Application of autonomous underwater vehicles (AUVs) for monitoring marine biodiversity hotspots

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Abstract

Underwater Autonomous Vehicles (AUVs) were only recently developed into functional instruments for examining and biomonitoring seabed features because they provide image acquisition and geophysical sensing. In this research, we aimed to assess the potential of an AUV in mapping benthic habitats and biodiversity in coastal and offshore regions of southeast Tasmania by AUV imagery and high-resolution multibeam bathymetric imaging from the vessel. The AUV monitored different marine habitats and life forms, including highly productive kelp rocky reefs, mid-shelf deep rocky reefs, and some sedimentary environments that are otherwise difficult to reach. To evaluate the broader-scale spatial distribution of these habitats, the AUV survey data were fused with more extensive multibeam surveys. Data collected by the AUV markedly improved the understanding of the spatial distribution of benthic habitats and marine life in the study, which subsequently aids in wiser management and protection decisions. In the document’s example, initial data showed the distribution of an introduced freshwater species Maoricolpeus roseus New Zealand screw shell, previously documented in the vicinity of the rocky reefs. Still, they now found in higher densities throughout the southeast shelf. Combining AUV data with broad-scale mapping allowed us to measure the relationships between biological and physical variables, which could be used to construct predictive models for regional biodiversity. The study shows how effective the AUV is as an innovative tool for spatially repeatable surveys. It demonstrates the effectiveness of these techniques for monitoring remote regions, particularly for

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surveying and managing biodiversity within newly established Commonwealth Marine Protected Areas (MPAs). Additionally, this method could be useful for climate change studies, tracking invasive species, monitoring the impact of fishing, and assessing marine ecosystems' uniqueness and representativeness.

Keywords: Autonomous underwater vehicles, Biological, Physical characteristics, Geophysical, Marine protected areas, And Marine ecosystems

Introduction

Measuring methods such as trawling have hampered quantitative assessments of the benthic fauna on deep reefs and shelf sediment habitats until quite recently (Barrett and Edgar, 2010). Notwithstanding this, economically important species such as the rock lobsters, striped trumpeter, morwong, flathead, and scallops also inhabit these reefs and sediments, respectively. Cтagically, with an increased focus on Ecosystem-Based Management (EBM) as one of the core elements of contemporary fisheries management, it is becoming increasingly critical for fishery managers to understand the health of these ecosystems. Furthermore, Australia is in the process of establishing an offshore network of Marine Protected Areas (MPAs) (Edgar, 2001), which further accentuates the urgency to describe and assess the range of habitats and living organisms found within such areas and devise non-intrusive monitoring methods for these MPAs. Some MPAs may include evaluating the success of restricting detrimental fishing activities such as trawling and other environmental threats posed by imported marine pests associated with climate change (Gupta and Watson, 2004). This work presents a multi-scale mapping initiative of southeast Tasmania and describes the IMOS AUV's role in the biophysical benthic processes there (Verma and Pillai, 2023).

This study sought to investigate whether emerging technologies could close existing information rifts by merging biological data from an AUV's imagery with multibeam sonar imaging from a ship-based device. The study centers on the 1) assessing the usefulness of multibeam products as potential substitutes for the habitats and biology by observing correlations between AUV-derived habitat and biological assemblage data with sonar bathymetry and acoustic backscatter multibeam sonar telemetry visual patterns, 2) devising techniques for mapping and observing seabed features without physical disturbance, and 3) developing efficient strategies for describing and capturing deep shelf area future biodiversity (Tong, Clark and Mé, 2010). Under the objective of formulating methods to describe and project biodiversity patterns in Australian waters to aid in resource management and planning, this was done along with the data collation from fieldwork done in two campaigns in 2008 and 2009 as part of the CT Environment Research Facility Marine Marine Biodiversity Hub at TAFI, University of Tasmania (Abdo *et al.*, 2006)

Methods

The research sites selected to capture the coastal and shelf seas of south-eastern Tasmania are shown in Figure 1 which consists of the deep reef features of Tasman Peninsula as well as the reefs contained within the recently formed Commonwealth Marine Reserves Freycinet CMR and Huon CMR. Mapping for these areas was done in 2008 and 2009 using Geoscience Australia's Konsberg EM3002 multibeam sonar system, which makes available extensive seabed data for the enhancement of AUV and towed video survey systems as well as habitat variation records. The seven research sites selected featured coastal swells with representative swells documented, various marine habitats, and water depths between 18 to 120 meters. The study sites contained primarily coastal reefs with sediments and small waterways and embayments that were more sheltered. The multibeam bathymetry also provided slope and rugosity for the more simple physical aspects of the biologically spatial structure that was compared with the AUV imagery of the physical structure of the seafed, coupled with backscatter which depicts coarse smooth features and biological assemblage spatial structure.

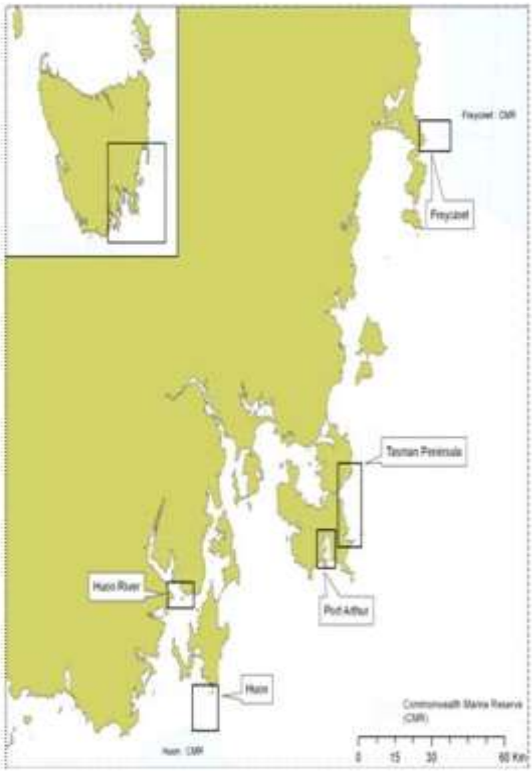

Figure 1: Map showing the survey locations covered during the 2008/09 multibeam surveys, highlighting the boundaries of the Huon and Freycinet Commonwealth Marine Reserves.

Multibeam bathymetric surveys done at high resolutions reveal prehistoric coastlines and high relief fractured rocky reefs, Huon River valley and Port Arthur drowned river valleys, and 30 m wide circular clasped depressions Huon River mouth (Figure 3). Before mapping the abiotic and biotic complexities of the seabed, my team's first step was a meso-scale towed video survey, followed by an AUV survey which highlighted finer details of the region.

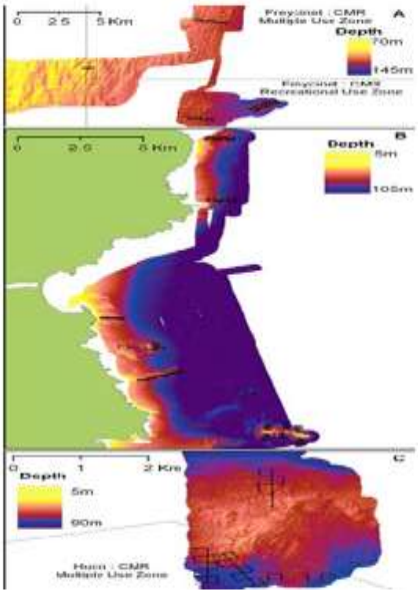

Figure 2: Example map of regions surveyed during the initial multibeam mapping, overlaid with the subsequent AUV deployment tracks. (A) Freycinet Commonwealth Marine Reserve; (B) Tasman Peninsula; (C) Huon Commonwealth Marine Reserve. Multibeam data provided by Geoscience Australia.

As noted in Nichols *et al.,* (2009), during February and March of 2009, we acquired towed video imaging along the multibeam sonar mosaic’s spatial, depth, and habitat ranges. During the towed video analysis, real-time classification of substrata, geomorphology, biota, and key taxa abundances was performed. The geographic coordinates were precisely aligned with the multibeam sonar maps via a USBL system connected to the AUV and the towed video systems. The habitat types were incorporated together with ArcGIS before AUV-based spatial analysis for all captured biota. In May and October of 2009, the AUV Sirius was deployed to these regions to collect high-resolution imagery of the spatially and relationally representative areas of the previously collected data down to 120 m depths (deployment locations shown in Figure 2).

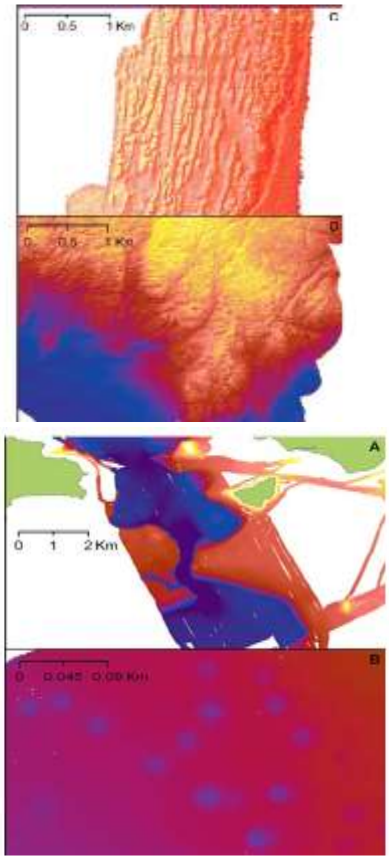

Figure 3: AUV surveys confirm the multibeam mapping which features representative selection of seabed features. (A) Drowned river valley at Huon River mouth; (B) slump features cluster in D’Entrecasteaux Channel s Sediments; (C) mid-shelf paleo shore line 90 - 105m depth Freycinet Commonwealth Marine Reserve; (D) mid-shelf dolerite reef dissected demolish in Huon Commonwealth Marine Reserve—Geoscience Australia provided Multibeam data.

The IMOS Autonomous Underwater Vehicle Facility at the University of Sydney operates a robot submarine known as the Autonomous Underwater Vehicle (AUV). Its duty is to maintain a preset altitude while autonomously capturing full-motion stereo video stills at predetermined intervals. Each AUV deployment includes a mission with self-navigation and position confirmation using image recognition at specific crossover points AUV follows with cross-over grid patterns (for example, see Figure 4). Surveying directions were usually set along the length and width of a designated seabed feature and bounded by its horizontal dimensions as well as the range of depth for the feature in question. Typically, AUV tracks were 1 km long, starting at a minimum safe depth of 15 m to avoid swell interference and kelp entanglement, continuing beyond the reef/sediment boundary. In the alongshore direction, multiple track lines were surveyed for image capture at each depth within each feature type.

This multiscale method enables us to examine regions with natural heterogeneity at several different levels (for example, the variation between neighboring images is at the meter scale, and the variation between neighboring tracks is at the 100 m scale) (Salman, Al-Noor and Khalaf, 2024). During each mission of the AUV, multibeam bathymetry was continuously recorded with a fine-scale footprint of 2 x 2 m. At the same time, stereo cameras took still snapshots of the track lines every second. Each AUV stereo image encompassed an area of 1.2 x 1.6 m with a resolution of 1360 x 1024 pixels. Because the 1-second stereo shots taken had some overlap, they could be sequentially overlapped to form a contiguous sequence of seabed images. Therefore, despite individual stereo images being scrutinized, the montage enabled the assembly of a 3D photo-mosaic depicting unfettered surveillance of the seabed throughout the AUV's journey (mastery over). The stereo images collected can be subjected to individual or combined ensemble analyses. With the proper software, users can reconstruct the unobstructed view over the sea floor throughout the AUV path (explicit visualization). For instance, in Figure 5, we show a small photomosaic estimate of the Tasman Peninsula at a 50m water depth.

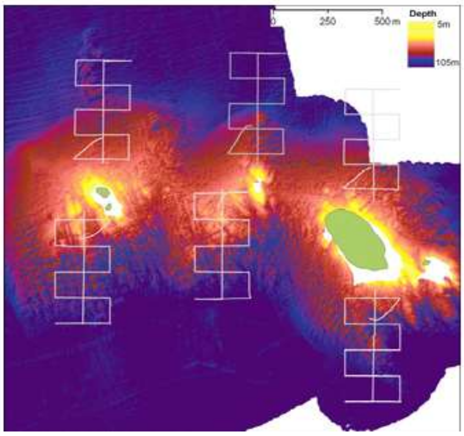

Figure 4: Representation of the grid configuration used for AUV operations in southeast surveys in the area around Tasmania. The particular AUV mission tracks have been plotted over a multibeam sonar image of Hippolyte Rock mid-shelf offshore island which has AUV survey lines that, in general, range from 15 m to 90 m in depth. The multibeam data was sourced from Geoscience Australia.

Figure 5: Mosaic of AUV imagery captured at the reef–sand boundary at a depth of 60 m offshore from Waterfall Bluff, Tasman Peninsula.

In order to cluster images by technofossil, substratum type, geomorphology, and biota percent cover and abundance, I has to process the AUV photograph sequentially using the free software, CPCe (Coral Point Count with Excel Extensions; (Nair and Rathi, 2023)) which is optimal for use in temperate cold biomes and not tropical ones. For my scoring, I began with every 100th picture which was a 50m distance, and then expanded to fill in focus areas and improve overlaps that were present. Every picture was given a score of fifty, as well as having all species and habitats grouped for every single point. Due to the low resolution of the pictures, a portion of the benthic fishes, mobile macroabundant invertebrates, and stationary organisms had to be viewed in generic or morphed forms. An ecological species could identify scallops, sea urchins, screw-shells, and crayfish. These taxa were named based on their picture and group size when possible. The importance of these taxa was measured by me with the program SeaGis PhotoMeasureTM. We had all the images of the seafloor geo-referenced and gridded with the seamlessly integrated multibeam sonar data. Afterward, I assessed how much each sonar contributed to our predictions of complexity and variety.

Results and Discussion

The AUV demonstrated remarkable operational capabilities within the coastal and shelf zones and potentially dangerous deep rocky terrain. The mission objectives were achieved 20 times, meaning useful digital photographs and physical measurements were taken Figure 5. AUV imagery mosaic captured at reef/sand interface at Waterfall Bluff, Tasman Peninsula offshore at 60m water depth. Important trends pertaining to management concerns are emerging and, to some extent, the analysis of AUV imagery in combination with attributes derived from multibeam has not been performed yet. Long-spined urchins (Centrostephanus rodgersii) are indeed examples of species which strongly impact their environment by removing kelp from rocky reefs transforming them into barren urchin fields (Gupta and Watson, 2004; Menon and Patil, 2023). At working hypothesis, it was believed C. rodgersii would be abundant at all depths from shallow to deep reefs. This study demonstrated that C. rodgersii is far less abundant in deep sponge covered reefs. This suggests that there are fewer temperate reef systems remaining to be concerned about than previously thought. From a management perspective, the efforts to restore the native urchin predators will now primarily concentrate in the shallow water systems to decrease barrens. We recorded a broader distribution and greater occurrence of New Zealand screw shells (Maoricolpeus roseus) than previously documented. This species, M. roseus, is presumed to have been introduced into Tasmanian waters in the early 1900s. It has since become widely distributed throughout the eastern Tasmanian seas. However, this study showed that M. roseus not only along the coast but as Figure 6 showed, also in very dense populations well beyond eastern Tasmanian continental shelf soft sediment regions (shown in Figure 6 AUV tracks) are also very abundant.

This species has been actively forming extensive dense shell beds geologically called biogenic habitats which are accumulations of shells inhabited by sponges and other sessile invertebrates that, unlike formerly existing, support distinct biological assemblages begot and transformed underlying screw shell beds. These AUV features enhance its capabilities as a fisheries management tool because it can locate, identify, and evaluate economically essential fisheries species such as reef lobsters and fish on rocky reefs and scallops and flathead in softer sediment areas.

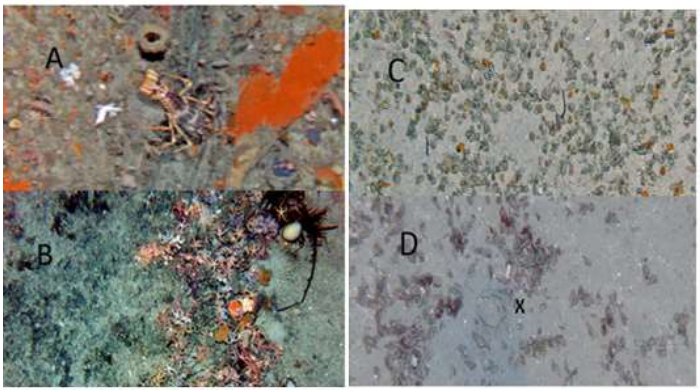

Figure 6: Biological features observed from the southeastern Tasmanian AUV survey. (A) Foraging southern rock lobster (Jasus edwardsii) within the Huon Commonwealth Marine Reserve; (B) aggregation of brittlestars marking the interface between reef and sandy flat in the Freycinet Commonwealth Marine Reserve; (C) offshore dense colonies of New Zealand screw shells Maoricolpeus roseus around Tasman Peninsula; (D) partially buried scallops 'x' right offshore of Tasman Peninsula.

The Friars'southern reefs, which are less sheltered, were described as having a more abundant concentration of Jasus edwardii than the south of reefs. Scallops are also quite conspicuous in many images (figure 6), particularly in areas where they had previously been dredged, and their numbers in the imagery were sufficienctn to offer informative size frequency distributions and density estimates. During analysis of the data, the night tests' results indicated that we could better assess the population of lobsters and sea urchins during our nighttime trials. Sea-urchins are more active at night, and lobsters come out of their dens to feed (Figure 6). Therefore, some species may benefit from AUV deployments that occur at night (SeaGIS Pty Ltd., 2025).

Operating the Sirius AUV system uncovered additional problems of limitations which will be, where able, analyzed and enhanced for future surveys. For the sake of this survey, coastal currents more than 1 knot were shown to hinder the AUV's ability to maintain heading or speed over the seafloor. Later versions may incorporate higher power modulations, which improve maneuverability in stronger currents; however, at this time, AUV surveys are restricted to weaker and moderate current environments (Andrew, 1993). Underwater stereo imagery suffers significant loss of quality in high turbidity environments. It is unknown whether the turbidity problems encountered in this study, such as those in the Huon River, were naturally perturbed or whether the AUV was actively resuspending fine silts into the water column. More tests are necessary to resolve this concern (Tong, Clark and Mé, 2010). Due to the current memory limitations and download time between missions, a tradeoff had to be made on the total number of stereo images about the mission versus the mission duration, the resolution, and file size of the photos. During these surveys, stereo images were captured at 1.4 Mb/sec per image resolution every second (Tong, Clark and Mé, 2010).

Despite the benthic habitats and biotas being distinctly visible on the photographs taken during these surveys (see Figure 6), the most distinguishing features important for resolving some other species were not well seen. An estimate from our image scoring experts indicates that resolving ID problems based on photographs would be solvable in almost all instances with an increase in resolution by an order of magnitude (Andrew and Underwood, 1989). In overcoming such obstacles for later implementations, for example, an additional camera mounted on the AUV could take wider images (10 mb) at much lower altitudes (1x1 m) and lower altitudinal frequencies (10-second intervals) while maintaining greater resolution (Sato, Hirose and Shikata, 2019).

As problem statements and areas of need, one might point out the requirements for stereo pair imagery for size estimation, which is inaudible by the SeaGis Photo Measure™ software (Nichol *et al.,* 2009; Priyalatha, 2024). The currently mounted stereo cameras are set 80 mm apart, for which there are known huge estimation errors for object size estimation (Singhal, Yadav and Dwivedi, 2024). However,these gaps can easily be adjusted in future AUV deployments where collecting size data is the main purpose. Such recommendations would further increase the attractiveness of the AUV for ecologists (Gupta and Joshi, 2025).

It is important to emphasize the speed with which AUV technology, engineering, and software are progressing. These suggest many additional possible functionalities and features that could be available soon, even though these changes can be made using the present system configuration (Kohler and Gill, 2006).

Conclusion

The autonomous underwater vehicle's deployment during the first trial off the south-eastern shore of Tasmania has fundamentally advanced our understanding of the area's biological assemblages and benthic habitats. Even AUV's first performance in the prosecution substantiates the device's usefulness in addressing diverse management problems. The AUV seems to be an exact and quantifiable apparatus for observing the sediment and biota of seabed regions, on a finer scale, and in a repeatable manner. This assists researchers, stakeholders, and managers in their efforts to visualize, comprehend, and interpret these recently surveyed areas. The primary mapping endeavor undertaken for deep reefs and sediment habitats by the CERF Biodiversity Hub program from 2008-2009 was in conjunction with collecting multi-scaled bio-physical data on sea-bed floors and living organisms, forming baseline data. Along with the retrospective analysis of data collected from AUV monitoring surveys, these baseline data sets can now measure change over time about potential threats such as invasive species, climate change, fishing, and habitat alteration due to bottom-trawling and dredging. In addition, they may help justify multibeam sonar-based habitat mapping, which enhances the ability to delineate critical habitat and biodiversity changes at broad management levels. As this technology becomes available, it will most likely aid future efforts aimed at comprehensively mapping these ecosystems and tracking their systems.

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