Establishment of a cost-effective monitoring program to detect changes in the structure of benthic invertebrate and macroalgae assemblages in the West Coast Bioregion.

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Project: 4.2. Assessment of marine communities and the impact of anthropogenic influences.
Milestone: Monitoring programs for benthic invertebrates and macroalgae completed.

Executive summary

- There is a need to regularly assess the health of benthic habitats to meet the objectives of Ecosystem Based Fisheries Management (EBFM). As part of the EBFM process for the West Coast Bioregion (WCB), a network of component trees has been established by the Department of Fisheries (WA), which outlines key ecological and socioeconomic assets, each of which has been allocated a risk rating in order to prioritise management efforts.
- To monitor the health of benthic habitats and the state of benthic biodiversity for EBFM, a cost-effective monitoring programme has been established at 3 key locations; Rottnest Island, Jurien Bay and The Houtman Abrolhos Islands.
- Surveys of benthic assemblages were conducted with an AUV (autonomous underwater vehicle), which captured over 150,000 high resolution images of the seabed. Surveys were designed to obtain 100% coverage of 25 x 25 m patches of benthos; these grids were sampled in triplicate at multiple sites along a depth gradient at each location. The AUV also gathered a wealth of physio-chemical data.
- Benthic assemblages have been ‘benchmarked’ at 14 individual sites, all of which will be resurveyed in 2011. Data from Rottnest Island show that benthic habitats can be precisely quantified using this methodology, which generates reliable estimates of (amongst other metrics) the areal coverage of the canopy-formers *Ecklonia radiata* and *Scytothalia dorycarpa*, red foliose algae, encrusting coralline algae and sponges, as well as facilitating examinations of the relative dominance of kelp vs. coral vs. bare substratum and multivariate assemblage structure.

- Work is ongoing to streamline the analysis process to maximise cost-effectiveness. Continued collaboration with the AUV team at the Australian Centre for Field Robotics (University of Sydney) will ensure efficient and reliable monitoring of benthic habitats within the WCB, and therefore maximise our ability to detect ecologically-relevant change driven by ever-increasing anthropogenic influences.

1. Introduction

Ecosystems based fisheries management (EBFM) requires documentation of ecosystem status and changes to that status. Without long-term data, short term natural variability can mask chronic and/or cumulative impacts, often until critical levels are reached (Hewitt et al. 2001). The necessity of long-term monitoring for understanding ecological variation and processes has been acknowledged for decades (Bernstein & Zalinski 1983). Monitoring for EBFM is essential because of the uncertainty involved in predicting the response of ecosystems to particular impacts or environmental change. In essence, the management of fisheries and marine resources must be ecosystem-based because, while the maintenance of the target stocks has long been the primary management goal for fisheries agencies, there is now recognition that non-target stocks and the broader ecosystem must also be maintained at acceptable levels in order to achieve stock sustainability (Pikitch et al. 2004).

In Western Australia (WA) the greatest threats to the marine ecosystem have been suggested to be the effects of fishing and climate change; climate change is a general term which encompasses a variety of predictions. For the marine environment the most pertinent pressures have been recognised to be changes in large and small scale current regimes (Gaughan 2007), changes in land run-off (Hobday et al. 2006), chemistry (Orr et al. 2005) and temperature (Pearce & Feng 2007, Caputi et al. 2009). However, the particular ecosystem impacts resulting from fishing and climate change pressures are not well known in this system and our predictive ability at the ecosystem level is currently low.

To develop, manage and highlight knowledge gaps for the EBFM process for the West Coast Bioregion (WCB) of WA, a network of component trees has been established by the Department of Fisheries (Fletcher et al. 2010). The component tree structure defines assets that need to be considered for EBFM, which include the environmental (ecological assets), social and economic assets as well as the ability to achieve management outcomes (institutional governance and external drivers). Each asset has subsequently been rated according to risk to aid prioritisation of management efforts and to identify knowledge gaps. However, in order to validate and, if necessary, alter individual risk ratings, information on the status of assets over time must be collected and fed back into the framework. A key asset within the ‘Ecosystem Structure and Biodiversity’ component of the framework is benthic habitats. An important habitat type is rocky reefs, which are found in both nearshore and inshore demersal coastal zones and at key locations such as the Houtman Abrolhos Islands and the Leeuwin/Naturaliste region. These rocky reefs support rich and abundant assemblages of macroalgae and sessile invertebrates, together with mobile invertebrates and reef fish (see Smale et al. 2011 for recent review) . These communities, in turn, provide food and habitat for economically important species such as the Western Rock Lobster and West Australian Dhufish.

Here, we report on the commencement of a cost-effective monitoring program to quantify the structure of benthic communities at 3 locations in the West Coast Bioregion. Repeat sampling of these locations will facilitate greater understanding of temporal variability in benthic community structure and population dynamics of key habitat-forming species. Moreover, continued monitoring will allow detection of large-scale ecological changes driven by, for example, oceanic warming, while time-series data can be used to regularly validate and/or amend the risk ratings associated with ecological assets (for relevant assets, see Fig. 1). .

2. Methods

2.1 AUV details

Surveys were conducted with a state-of-the-art Autonomous Underwater Vehicle (AUV), which is operated by the Australian Centre for Field Robotics (University of Sydney) and part-funded by IMOS. The submersible is equipped with a full suite of oceanographic instruments, including a high resolution stereo camera pair and strobes, multibeam sonar, depth, conductivity and temperature sensors, Doppler Velocity Log (DVL) including a compass with integrated roll and pitch sensors, Ultra Short Baseline Acoustic Positioning System (USBL) and forward looking obstacle avoidance sonar. For biological survey work, the vehicle is also fitted with a Wetlabs Eco Puck, measuring chlorophyll-a, CDOM and scattering (red), and an Aanderaa Optode, measuring dissolved oxygen concentrations.

The ‘flight path’ for each AUV dive can be precisely pre-programmed with a range of sampling designs, depending on the ecological question at hand (see below). The AUV was capable of conducting dives of up to 3 hours (limited by battery-life) and 3 or 4 dives per day. The vehicle was operated and deployed by a team of 4 scientists/technicians from ACFR; surveys were conducted from the CSIRO-operated research vessel ‘*Linnaeus*’ in April 2010.

2.2 Survey locations and design.

Long-term monitoring was established at 3 key locations within the WCB; Rottnest Island (‘Rottnest’), Jurien Bay (‘Jurien’) and The Houtman Abrolhos Islands (‘Abrolhos’) (Fig. 2). The key objective of the sampling was to survey predominantly rocky reef/coral habitat that could be established as LTM sites and revisited as part of monitoring efforts. As such, sites were selected, based on bathymetry maps and existing knowledge (i.e. Marine Futures project), to target moderate to high relief reef. At each location, replicate sites were chosen along a depth gradient, with 2 sites at 15, 25 and 40 m depth (Fig. 2). At Rottnest, one of the sites at both 15 and 25 m was positioned within the Kingston Reef marine sanctuary, to enable cost effective monitoring of this ecologically and socioeconomically important zone.

Within each site, 3 replicate ‘grids’ were surveyed by AUV. Each grid represented 25 x 25 m of seabed and grids were ~50 to 200 m apart (Fig. 3). The AUV performed parallel transects at each grid, to obtain 100% coverage of the seabed (Fig. 3). During the dive, the AUV captured overlapping geo-referenced stereo images of the benthos, as well as bathymetric data at 2 resolutions and physiochemical data (temperature, salinity, light, chlorophyll).

2.3 Post-processing and analysis

The AUV captured over 130,000 benthic images during the survey. Each grid comprised of ~1000 stereo image pairs, which were used to generate ‘meshes’ – composite images of the entire 25 x 25 m grid - of the seabed. These meshes represent a powerful tool for monitoring, amongst other things, kelp patch dynamics and coral cover at relevant spatial scales (Fig. 4). However, due to constraints associated with swell and the physical properties of kelp, the construction of meshes was not possible for all grids; work on meshes is ongoing. For more detailed analysis, individual images, each capturing approximately 1.5 x 1.0 m of seabed, were subsampled from each grid to quantify assemblage structure using image analysis techniques. Subsamples were selected at 20 second intervals from the AUV dive to generate a sample set of 101-129 non-overlapping images that maximised spatial coverage of each grid.

When analysing images 50 random points were digitally overlaid onto each sample, and the number of points covering each benthic grouping was counted. This value was then doubled to give a proxy of percent cover. Benthic groupings included dominant flora, fauna and substratum characteristics and were largely determined a priori based on previous observations and research (Table 2). Care was taken to include conspicuous species of considerable ecological importance, such as the canopy-forming brown algae *Ecklonia radiata* and *Scytothalia dorycarpa*, while maintaining a general, holistic approach to describing the benthos. The benthic groupings were designed so that minimal training and experience would be required to analyse the images, while aiming to retain ecological pattern by including the complete range of biota likely to be sampled. Encrusting organisms were assumed to be living unless obvious discolouration or structural damage was observed. It was evident from the images that the methods were inappropriate for sampling mobile fauna (i.e. echinoids, gastropod molluscs), which generally have low abundances, highly variable distributions and utilise cryptic habitats in Western Australia (Vanderklift & Kendrick 2004). Therefore, mobile invertebrates were excluded from analysis and assemblage composition was derived from dominant macroalgae and sessile invertebrates.

Subsamples were pooled for each grid and analysis was conducted using the three grids per site as true, independent replicates. Assemblage structure at each grid was 'benchmarked' by calculating the percent cover of dominant benthic groupings. Statistical differences in multivariate assemblage structure between depth increments and sites (nested within depths) at each location were tested with PERMANOVA using PRIMER 6 software with the PERMANOVA+ add-on.

3. Preliminary results

The proposed sampling design was achieved with little modification and the AUV proved to be a cost-effective, efficient tool for collecting large quantities of data on benthic habitats. Three replicate grids were surveyed at every site except one, Abrolhos 40-S, where only two grids were completed due to time constraints (Fig. 2). A summary of the surveys is presented in Table 1. A key objective was to sample moderate to high relief reef that can be revisited over time as part of the monitoring process. However, even with recent bathymetry data, some surveys were conducted over sand or sand inundated reef, and will not serve as useful monitoring sites for detecting changes in hard-bottom ecological communities. This was due to a combination of time restraints preventing detailed reconnaissance of potential sites and considerable movement of sand onto previously exposed reef. As such, replacement sites will be surveyed in 2011 to achieve the proposed sampling design. Even so, 14 out of 18 sites surveyed were predominantly hard bottom habitats that have yielded useful information for continued monitoring (Table 1).

The surveys generated a vast amount of data that are currently being processed. With regards to benchmarking benthic assemblage structure at each of the survey sites, 7000 individual images require analysis prior to formal statistical examination of ecological pattern. This process is ongoing and work is also underway at both UWA and USyd to streamline the analysis of these images, to maximise cost-effectiveness. Here we present data from Rottnest, to provide examples of outputs from the AUV surveys and ecological indicators that can be monitored over time at each of the key locations within the WCB.

The kelp *Ecklonia radiata* was the dominant space occupier at all sites and depths at Rottnest Island (Fig. 5), and covered over 50% of the entire seabed surveyed at 3 sites. Although its relative dominance decreased with depth, the areal coverage of *E radiata* exceeded 30% at 40 m depth. Other important components of the benthic assemblage included *Scytothalia dorycarpa*, red foliose algae, turfing algae and encrusting coralline algae. At the deeper sites, the space coverage of sponges and bare rock/sand increased (Fig. 4). An MDS ordination indicated a general shift in assemblage structure along the depth gradient, but with high variability between sites within depths and grids within sites, particularly at 40 m depth (Fig. 6). PERMANOVA detected significant variability between sites (nested with depths) but not between depths (sites: $df = 3$, F = 2.71, $P = 0.001$; depths: $df = 2$, F = 2.51, $P = 0.12$; 999 permutations).

4. Discussion

The surveys described here are the first to be conducted by the IMOS supported AUV system in temperate Western Australia. The AUV represents a very powerful, cost-effective tool for assessing the quantity and quality of benthic habitat for fisheries management, and far exceeds the ability of ‘drop camera’, towed video or diver-operated systems to obtain large amounts of quantitative photographic data of the benthos. Inevitably, as this was the first deployment of the AUV along this stretch of coastline the expedition involved some testing and subsequent recalibration and modification, especially regarding the piloting and retrieval of vehicle in heavy swells. Even so, the proposed sampling plan was completed and a number of sites have been established for long-term monitoring. In summary, the use of the AUV and the survey design it has completed is highly desirable for the following reasons:

1. Each long-term monitoring grid is precisely geo-referenced and can be revisited by pre-programming the flight path of the AUV.
2. Each long-term monitoring grid is surveyed at 100% areal coverage, generating precise ecological information for each 25 x 25 m patch of seabed. The amount of data collected allows small-scale patchiness, which is pronounced in these ecosystems, to be accounted for, thereby facilitating monitoring of community structure at relevant spatial scales.
3. The AUV can collect a vast quantity of physio-chemical data, such as fine resolution bathymetric data, temperature, salinity, chlorophyll *a* and dissolved oxygen. These data will form part of the time series and, when coupled with the ecological information, will improve our understandings of key processes that drive the ecology of these areas.

Data collected from Rottnest Island demonstrated the usefulness of the AUV and facilitated quantitative ‘benchmarking’ of benthic assemblages at each of the established monitoring sites. As has been shown previously with a ‘drop camera’ system, rocky reefs are dominated by *Ecklonia radiata*, which decreases in abundance along a depth gradient and consequently drives depth-related changes in overall assemblage structure (Smale et al. 2010a). Even so, the kelp was the dominant space occupier at 40 m depth, which indicates both the clarity of the overlying water column and the importance of this species in nearshore benthic habitats. Crucially, the collection of a large number of subsamples (i.e. >100) generated realistic and precise estimates of the percent cover of all taxonomic groups, which can be tracked over time to provide powerful tests of ecological change.

For long-term monitoring, previous work as part of the WAMSI process has suggested key ‘indicators’ that should be quantified over time to provide a cost-effective, powerful, ecologically-relevant assessment of the quality and extent of benthic habitats (Smale 2010, Smale et al. 2010b, Smale et al. 2011). These indicators include the areal extent of the canopy-forming macroalgae *Ecklonia radiata* and *Scytothalia dorycarpa*, and relative dominance of coral vs. kelp, the areal extent of bare rock or sand, and a measure of multivariate assemblage composition, as multivariate indicators are generally more sensitive to ecologically relevant change (Anderson & Thompson

2004). These indicators were quantified at Rottnest and will be repeat-sampled in 2011 to examine short-term variability and commence the time series.

5. Data management/storage

All data (i.e. images, meshes, physical data, and processed ecological outputs) is being transferred to IVEC for long term management and storage. In addition, copies of all AUV captured data are held at UWA, USyd (ACFR) and CSIRO. As part of commitments to IMOS, ACFR will make all data accessible to potential end users.

6. Expenditure

The costs associated with the use of the AUV and the team of technicians, plus transportation of equipment and pax, were covered by the IMOS AUV Facility. The total contribution from this WAMSI project was ~$80K and is outlined in Table 2.

7. Further research

Additional AUV surveys are scheduled for early April 2011. The priorities for this sampling effort will include:

1. Establish long-term monitoring grids over moderate/high relief rocky reef at Jurien and Abrolhos to replace 'sandy grids' sampled in 2010, where necessary.
2. Survey benthic habitat structure in the newly established WRL protection zone (offshore Jurien), and establish sites for long-term monitoring.
3. Resurvey established grids at Rottnest, Jurien and Abrolhos, to examine temporal variability in ecological structure and assess the practicalities of relocating and resurveying grids.

Concurrently, work is underway at both UWA and USyd to streamline analysis of benthic images to maximise cost-effectiveness and data outputs.

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Table 1. Summary of the surveys conducted by AUV during the 2010 sampling program. Information is provided on: the positions of the grids established within each site; the dominant habitat type within each grid; and whether the grids will be maintained as part of the long term monitoring process (LTM).

Location	Site	Depth	Grid locations	Habitat type	Survey date	LTM?
Rottnest	40-S	40	-32.0211269,115.4260693	Rocky reef	20/04/2010	Y
			-32.0202124, 115.4260707	Rocky reef	20/04/2010	Y
			-32.021185, 115.4250087	Rocky reef	20/04/2010	Y
	40-N	40	-32.0147124, 115.4208430	Rocky reef	20/04/2010	Y
			-32.0140406,115.4210439	Rocky reef	20/04/2010	Y
			-32.0142224,115.420664	Rocky reef	22/04/2010	Y
	25-S	25	-32.0347219,115.4602123	Rocky reef	21/04/2010	Y
			-32.0342915,115.4598798	Rocky reef	21/04/2010	Y
			-32.0338628,115.4596402	Rocky reef	21/04/2010	Y
	25-N	25	-32.0205415,115.4410099	Rocky reef	21/04/2010	Y
			-32.0201883,115.440210	Rocky reef	21/04/2010	Y
			-32.0210097,115.4402445	Rocky reef	23/04/2010	Y
	15-S	15	-32.0167782,115.4428551	Rocky reef	22/04/2010	Y
			-32.0161451,115.4427011	Rocky reef	22/04/2010	Y
			-32.0164177,115.4423385	Rocky reef	22/04/2010	Y
	15-N	15	-32.0120746,115.4463358	Rocky reef	22/04/2010	Y
			-32.0116841,115.4462	Rocky reef	22/04/2010	Y
			-32.012816,115.4458481	Rocky reef	22/04/2010	Y
Jurien	40-S	45	-30.401135,114.7943072	Low relief reef	24/04/2010	Y
			-30.4005648,114.7932622	Low relief reef	24/04/2010	Y
			-30.3999823,114.792147	Low relief reef	24/04/2010	Y
	40-N	45	-30.3268263,114.78594	Low relief reef	24/04/2010	Y
			-30.3262439,114.7848609	Low relief reef	24/04/2010	Y
			-30.3256448,114.7839172	Low relief reef	24/04/2010	Y
	25-N	25	-30.3759799,114.9764375	Low relief reef	26/04/2010	Y
			-30.3757098,114.974586	Low relief reef	26/04/2010	Y
			-30.3753188,114.9752409	Low relief reef	26/04/2010	Y
	25-S	25	-30.4118882,114.9741209	Sand/rubble	25/04/2010	N
			-30.4111681,114.9746032	Sand/rubble	25/04/2010	N
			-30.4108463,114.9739348	Sand/rubble	25/04/2010	N
	15-N	15	-30.382269,114.9819994	Low relief reef	26/04/2010	Y
			-30.3815912,114.98148	Low relief reef	26/04/2010	Y
			-30.3807125,114.9820004	Low relief reef	26/04/2010	Y
	15-S	15	-30.411294,114.9786709	Sand/rubble	25/04/2010	N
			-30.4106898,114.9786709	Sand/rubble	25/04/2010	N
			-30.4102807,114.9777126	Sand/rubble	25/04/2010	N
Abrolhos	40-N	35	-28.7735452,113.9756591	Sand	29/04/2010	N
			-28.7719627,113.9743337	Sand	29/04/2010	N
			-28.770566,113.9732757	Sand	29/04/2010	N
	40-S	40	-28.8470808,114.047038	Low relief reef	30/04/2010	Y
			-28.8470808,114.0440973	Low relief reef	30/04/2010	Y
	25- N	30	-28.8587862,114.0313237	Low relief reef	29/04/2010	Y
			-28.8585184,114.0320682	Low relief reef	29/04/2010	Y
			-28.8576477,114.0326162	Low relief reef	29/04/2010	Y
	25-S	25	-28.8072503,113.9611601	Low relief reef	28/04/2010	Y
			-28.8070308,113.9620181	Sand	28/04/2010	N
			-28.8066213,113.9598663	Sand	28/04/2010	N
	15-N	15	-28.8485482,114.0278472	Rocky/coral reef	29/04/2010	Y
			-28.8476021,114.0283862	Rocky/coral reef	29/04/2010	Y
			-28.8467275,114.028891	Rocky/coral reef	29/04/2010	Y
	15-S	15	-28.8140192,113.9468588	Rocky/coral reef	28/04/2010	Y
			-28.8136589,113.9472558	Rocky/coral reef	28/04/2010	Y
			-28.8131696,113.946747	Rocky/coral reef	28/04/2010	Y

Table 2. Expenditure associated with AUV sampling programme, as covered by WAMSI. Costs associated with transport and operation of the AUV and the team of technicians from ACFR were covered through IMOS.

Item	**Cost (AUD)**
Accommodation	4500
Consumables	6000
Travel	1200
RV Linnaeus	41000
Image analysis	28000
TOTAL	80700

Figures

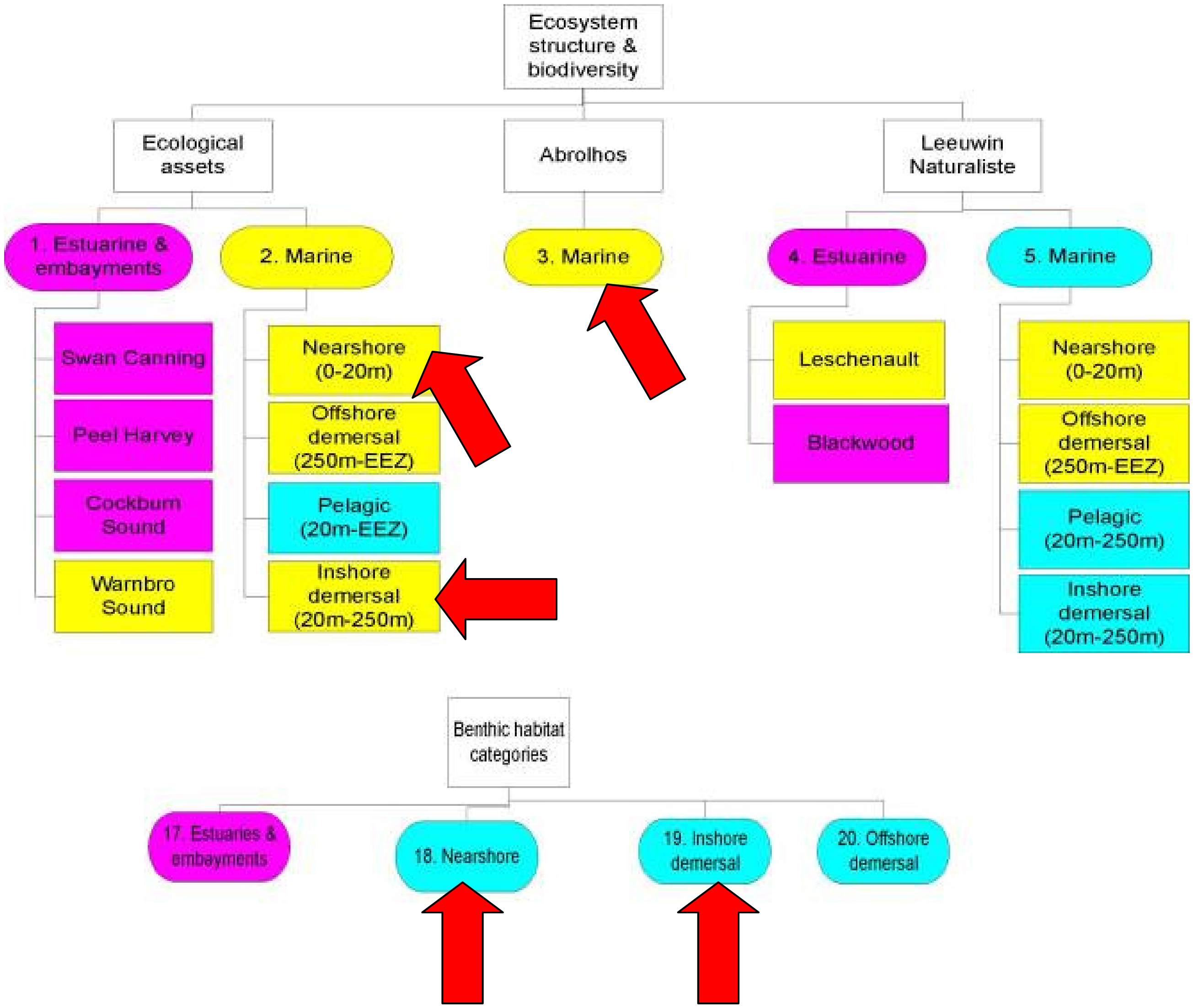

Fig. 1. Assets within the West Coast Bioregion component trees that can be assessed and monitored with AUV surveys.

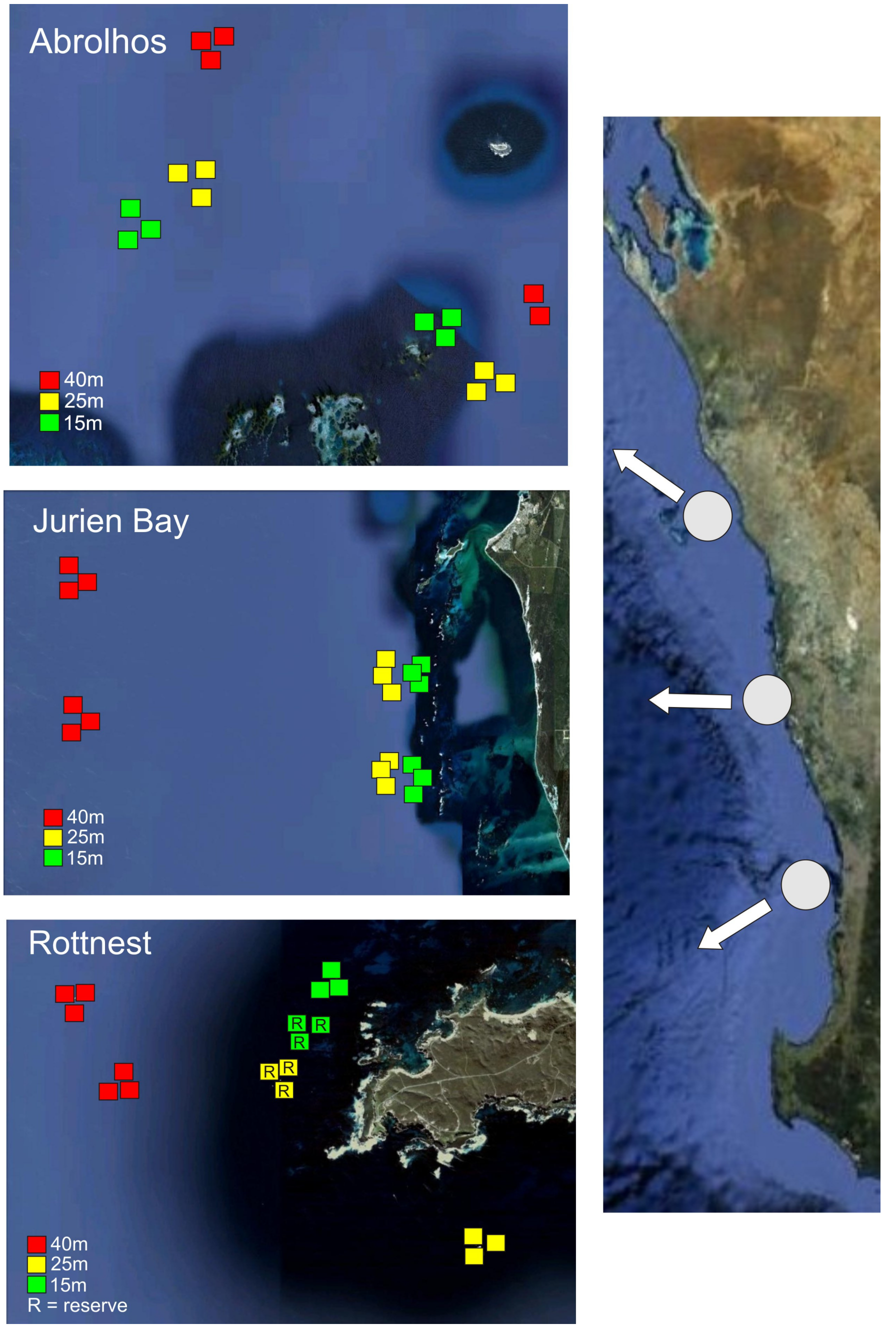

Fig. 2. Locations and sites sampled by AUV during the 2010 cruise. Satellite map on the right indicates the locations of Rottnest, Jurien and Abrolhos along WA coastline. Expanded maps on the left indicate approximate position of each survey grid at each location. Three replicate grids were surveyed at each site (except for Abrolhos ‘deep 2’) and sites were selected along a depth gradient at each location (defined by colour in the figure). At Rottnest, sites were selected inside and outside the Kingston Reef sanctuary zone (sites inside sanctuary denoted with ‘R’).

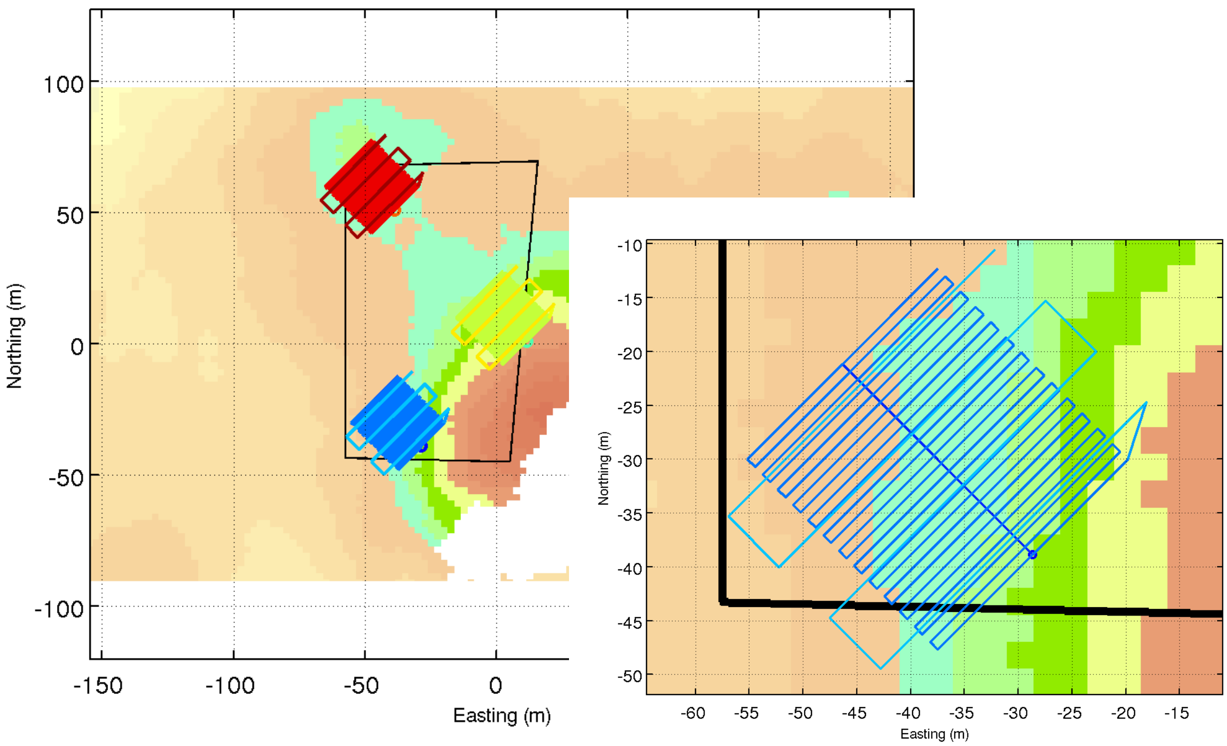

Fig. 3. Representative mission plan for a single site, which was completed within one 2-3 hour AUV dive. Triplicate 25 x 25 m grids over predicted rocky reef were surveyed within each site (left). Inset (right) shows AUV flight path during survey of a single grid.

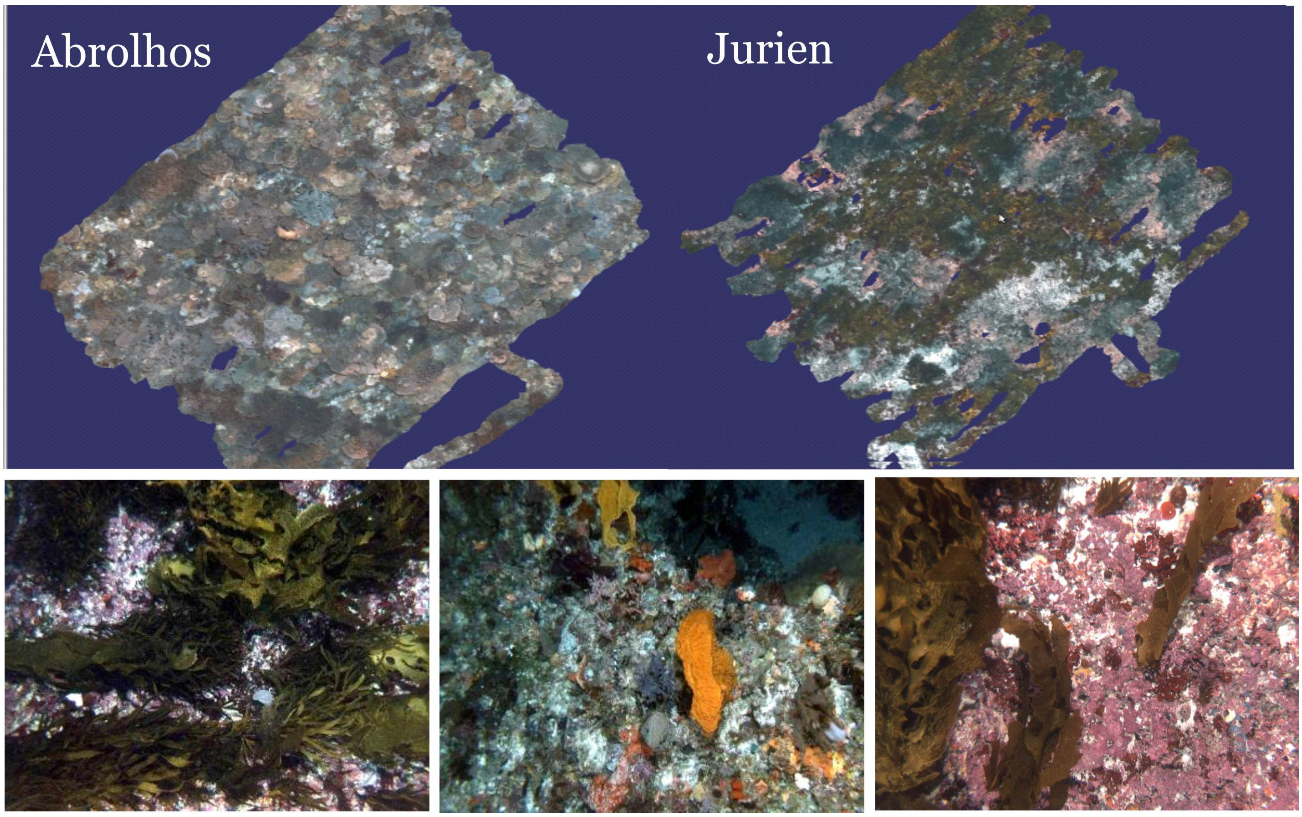

Fig. 4. Representative meshes of 25 x 25 m grid sampled at Abrolhos and Jurien, showing coral and kelp dominated benthos (top). Individual images (below) provide examples of samples dominated by kelp, benthic invertebrates and bare rock/encrusting coralline algae.

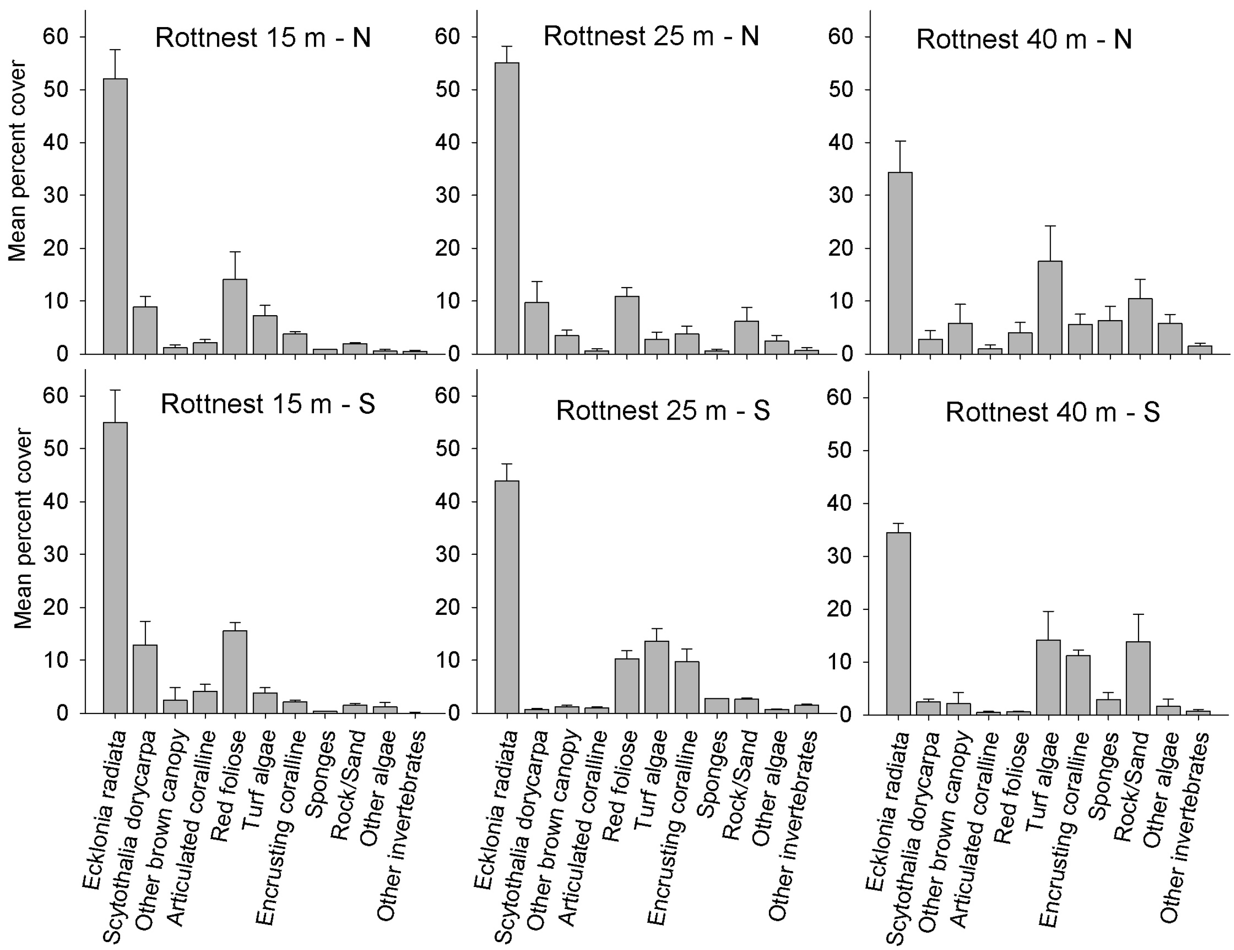

Fig. 5. Mean percent cover (± S.E.M.) of benthic categories at each of the established LTM sites at Rottnest Island, WA. Cover estimates are means of 3 replicate 25 x 25 m grids within each site. Each grid comprised of >100 subsampled images that were selected for analysis.

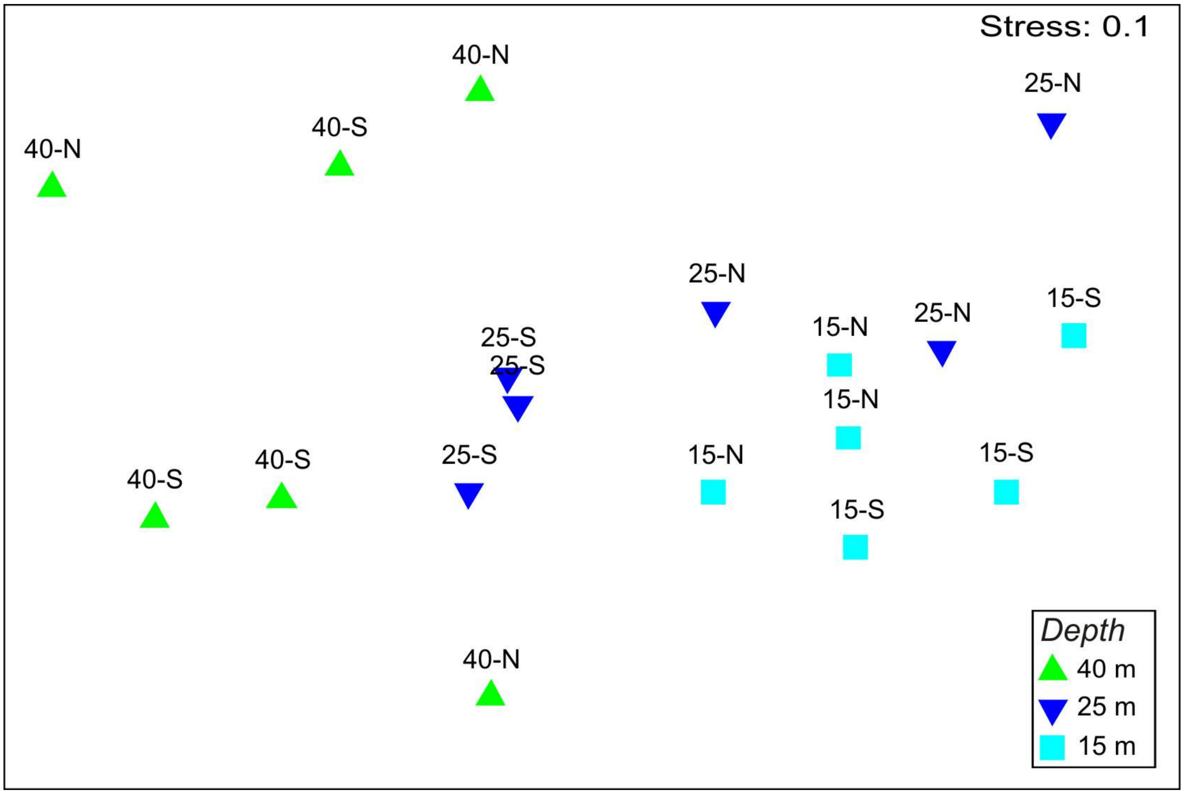

Fig. 6. MDS ordination, based on a Bray-Curtis similarity matrix generated from square-root transformed percent cover data, to indicate assemblage structure at each of the establish monitoring sites at Rottnest Island, WA. Each centroid represents one of three 25 x 25 m grids sampled per site. Sites were selected along a depth gradient, with 2 replicate sites surveyed per depth.