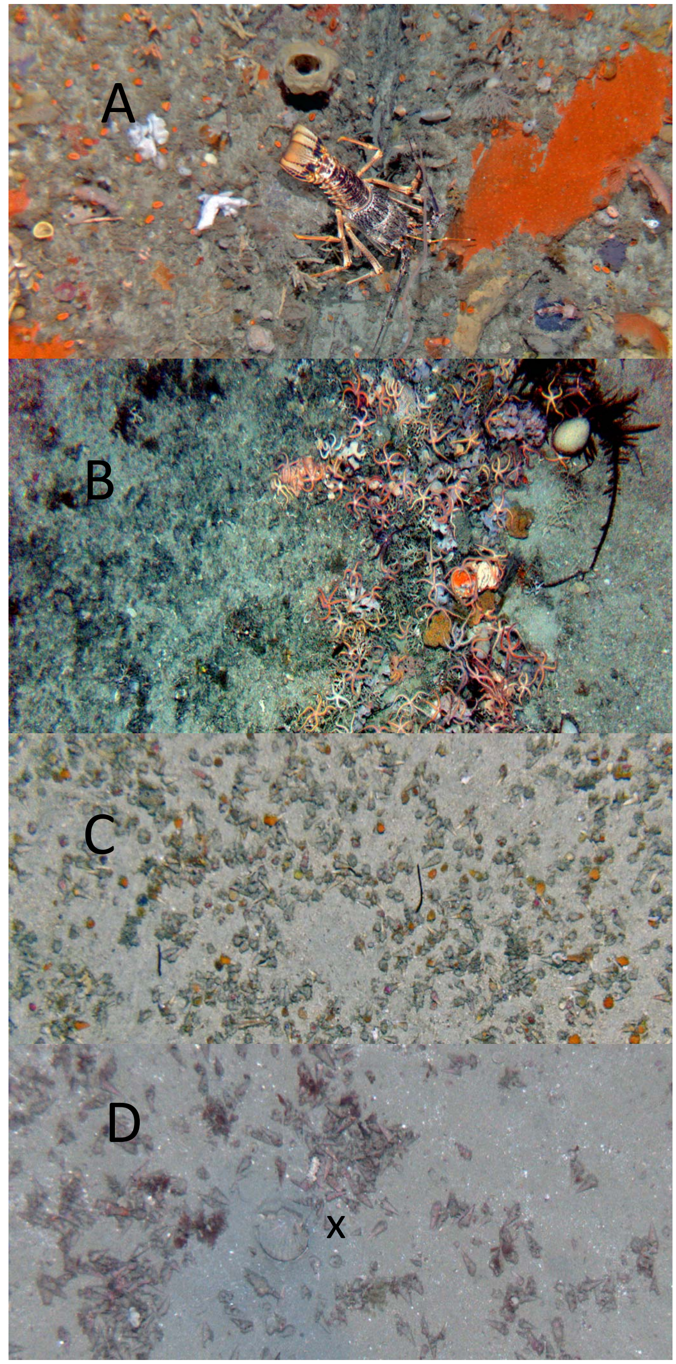

Figure 6. Examples of biological features identified during SE Tasmanian AUV surveys. (A) southern rock lobster (Jasus edwardsii) foraging within the Huon CMR, (B) brittlestar aggregation marking the boundary between Reef and flat sediment in the Freycinet CMR, (C) dense aggregations of New Zealand screw shells (*Maoricolpeus roseus*) offshore Tasman Peninsula, (D) scallops (marked by an x to right) buried in sediments, offshore Tasman Peninsula.

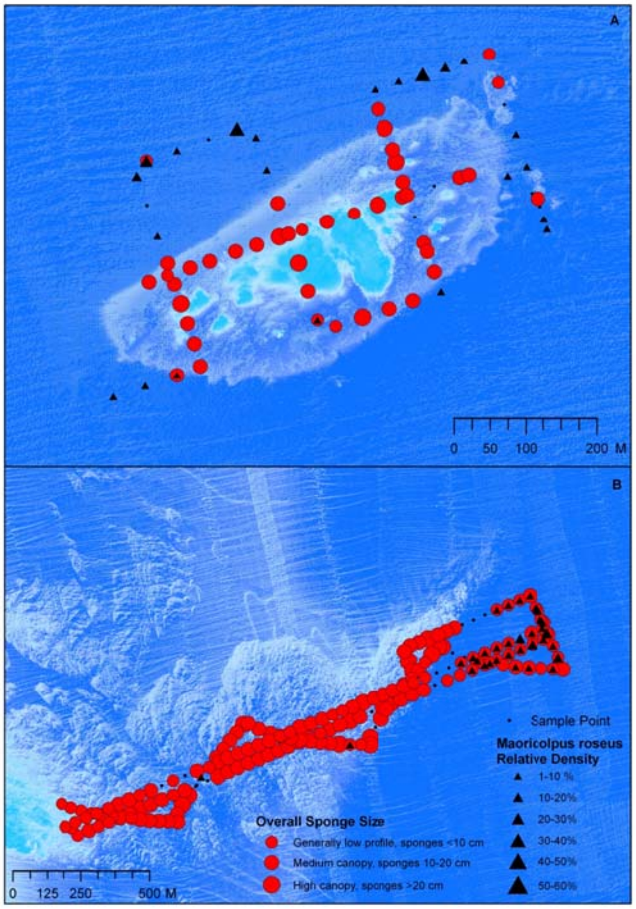

Figure 7. Mapped distribution of estimated sponge canopy height per image, and % cover of screw shells based on point-counts per image, for AUV transects across (A) Roxy's reef and (B) O'Hara Bluff reef, Tasman Peninsula, Tasmania.

In summary, the AUV has, in its initial trial in offshore waters in SE Tasmania, provided a significant improvement to our understanding of benthic habitats and biological assemblages in south-eastern Tasmania, and has clearly demonstrated the effectiveness of this innovative tool for addressing a range of management issues. The combination of high resolution and spatially referenced imagery makes the AUV an invaluable tool for quantifying seabed habitats and biota at fine-scales in a repeatable manner, thereby assisting researchers, stakeholders and managers in visualising and understanding these newly mapped and important marine environments. The multi-scaled bio-physical mapping data, collected as part of the CERF Biodiversity Hub program in 2008-2009, provides the first baseline information on seabed habitats and biota for these deep reef and sediment habitats. These baseline data can now be used in combination with future AUV monitoring surveys to quantify temporal changes in these systems relative to a range of potential threats, including introduced pests, climate-change, fishing pressure and habitat modification resulting from techniques such as bottom-trawling and dredging. In addition they can inform the validation of multibeam sonar based habitat mapping, leading to greater confidence in our ability to differentiate important habitat and biodiversity variability over large management scales, and as this technology becomes more widely available will most likely underpin future programs aimed at comprehensively mapping and monitoring the health of these ecosystems.

Acknowledgment

This research was funded through the CERF Marine Biodiversity Hub and the IMOS marine facility funding from the Commonwealth of Australia. We thank a broad range of staff at TAFI, GA and Uni of Sydney for their assistance in establishing and undertaking this research including Colin Buxton, Vanessa Lucieer, Justin Hulls, Hugh Pederson (TAFI), Peter Harris, Brendan Brooke, Matthew McArthur, Andrew Heap, Ian Atkinson, Cameron Buchanan, Michele Spinoccia (GA), Oscar Pizzaro, Michael Jakuba, Duncan Mercer, George Powell (USyd), the crew of R.V. Challenger-Matthew Francis and Jac Gibson, and finally Richard Coleman (UTas) for initiating the AUV collaboration.

References

[1] N.S. Barrett and G.J. Edgar, "Distribution of benthic communities in the fjord-like Bathurst Channel ecosystem, south-western Tasmania, a globally anomalous estuarine protected area," *Aquatic Conservation: Marine and Freshwater Ecosystems,* in press.

[2] G.J. Edgar, *Australian marine habitats in temperate waters.* Sydney, Aust: Reed New Holland, 2001.

[3] http://www.environment.gov.au/coasts/mpa/publications/pubs/nrsmpa-report.pdf

4] www.environment.gov.au/about/programs/cerf/research.html#marinebio.

[5] S.L. Nichol, T.J. Anderson, M. McArthur, N. Barrett, A.D. Heap, *Southeast Tasmania Temperate Reef Survey: Post Survey Report.* Geoscience Australia Record. Canberra: Geoscience Australia, 2009, pp1-73.

[6] K.E. Kohler and S.M. Gill, " Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology" *Computers and Geosciences,* vol. 32, pp. 1259-1269, 2006.

[7] N.L. Andrew and A.J. Underwood, "Patterns of abundance in the sea urchin *Centrostephanus rodgersii* on the central coast of New South Wales" *J. Exp. Mar. Biol. Ecol.,* Vol. 131, pp. 61-80, 1989.

8] N.L. Andrew, "Spatial heterogeneity, sea urchin grazing, and habitat structure on reefs in temperate Australia" *Ecology*, vol. 74, pp. 292-302, 1993.

[9] http://www.seagis.com.au/.

[10] D.A. Abdo, J.W. Seager, E.S. Harvey, J.I. McDonald, G.A. Kendrick, and M.R. Shortis, " Efficiently measuring complex sessile epibenthic organisms using a novel photogrammetric technique" *J. Exp. Mar. Biol. Ecol.,* vol. 339, pp. 120–133, 2006.