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Seascapes for the Australian Margin and Adjacent Seabed

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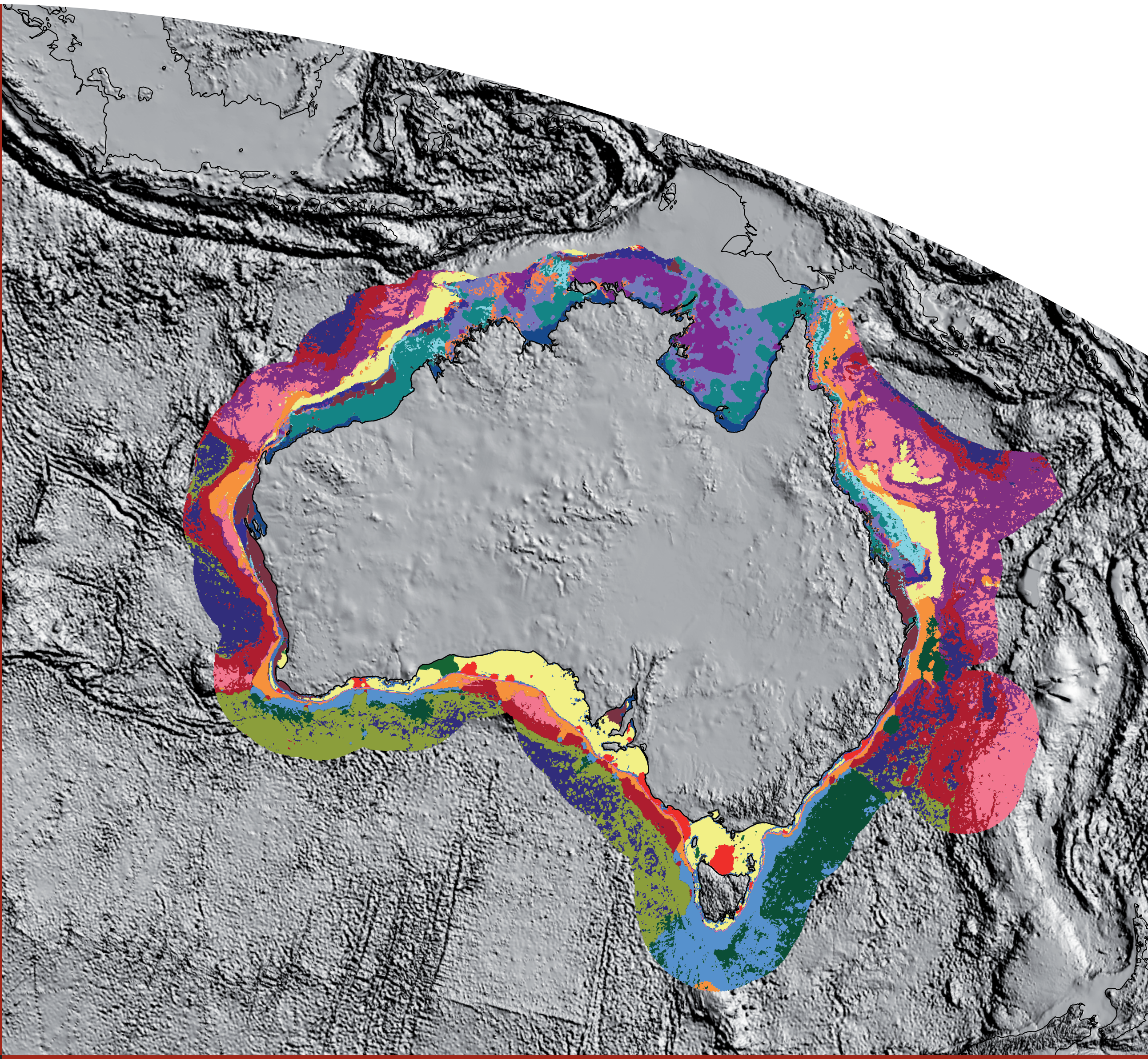

APPLYING GEOSCIENCE TO AUSTRALIA'S MOST IMPORTANT CHALLENGES

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Executive Summary

Seascapes describing a layer of ecologically-meaningful biophysical variables that spatially represent potential seabed habitats have been derived for the Australian margin and adjacent seabed in a new analysis of existing biophysical data. Seascapes were derived separately for the shelf and off-shelf regions due to different data availability. A total of 13 and nine seascapes were derived for the on-shelf and off-shelf regions, respectively, using the unsupervised ISOclass classification in the software package ERMapper. The on-shelf seascapes divide into two broad latitudinal groups. The southern group (seascapes 1–7) is characterised by sandy, cooler environments relative to the northern group (seascapes 9–13) which is characterised by muddier, warmer environments. Seascape 8 occurs predominantly on the west and east margins, separating the two groups. Off-shelf seascapes lack a distinct latitudinal pattern and their distribution is more related to seabed temperature as a function of depth. For the deep-sea regions on the southern and western margins the seascapes are principally defined by rugosity and primary production. For other areas off-shelf seascape distribution is more complex and related to bathymetry and slope (rugosity).

Evaluating the seascapes using existing biological data at the national, regional and local scale provides insights into their ecological significance. At the national scale, the seascapes capture the tropical-temperature contrasts and the less distinct east-west differences in biodiversity. The seascapes contribute to explanatory ability in some limited conditions—generally in the more heterogeneous environments of the northern on-shelf provinces. Beyond this, the seascapes are limited to explaining minor differences in biological assemblage structure, which the data show is driven largely by differences in broad-scale seabed substrate types. Overall, the seascapes capture physical characteristics of the environment very well but are simplistic predictors of national-scale biological assemblages for all taxa analysed.

Regional-scale assessments show that for the very spatially heterogenous Great Barrier Reef (GBR) shelf, seascapes are not strong predictors of biodiversity, with generally <50% prediction success. This low prediction success is based on: 1) multiple seascapes describing the same habitat type and assemblage resulting in misclassifications; 2) a single seascape encompassing multiple habitats and assemblages also found in other seascapes, and were therefore not biologically distinct to that seascape; and 3) the relatively coarse seascape classification resolution was not sufficient to capture the inherent spatial variability within this region. By contrast, the area examined for the Great Australian Bight (GAB) was characterised by homogenous soft-sediments across the shelf and a strong depth gradient. The benthic invertebrate assemblages exhibited a strong depth gradient which was meaningful but weakly correlated with seascape classifications. Strongest and most significant correlations came from a combination of depth, percent mud, and seabed temperature.

At the local scale, integration of biological data may produce seascapes that more accurately reflect shelf geomorphology. No single environmental variable used in the derivation of the local seascapes was significantly correlated with the biological data, rather a combination of depth, percent mud, primary production, and effective disturbance together largely explain the biodiversity patterns. Furthermore, integration of biological data into local seascape derivations also produces focal variety analyses that are more representative of the biodiversity in the broader region. When applied to the regional scale, relationships between seascapes, biodiversity, and geomorphology are more complex, and

the addition of biological data produces seascapes that only slightly better matched the boundaries of other geomorphic features.

Reducing the taxonomic resolution and applying functional groups decreases the ability of seascapes to differentiate between biological assemblages, a finding that supports previous research. Although integration of both biological and physical data provides a holistic approach, in which both biological and physical factors are of intrinsic interest, this is probably limited for features where the biological assemblages are very distinct compared to the surrounding region.

In the existing seascapes model physical variables were included where there was continuous data, at a national scale. The assessment of the seascapes model against biological data identified several areas for improvement. Although the process of deriving seascapes requires an iterative approach, future derivations should include updated layers of the biophysical data, including: effective disturbance, primary productivity, seabed substrate type, and nutrient fluxes, and differential weighting of abiotic variables that account for interactions between them. Presently, soft-sediment information is available across Australia's margin. In contrast, knowledge of the location and extent of hard-grounds (i.e. outcrops of rock, etc.) around Australia is patchy. The absence of data on hard and soft seabed types was a major impediment to correctly classifying marine assemblages, particularly in areas comprising complex seabed features (e.g. GBR, Northwest Shelf). The inclusion therefore of a hard/soft layer would greatly improve the explanatory power of the seascapes. Advances in interpolation methods using multiple datasets (e.g. co-kriging sediment maps using measures of bed stress) may enhance the ability to predict the location of hard and soft grounds. Similarly, advances in national and regional scale interpolation methods, such as the national sediment data, will also improve the application of physical datasets for predicting Australia's marine biodiversity. As many biological organisms respond to physical gradients in a non-linear way, future seascapes models would be enhanced by incorporating thresholds that reflect known bio-physical boundaries. Trialling alternative models that incorporating the spatial distribution of biological data along with applying a classification model that reflects the processes driving biodiversity patterns would likely improve the predictive ability of the seascapes. Nevertheless, improvements based on these approaches will be limited without development of a comprehensive, robust and consistent national-scale biological dataset for evaluation.

Abiotic variables used to derive Australia's national seascapes and linked to predicting biological assemblages in the present study are the same as those identified in surrogacy studies. The existing seascapes represent a first step in modelling Australia's benthic marine biodiversity. Despite the short-comings in the present seascape derivation, we are still faced with the significant challenge of representing Australia's national benthic marine biodiversity within a reduced dimension for resource management purposes. Establishing a complete (or even comprehensive or representative) inventory of Australia's *actual* marine biodiversity is not possible. Modelling Australia's marine biodiversity through a seascapes approach is a realistically effective and practicable alternative.

1. Seascape Models

1.1. INTRODUCTION

One of the biggest challenges facing marine scientists is the development of a robust and defensible way to represent seabed habitats and ecosystems based on easily mapped and spatially-abundant biophysical properties. Over recent years, Geoscience Australia has undertaken a program of research to develop nationally consistent biophysical datasets to create seabed habitat maps or 'seascapes' for Australia's marine region (Harris, 2007; Harris et al., 2007; 2008). Seascapes describe a layer of ecologically-meaningful biophysical properties that spatially represent potential seabed habitats (Fig. 1.1). Each seascape corresponds to a region of seabed that contains similar biophysical properties and, by association, similar seabed habitats and biological assemblages. Maximum seabed biodiversity is likely to coincide with maximum seabed habitat heterogeneity, which is assumed to be in regions of maximum seascape diversity. The approach for creating the seascapes is inspired by the hierarchical shelf classification applied in eastern Canada by Roff and Taylor (2000) and Roff *et al.* (2003), and has previously been adapted by Geoscience Australia for parts of Australia's marine region (Whiteway *et al.*, 2007).

Hierarchical classification schemes have the intrinsic predictive power of describing the relationships between physical habitats and their associated biological assemblages. Roff and Taylor (2000) suggest that a hierarchical classification scheme is essential for the selection of representative or distinctive habitats. This has prompted the development of a number of different classification schemes and recognition that marine regions can be divided into broad hierarchical units. In Australia, Butler *et al.* (2002) devised a nested, hierarchical, benthic classification scheme of which the four highest levels are relevant to the present discussion:

<u>Level 1 Provinces</u> Broad-scale biogeographic units. Evolutionary biogeography is the key process at this level as reflected by the presence of regions of endemism. Provinces are typically of the order of ~1,000 km in extent.

<u>Level 2 Biomes</u> Comprised of neritic and oceanic zones divided by the continental shelf break. The neritic zone has three primary benthic biomes (estuarine, coastal marine, and shelf) whereas the oceanic zone consists of two primary benthic biomes (continental slope and abyssal). Sub-biomes may also be recognised based on distinct variations in the composition of biota. Biomes are nested within provincial units and are typically several 100s of km or more in extent.

<u>Level 3 Geomorphological Units</u> Areas characterised by similar geomorphology. These may include (on the continental shelf) fields of sand-waves, rocky outcrops, incised valleys, flat muddy seabeds, etc., and (on the slope and at abyssal depths) submarine canyons, seamounts, oceanic ridges and troughs, etc. Such units may typically be about 100 km in extent.

<u>Level 4 Biotopes</u> Defined on the bases of substrate type (rocky, sediment-covered or a mixture), with associated suites/collections of floral and faunal communities, modified by hydrological variables such as wave exposure, turbidity, and current speed. Biotopes are typically from one to several 10s of km in extent.

Other equally valid terms may be used in place of these, and there is any number of possible different divisions in the hierarchy. However, the above hierarchical scheme can be used to guide the derivation of the seascapes for Australia's margin and adjacent deep seabed.

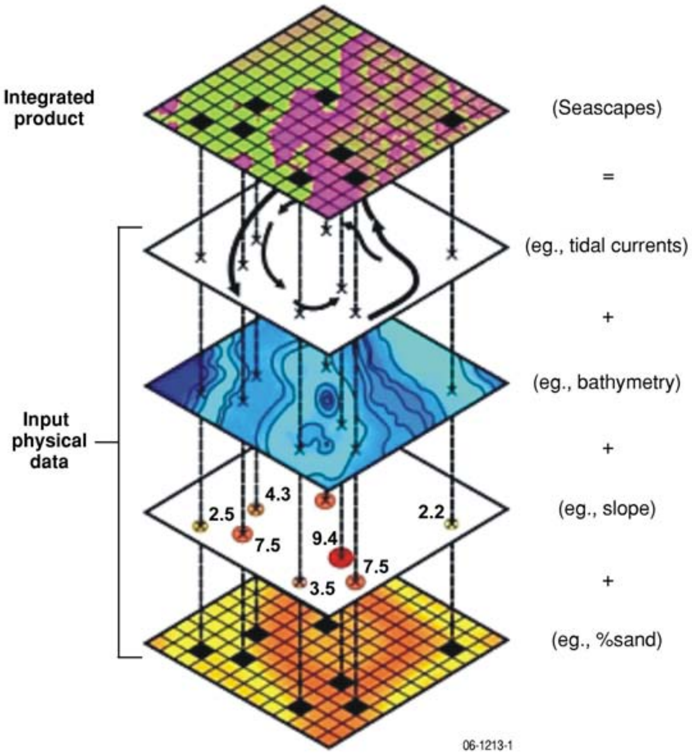


Figure 1.1. Schematic diagram showing derivation of seascapes from multiple spatial layers of biophysical data. The seascapes represent the integrated product of the individual datasets.

1.2. DATASETS AND THEIR ECOLOGICAL SIGNIFICANCE

The assumption that biophysical properties can be used as surrogates to represent marine biodiversity is central to the seascapes approach. While linkages between the biophysical environment and biota seem intuitive, understanding how the biota relates to biophysical physical properties is only half the story. It is equally important to identify which biophysical properties are important. Biophysical variables that are most suited to deriving seascapes are those that are easily quantified, have a wide distribution, and a known and measurable association with the biota (Post, 2008; Bax & Williams, 2001). Given the availability and distribution of common datasets for Australia's marine region, separate seascapes were derived for the shelf (on-shelf) and slope, rise and abyssal plain/deep ocean floor (off-shelf) environments due to an extra dataset being available for the shelf (Table 1.1). Sediment data were interpolated from 12,506 samples collected across the margin. Final datasets were gridded at 0.05° (~5 km) resolution to provide 100% coverage of the seabed. Images of the input data are contained in Appendix A.

The biophysical parameters included in deriving the seascapes are known to exert control on (or be a surrogate for) the occurrence of species. Water depth (i.e., vertical distance from the sea surface), for example, is correlated with temperature, pressure, light availability and food supply and therefore exerts a first order control over the occurrence of species in the oceans (Grassle & Maciolek, 1992; Etter & Grassle, 1992). However, water depth is in fact an indirect surrogate for the distribution of benthic species in the context of Austin (2002) because depth itself has no direct physiological impact on benthic organisms. Rather, it is the effects of correlated parameters (temperature, pressure, calcium carbonate solubility and food supply) that exert control. We employ water depth as a surrogate because it is a value that is commonly measured and the existing Australian bathymetry database for depth contains far more data points than any other single parameter. The Australian 250 m

Table 1.1. Datasets used in the derivation of the seascapes.

Dataset	Units
On-shelf	
Water depth	(m)
Seabed Temperature	(°C)
% Gravel	(weight %)
% Mud	(weight %)
Primary Production	(mg C m^{-2} day^{-1})
Slope	(°)
Effective disturbance	(dimensionless)
Off-shelf	
Water depth	(m)
Seabed Temperature	(°C)
% Gravel	(weight %)
% Mud	(weight %)
Primary Production	(mg C m^{-2} day^{-1})
Slope	(°)

bathymetry grid used in this analysis was created from survey, satellite and digitised data by Geoscience Australia (Webster & Petkovic, 2005). The seabed slope was derived from this grid using the slope algorithm in ARC GIS.

A fundamental parameter that controls benthic ecosystems is food supply, represented in our seascapes model by primary production in surface waters. The primary productivity dataset used here was created by CSIRO in 2004 and is based on analysed satellite imagery. In some locations having extreme tidal range, such as the Kimberly coast, Joseph Bonaparte Gulf and Torres Strait, this dataset incorrectly classifies turbid waters as high productivity areas. This artefact captures differences in the coastal zone due to high turbidity which affects some seascapes but the label of "high productivity" for such seascapes is not correct (discussed later in the text).

The temperature of bottom water also exerts a direct control over the distribution of benthic animals; most benthic animals are confined to live within a specific temperature range and metabolic rates are lower with decreasing temperature (Levin *et al.*, 2001; Snelgrove, 1999). Bottom-water temperature (DEH, 2005) varies with latitude as well as depth, and this is important in distinguishing warmer northern from the cooler southern seascapes.

Several studies have demonstrated that the shear stress imparted on the bed by waves and currents has a role in determining which particular species are present (e.g., Warwick & Uncles, 1980; Long *et al.*, 1997). In order to represent both intensity and frequency of disturbance in a shelf classification, Hemer (2006) examined the "exposure" of the Australian continental shelf to combined waves and currents (including intruding ocean currents). Three methods were investigated and Hemer (2006) concluded that an approach using spectral analysis is the best choice for characterising oceanographic exposure on benthic habitats, because it showed the strongest relationship to available sediment data (and benthic habitats are likely to respond to magnitude and frequency of exposure in a similar manner to sediments). In the spectral regionalisation, an analysis was carried out on the combined flow bed shear stress (u and v components) for each cell in a fixed 0.1 degree grid, using an 8-year time-series of surface waves, tides and ocean currents derived from calibrated models, to determine the energy-frequency distribution. The effective disturbance parameter does not apply to water depths of <20 m due to the large errors that are produced in the modelling as waves shoal onto the coast. These wave transformations have not been accounted for in the modelling of effective disturbance and thus the on-shelf seascapes do not extend to <20 m water depth.

Previous studies have detailed the significance of the relationship between habitat and substrate sediment type (e.g., Greene *et al*., 1995; Auster & Langdon, 1999; Pitcher *et al*., 2002; Post et al., 2006). These studies show that substrate type influences the occurrence of benthic organisms. Geoscience Australia's marine sediment database (MARS: http://www.ga.gov.au/oracle/mars/index.jsp) provides key information on sediment types, specifically percentage mud and gravel, used in the present seascapes analysis.

1.3. CLASSIFICATION METHODOLOGY

Below is a summary of the classification methodology used by Geoscience Australia for the new analysis undertaken here to derive the national seascapes. A full description of the methodology adopted is presented in Whiteway *et al*. (2007).

1.3.1. Unsupervised Classification

The seascapes were classified using the Iterative Self Organising Classification (ISOclass) methodology in the computer software package ERMapper. This methodology is an unsupervised crisp classification meaning that the classification is run without any user input to help define the classes and each data point can only belong to one class.

There are several solutions to finding the final classification and selecting the optimal number of classes and location of the best class boundaries is essential. Statistically, there will be an optimal number of classes into which the data can be divided that will minimise the uncertainty.

For the purposes of deriving the seascapes for Australia's marine region, the optimal number of classes (i.e., seascapes) was identified using the distance ratio method. The distance ratio is the ratio of the average of the mean distance of each class member from its class mean to the overall average distance of each member from the overall mean. The distance ratio gives an indication of how good the classification is, in that the smaller the value, the closer on average the individual class members are to their class means. For the purposes of deriving the optimum number of seascapes for Australia's marine region, a plot of distance ratio versus number of classes was calculated for a range of 3 to 20 classes.

The optimal number of seascapes was determined from the distance ratio graph as a local minimum; usually taken as the first local minimum before the overall gradient of the graph begins to decrease (Figs. 1.2 & 1.3).

1.3.2. Seascape Names

The seascapes are named with reference to the hierarchical scheme outlined in section 1.1. At the scale of provinces and biomes, water depth is the most important variable. A plot of the mean and standard deviation values of water depth allow each of the seascapes to be ranked in order of increasing water depth (Figs. 1.4 & 1.5). At the scale of geomorphic features, correlation of the seascapes with the geomorphic features map of Australia's margin (Heap & Harris, 2008) provides an independent check on seascape character and spatial extent. After depth, the seascapes are named using geomorphic features that comprise >25% of the area of each of the seascapes, except for on-shelf seascapes 2 and 8, where the feature with the highest percent area covered is used (Table 1.2). Finally the seascapes can be ranked

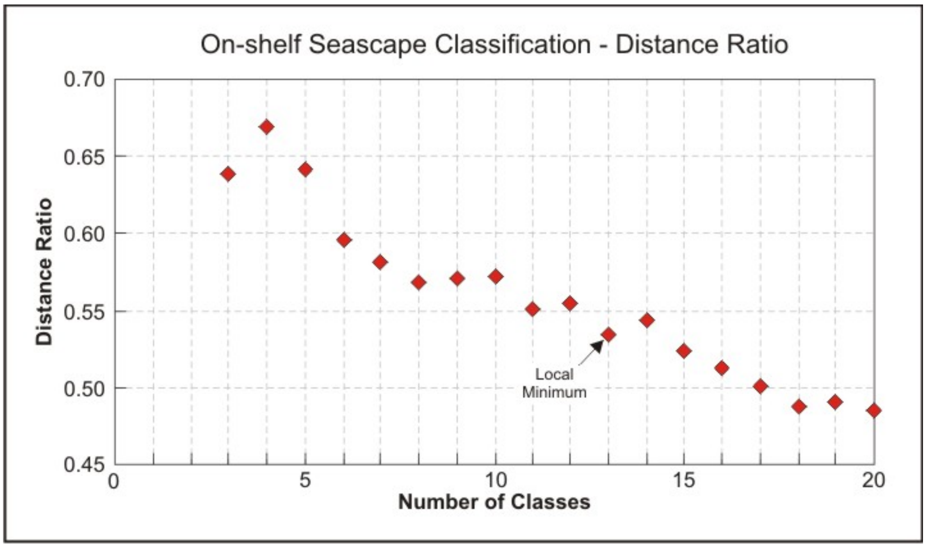


Figure 1.2. Distance ratio graph for the on-shelf classification. A total of 13 seascapes were defined for the on-shelf region based on the "local minimum" of the series. This minimum was also chosen because it provides for an ecologically-meaningful classification and has the greatest difference between adjacent class solutions.

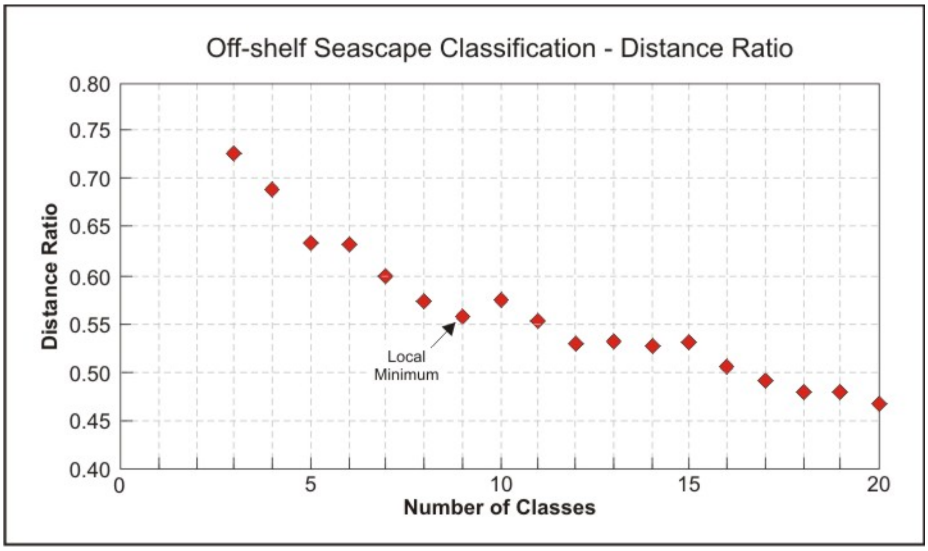


Figure 1.3. Distance ratio graph for the off-shelf classification. A total of nine seascapes were defined for the off-shelf region based on the "local minimum" of the series. This minimum was also chosen because it provides for an ecologically-meaningful solution and represents the point where the gradient of the graph diminishes and increasing the number of seascapes results in relatively small decreases in the distance ratio.

using the mean values of the remaining physical properties. Where a seascape is ranked in the top or lowest three of the mean values for any of the physical properties then that property is included as a descriptor for the seascape (Table 1.2).

1.4. SEASCAPES FOR THE AUSTRALIAN MARGIN

A total of 13 and nine ecologically-meaningful seascape classes were derived for the on-shelf and off-shelf regions of the Australian margin, respectively (Figs. 1.6 & 1.7; Table 1.3). The seascapes are most strongly delineated by variations in seabed sedimentology, slope, and temperature.

1.4.1. On-shelf Seascapes

At a continental scale, several trends are apparent in the occurrence and distribution of the on-shelf seascapes. Firstly, seascapes divide into two broad latitudinal groups (Fig. 1.6). The

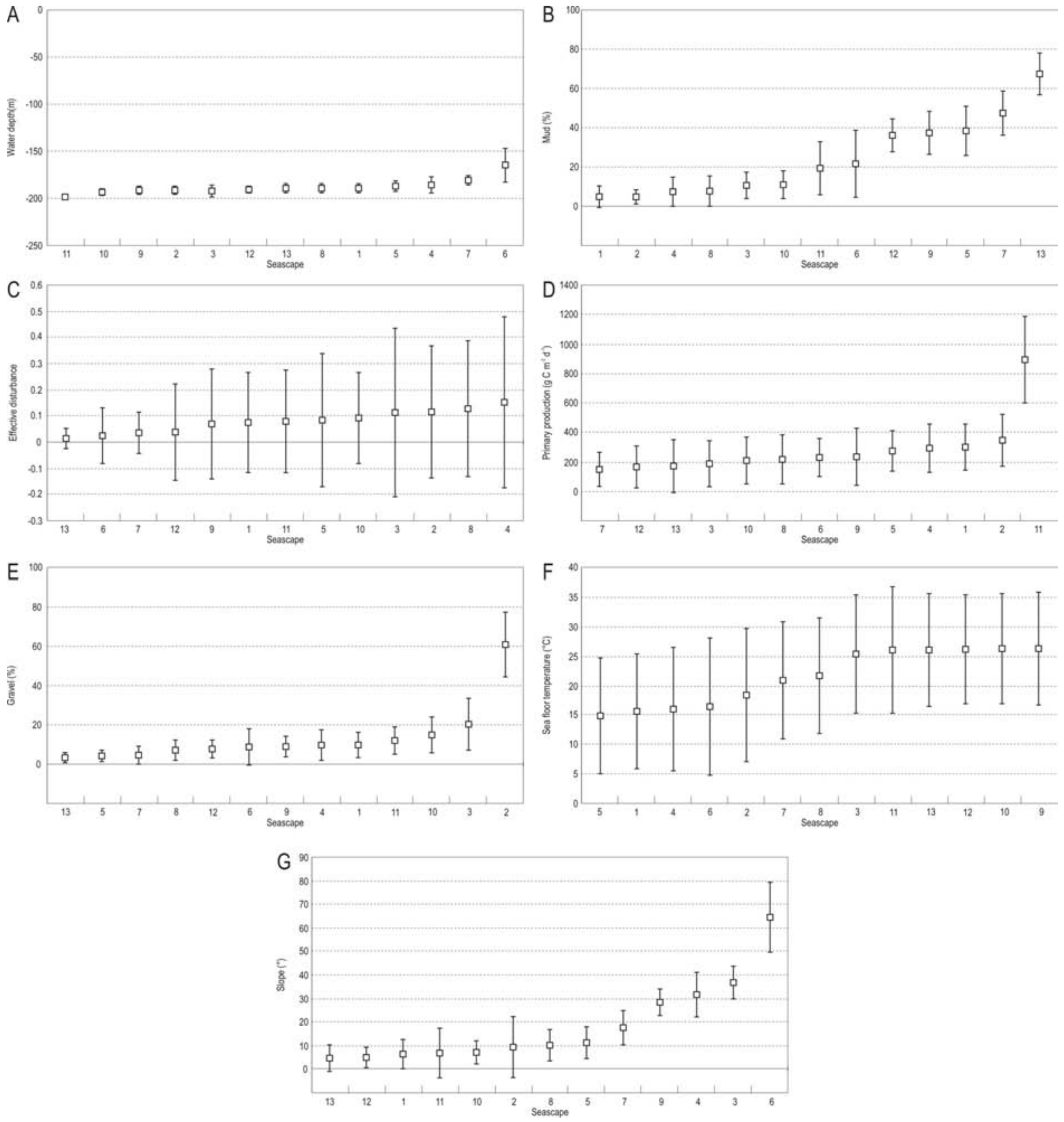


Figure 1.4. Graphs of on-shelf seascape versus: (A) water depth; (B) mud content; (C) effective disturbance; (D) primary production; (E) gravel content; (F) sea floor temperature; and (G) slope. Physical properties with the three highest and lowest mean values are used as distinguishing properties in naming each of the seascapes. Plots show means and limits of one standard deviation.

southern group (seascapes 1–7) is characterised by generally sandy, cooler environments relative to the northern group (seascapes 9–13) which is characterised by muddier, warmer environments and shallower water. Interestingly, seascapes dominated by gravel occur only on the southern margin. Additionally, the overall distribution of seascapes appears to be more diverse and variable for the northern seascape group, with significant heterogeneity over many parts of the shelf, particularly the central and northern Great Barrier Reef shelf and the outer Arafura and Sahul Shelves. Conversely, the distribution of seascapes in the southern group is more uniform with each of the seascapes covering a relatively large area of the shelf. Further work is required to determine if this difference in variability is a true reflection of the seascape distribution or merely a function of data density. Data from >6,500 samples were available for analysis for the northern margins compared with <4,000 for the southern regions.

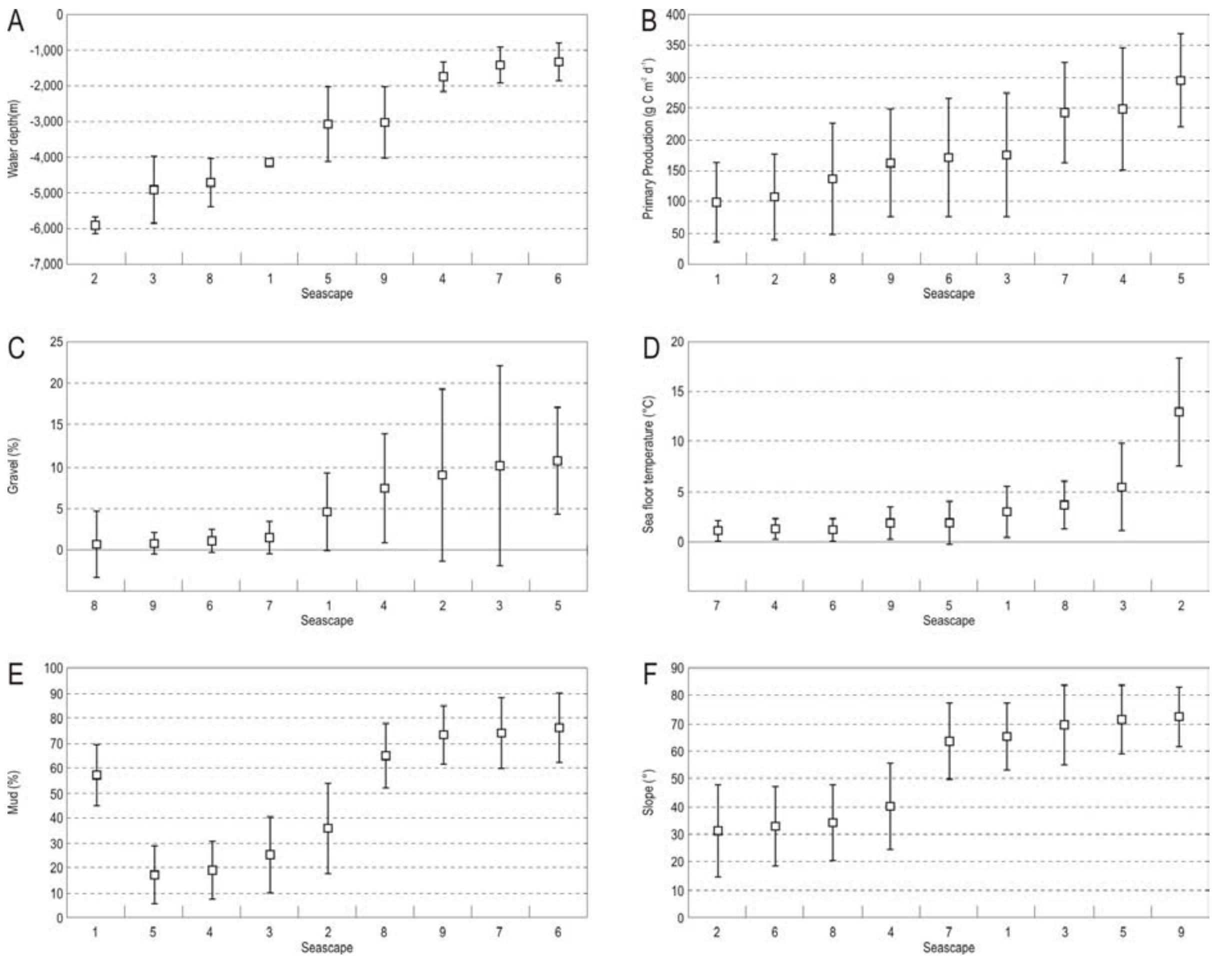


Figure 1.5. Graphs of off-shelf seascape versus: (A) water depth; (B) primary production; (C) gravel content; (D) sea floor temperature; (E) mud content; and (F) slope. Physical properties with the three highest and lowest mean values are used as distinguishing properties in naming each of the seascapes. Plots show means and limits of one standard deviation.

On-shelf environments characterising the relatively flat and muddy shallow shelf basins of the Gulf of Carpentaria, Joseph Bonaparte Gulf, Gulf of Carpentaria and Bass Strait are captured by seascapes 13 and 5, respectively. Seascape 8 occurs predominantly on the west and east margins and may represent a transitional environment between temperate and sub-tropical and tropical environments on each margin. Seascape 11 occurs on the inner shelf, principally in the north, and is characterised by very high primary production (Fig. 1.6). This appears to be an anomaly, as this zone is a region of elevated turbidity caused by river runoff, strong tidal and wave currents. This seascape, although correctly identified as a different region, is most likely to be a zone of high turbidity and possibly lower primary productivity due to reduced light penetration to the bed.

1.4.2. Off-shelf Seascapes

Off the shelf, the distribution of seascapes lacks a distinct latitudinal pattern seen in the on-shelf seascapes and is more related to sea floor temperature as a function of depth (Fig. 1.7). The seascapes are associated with a general decrease in grain size with depth and distance offshore. For the mid- to lower-slope, abyssal plain and deep ocean floor environments on the southern and western margins, seascapes are principally defined by slope and primary production. For other areas, seascape distribution is more complex, with bathymetry and slope emerging as key descriptors.

Table 1.2. Percentage of geomorphic feature (from Heap & Harris, 2008) comprising the total area each of: a) on-shelf and b) off-shelf seascapes for the Australian margin. Highlighted cells identify the geomorphic features used to characterise each seascape.

a) On-shelf seascapes

	Seascape												
Feature	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Abyssal plain/deep ocean floor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apron/fan	0.00	2.04	1.55	1.22	15.71	2.53	65.31	10.34	1.29	0.00	0.00	0.00	0.00
Bank/shoals	3.31	0.16	16.98	0.73	0.04	0.31	0.65	1.59	26.50	15.27	0.70	20.56	13.20
Basin	2.82	0.08	0.92	0.07	4.01	0.14	1.16	0.00	1.61	9.91	0.84	44.02	34.40
Canyon	0.00	0.08	1.99	0.59	3.23	7.68	57.04	10.92	2.79	0.29	0.00	1.93	13.46
Continental rise	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deep/hole/valley	19.04	0.29	9.95	3.64	5.62	1.35	11.21	11.34	8.44	13.87	1.12	9.60	4.55
Escarpment	20.46	0.00	0.00	35.70	25.69	18.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Knoll/abyssal-hills/hills/mountains/peak	73.09	0.00	0.00	19.13	4.80	2.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pinnacle	1.18	0.00	13.61	5.02	0.29	3.08	12.72	3.84	19.04	5.50	0.00	9.96	25.76
Plateau	19.57	1.28	31.72	4.36	1.84	0.41	0.05	0.15	5.72	27.15	0.47	7.26	0.03
Reef	0.54	1.35	47.69	0.93	0.02	1.95	0.29	2.61	25.07	13.85	1.41	2.59	1.70
Ridge	0.00	0.44	8.46	0.90	0.33	4.50	50.23	21.49	8.49	3.69	0.00	0.33	1.14
Saddle	0.00	0.00	2.82	0.00	0.00	0.00	0.44	1.04	7.89	34.37	0.00	36.04	17.40
Seamount/guyot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shelf	20.67	1.57	2.61	4.90	3.92	0.94	1.06	9.21	3.34	22.34	7.82	11.46	10.16
Sill	15.26	1.61	0.38	0.29	0.01	0.00	0.00	0.00	0.26	9.56	0.00	42.15	30.48
Slope	1.11	0.42	10.40	17.90	1.03	22.82	20.56	18.67	5.16	1.11	0.02	0.72	0.08
Terrace	18.33	0.30	5.47	2.76	2.43	3.39	6.76	7.67	6.28	24.13	0.76	16.10	5.62
Tidal-sandwave/sand-bank	26.97	1.83	2.42	5.74	0.01	0.00	0.00	0.54	3.08	18.36	32.68	2.07	6.29
Trench/trough	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

b) Off-shelf Seascapes

	Seascape								
Features	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Abyssal plain/deep ocean floor	4.28	0.00	0.26	24.63	3.81	35.82	25.16	0.54	5.51
Apron/fan	27.18	48.05	21.89	0.00	0.00	0.00	0.00	2.88	0.00
Bank/shoals	0.00	8.59	0.77	9.60	56.05	0.00	24.98	0.00	0.00
Basin	14.99	0.01	0.00	1.19	2.18	33.12	0.74	15.52	32.24
Canyon	4.40	1.65	11.25	0.56	34.66	0.17	8.26	2.14	36.92
Continental rise	12.50	0.00	4.28	4.35	0.00	45.93	8.64	0.00	24.31
Deep/hole/valley	26.69	7.60	5.33	0.00	0.01	9.80	7.50	29.21	13.87
Escarpment	0.00	0.00	3.90	0.39	46.36	2.79	15.55	0.00	31.01
Knoll/abyssal-hills/hills/mountains/peak	3.62	0.11	0.17	2.14	6.23	4.76	78.46	1.03	3.48
Pinnacle	19.27	6.62	3.67	4.17	30.24	3.59	12.44	0.72	19.27
Plateau	26.72	5.15	1.67	0.73	6.89	0.36	0.63	38.18	19.68
Reef	10.46	80.70	8.40	0.00	0.00	0.00	0.00	0.15	0.29
Ridge	3.17	0.08	0.46	0.97	14.09	0.31	77.16	0.74	3.01
Saddle	23.80	6.88	1.03	7.83	23.41	5.39	0.00	11.01	20.65
Seamount/guyot	29.71	0.18	12.30	1.96	20.49	0.32	0.42	0.67	33.95
Sill	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Slope	15.56	7.47	14.00	6.94	14.92	2.80	13.65	3.95	20.70
Terrace	21.51	13.51	26.63	0.05	1.10	0.02	0.65	22.42	14.11
Tidal-sandwave/sand-bank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trench/trough	26.33	5.69	11.63	0.48	1.75	1.61	1.39	45.66	5.43

Off-shelf seascape 6 coincides with vast, mostly sedimented, relatively flat abyssal plain environments. Deep-ocean environments that have high relief, including on the southern margin associated with margin spreading and in the vicinity of submarine canyons at the base of the slope, are dominated by seascape 7. On the southeast margin, off-shelf seascapes 4 and 5 replace seascapes 6 and 7 as being the dominant types in the deep ocean. We note that the boundary between the dominant seascape types south of Tasmania coincides with an ecological boundary based on demersal fish data (DEH, 2005).

Seascapes 1 and 9 are associated with relatively rugose sections of the margins of offshore plateaus and terraces. Seascape 1 is restricted to the margins of tropical and sub-tropical plateaus and terraces, while the distribution of seascape 9 is wider and coincides with the margins of all the plateaus and terraces around the margin.

Seascapes 2 and 8 are associated with the flat to shallow-gradient tops of the offshore marginal plateaus and terraces. Seascape 2 coincides with tropical environments characterised by warmer water and low primary production including the extensive shallow-gradient carbonate ramp of the North West Shelf and shallow water carbonate plateaus on the northeast margin (Marion and Queensland Plateaus). Seascape 8 coincides

Table 1.3. Description of seascapes for the Australian margin and adjacent seabed.

Seascape	Description
On-shelf	
1	Shelf; knoll/abyssal-hills/hills/mountains/peak, tidal sandwave/sand bank; low mud; high primary production; cool; flat
2	Shelf; apron/fan; high effective disturbance; very gravelly; low mud; high primary production
3	Shelf; reef, plateau; gravelly; rugose
4	Shelf; escarpment; very high effective disturbance; low mud; cool; rugose
5	Shelf; escarpment; low gravel; muddy; cold
6	Shelf/upper slope; low effective disturbance; very rugose
7	Shelf; apron/fan, ridge; low effective disturbance; low gravel; muddy; very low primary production
8	Shelf; ridge; high effective disturbance
9	Shelf; bank/shoals, reef; very warm
10	Shelf; saddle, plateau; gravelly; warm
11	Shelf; tidal sandwave/sand bank; very high primary production
12	Shelf; basin, sill saddle; moderate primary production; cool; flat
13	Shelf; basin, sill, pinnacle; very low effective disturbance; very low gravel; very muddy; low primary production; very flat
Off-shelf	
1	Abyssal; seamount/guyot, apron/fan, plateau, deep/hole/valley, trench/trough; very low mud, very low primary production
2	Abyssal; reef, apron/fan; gravelly; low primary production; very warm, flat
3	Abyssal; terrace; high gravel; warm; rugose
4	Bathyal; abyssal plain/deep ocean floor; low mud, high primary production, cold
5	Abyssal; bank/shoal, escarpment, canyon, pinnacle; very gravelly, muddy; very high primary production; rugose
6	Bathyal; continental rise; abyssal plain/deep ocean floor, basin; low gravel; very muddy; cold; flat
7	Bathyal; knoll/abyssal-hill/hill/mountain/peak, ridge, abyssal plain/deep ocean floor; muddy; high primary production; very cold
8	Abyssal; trench/trough, plateau, deep/hole/valley; very low gravel; low primary production; warm; flat
9	Abyssal; canyon, seamount/guyot, basin, escarpment; low gravel; muddy; very rugose

with the deeper offshore marginal plateaus in sub-tropical to tropical waters. Each of these environments is also characterised by relatively low primary production values.

Seascape 3 is associated with the upper- to mid-slope regions of the Australian margin characterised by relatively low gradients and moderate primary production values. Interestingly, the distribution of this seascape mostly coincides with regions of the margin that contain large offshore marginal plateaus and terraces. This implies that seascape 3 represents upper- to mid-slope environments where offshore features preclude significant upwelling and reduce primary production in the surface waters.

Seascape 4 is associated with the mid- to lower-slope and deep-ocean environments on the southern, southeast and eastern margins and is characterised by a relatively coarse grain size relative to the other seascapes that characterise these deep-sea environments elsewhere on the margin (i.e., seascapes 6 & 7). An ecological explanation for discriminating this seascape is unclear at present, and its existence and wide distribution on the southeast margin is possibly related to the paucity of sediment data for this region.

Seascape 5 is associated with the mid- to upper-slope regions southern and southeast margins. It is the most latitudinally constrained seascape and coincides with regions of the

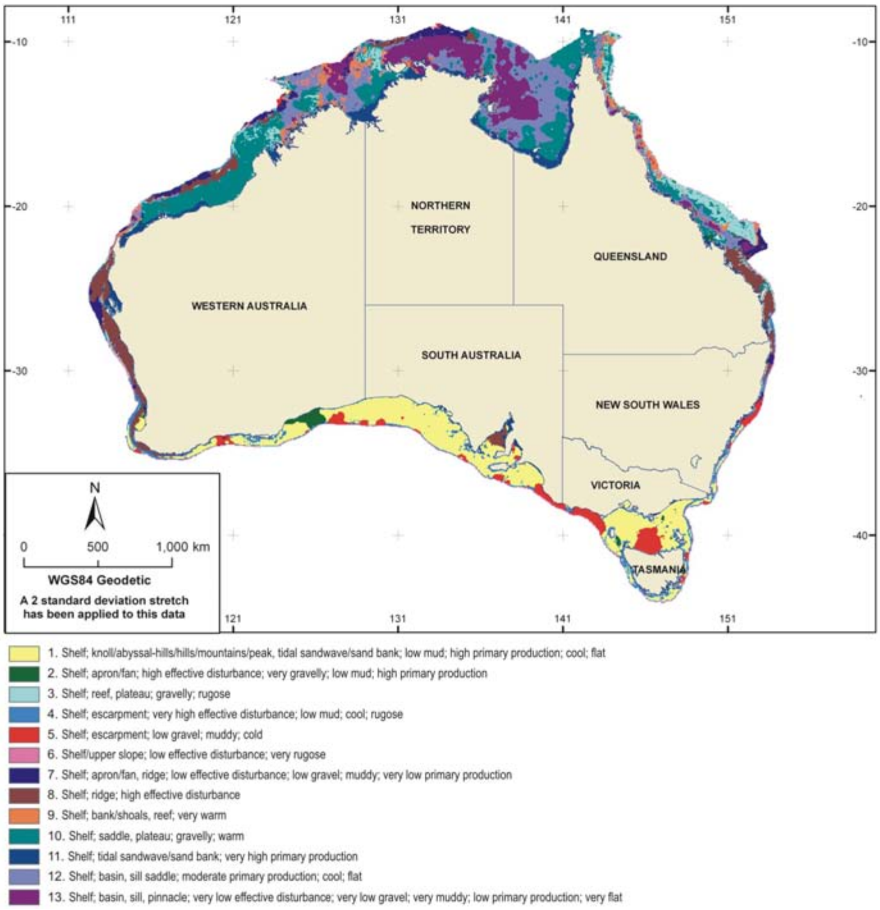


Figure 1.6. Seascapes for the on-shelf region of Australia. A total of 13 seascapes were identified and are described in Table 1.3.

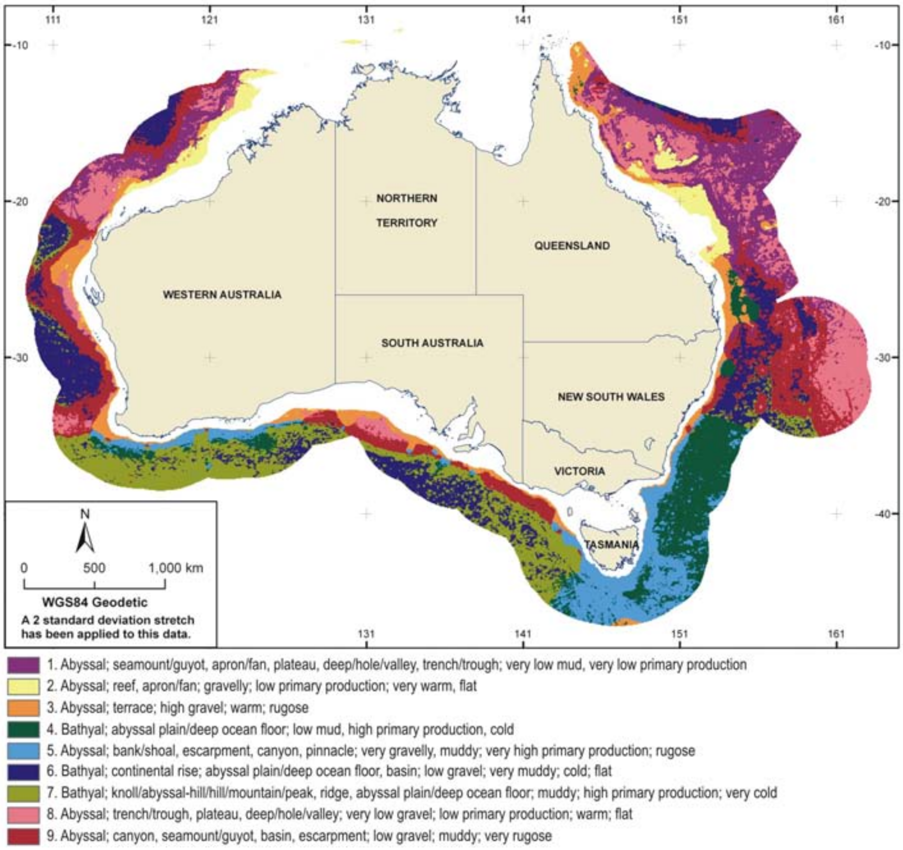


Figure 1.7. Seascapes for the off-shelf region of Australia. A total of nine seascapes were identified and are described in Table 1.3.

margin that are dissected by large and numerous submarine canyons (cf. Heap & Harris, 2008). This seascape is discriminated by very high primary production values, probably a result of upwelling and advection of cooler, nutrient-rich water from the Southern Ocean (e.g., McClatchie *et al*. 2006; Middleton & Bye, 2007). Interestingly, this seascape does not occur on sections of the western margin cut by numerous canyons. On this margin, these environments are associated with seascape 3 and characterised by only moderate primary production values, where upwelling to the surface waters is possibly partly limited by the presence of the shallow (<200 m) and southward-flowing Leeuwin Current.

Seascape 6 coincides with the vast, mostly sedimented, relatively flat abyssal plain environments around the margin. Where these deep-ocean environments have relief, including on the southern margin associated with margin spreading and in the vicinity of submarine canyons at the base of the slope, they are dominated by seascape 7. On the southeast margin, seascapes 4 and 5 replace seascapes 6 and 7 as being the dominant types in the deep ocean. This may be a true change in seascape type, and the boundary south of Tasmania coincides with a potential ecological boundary based on demersal fish data (DEH, 2005). We note that relatively few data were available for the deep southeast region, and it could be that the change in dominant seascape is a reflection of the paucity of sediment data in this region.

2. Correlation with Biological Data - National Scale

2.1. INTRODUCTION

In this chapter we evaluate how well the on-shelf and off-shelf seascapes represent benthic biological assemblages at a national scale. To do this we analyse biogeographical data from the Ocean Biogeographic Information System (OBIS).

2.2. METHODS

2.2.1. Data Sources

Data was obtained from the OBIS, which provided a large, geo-referenced record of species occurrences from a wide range of taxa for Australia's EEZ. OBIS is a Census of Marine Life website (http://www.iobis.org) that collates international species occurrence data. Data are listed by taxonomic information (i.e., Phylum, Class, Order, Family, Genus, Species) and geographic location (latitude and longitude). Although OBIS data is available on-line, only small data queries are possible using the web search engine. To enable data queries to be undertaken on the extremely large OBIS Australian EEZ dataset (1,142,266 records) data were obtained directly from the Divisional Data Centre at CSIRO Hobart (Table 2.1). OBIS data includes records in Australia's Maritime Jurisdiction (AMJ) from the Australian Antarctic Territory, territorial islands, and mainland. However, seascape analyses in this study were only undertaken for the mainland Australia out to the outer limit of the EEZ, including Lord Howe Island. Of the 1,142,266 OBIS records available for the Australian EEZ and Territorial sea, 479,818 records (42% of all records, 92.7% of all mainland records) occurred within seascapes (Table 2.2; Fig. 2.1). Seascapes did not extend all the way to the coast: 7.3% of mainland records occurred in this non-defined nearshore region between the inner edge of the seascapes and the coast. Of the records coinciding with the seascapes, 79% coincided with on-shelf seascapes (380,412 records) while 21% coincide with off-shelf seascapes (99,406 records) (Tables 2.3 & 2.4; Figs. 2.1–2.3).

The OBIS dataset contained entries analysed to varying levels of taxonomic resolution, with 430,442 of the records coinciding with the seascapes (90%) containing genera and species data. Although species level data would have been preferable, data were pooled to genus level rather than species for two reasons: spelling errors and synonymies at the species level. Data screening across all taxa would require a team of taxonomic specialists to identify errors, synonymies, and uncertain identifications and would be a logistically expensive exercise. Second, analysis at the species level would have resulted in too many zero values for a meaningful analysis. Generally, the genus level data sufficed for this scale of analysis, as OBIS family-genera-species level patterns were positively and linearly correlated, and genera typically have similar broad-scale environmental constraints on their distributions.

Table 2.1. Data source used for national seascape evaluation (http://www.iobis.org).

Data type	Scale	No. data points	*Biases*
OBIS (Australian EEZ)	National	1,142,266 records	*Species presence (no absences)*

Table 2.2. Summary of OBIS data records by region of the Australian Maritime Jurisdiction (AMJ).

Region of Australian Maritime Jurisdiction	**Number of records**
$^{\Delta}$Antarctic (south of latitude 59^{o})	301,130
$^{\Delta}$Territory Islands South (Macquarie Island; Heard Island)	258,421; 61,579
$^{\Delta}$Territory Islands North (Christmas Island; Cocos (Keeling) Island)	2,681; 727
* Mainland including Lord Howe Island	517,728
*[1] Mainland incl. Lord Howe Island (within seascapes)	479,818 (92.7%)
*[2] Mainland incl. Lord Howe Island (outside seascapes)	37,910 (7.3%)

$^{\Delta}$ Australian territorial waters, but no seascape analyses or classifications are available. * Mainland excluding Antarctic (south of 59^{o}) and all territory Islands except Lord Howe Island. *[1] Records within seascapes (data used in this study). *[2] Records outside seascapes.

Table 2.3 Summary of OBIS data records relative to the 13 on-shelf seascapes.

On-shelf	**Area (km^2)**	**Numbers of OBIS records**	**Families**	**Genera**
1	334,207	60,969	463	899
2	22,393	1,232	173	268
3	111,955	44,394	428	1087
4	92,067	86,146	527	1147
5	71,036	14,501	334	597
6	43,585	11,910	465	977
7	70,047	5,809	306	572
8	157,832	15,183	464	1155
9	94,599	28,660	403	1081
10	389,178	67,049	389	1007
11	107,234	7,291	422	912
12	322,168	17,680	310	742
13	241,837	19,588	362	899
Total	**2,058,136**	**380,412**	**-**	**-**

Table 2.4 Summary of OBIS data records relative to the nine off-shelf seascapes.

Off-shelf	**Area (km^2)**	**Numbers of OBIS records**	**Families**	**Genera**
1	737,932	10,989	461	1084
2	229,273	12,228	432	949
3	315,378	20,751	550	1336
4	437,629	6,329	212	340
5	366,102	16,005	352	658
6	666,604	7,244	167	270
7	630,740	1,882	206	352
8	664,601	7,216	349	799
9	759,498	16,762	408	974
Total	**4,807,758**	**99,406**		

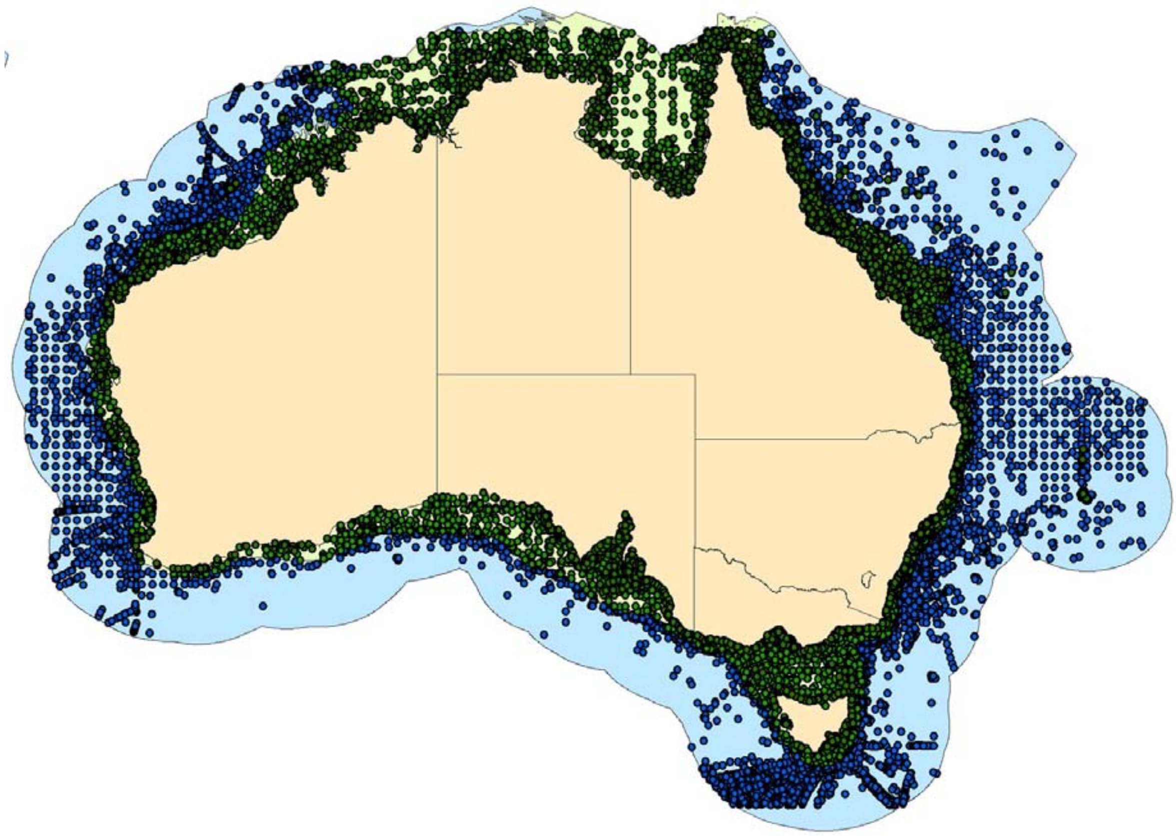


Figure 2.1 Location of OBIS records around Australia relative to on-shelf (blue filled circles on light blue background) and off-shelf (green filled circles on light green background) seascape regions.

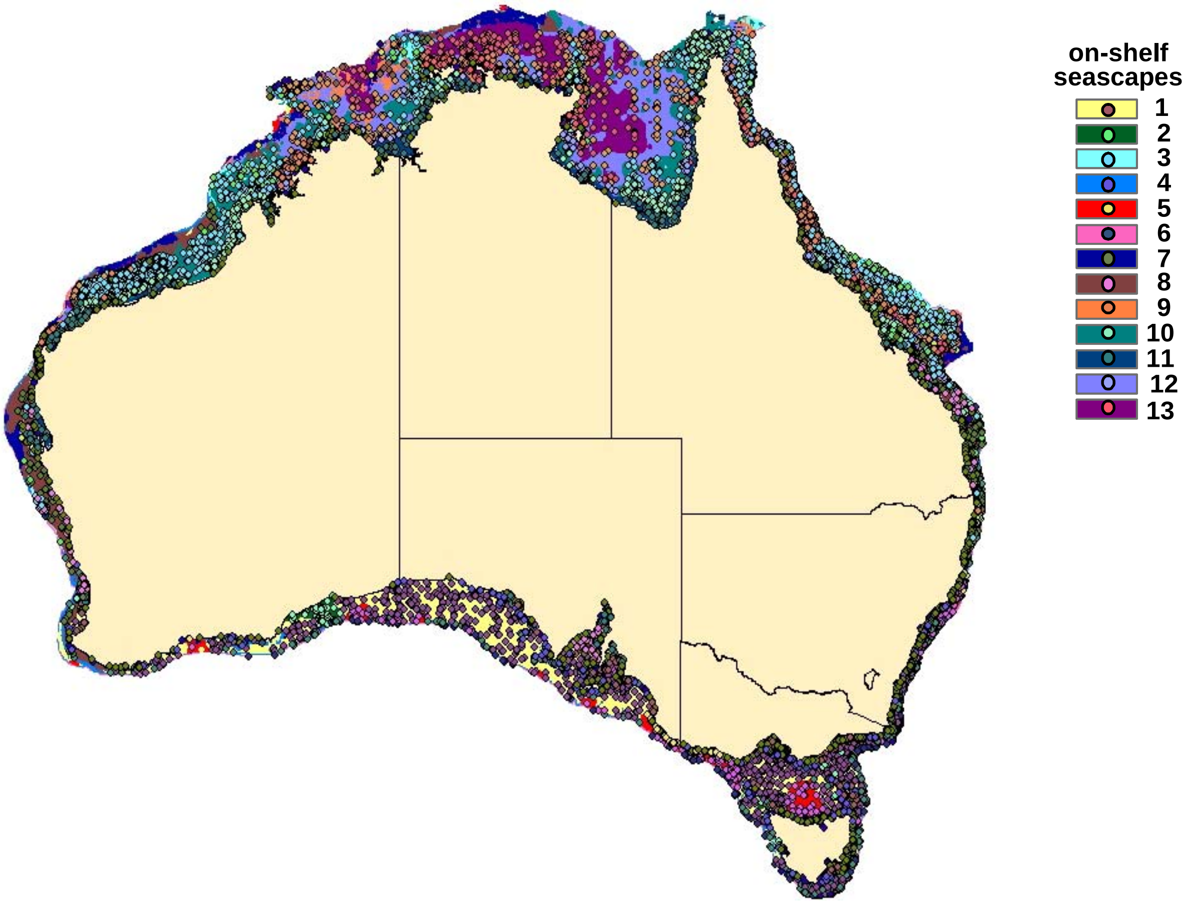


Figure 2.2 Location of OBIS records around Australia relative to the on-shelf national seascapes. Circles represent the location of OBIS records, while the colour of the circle and underlying polygons indicate the different seascapes.

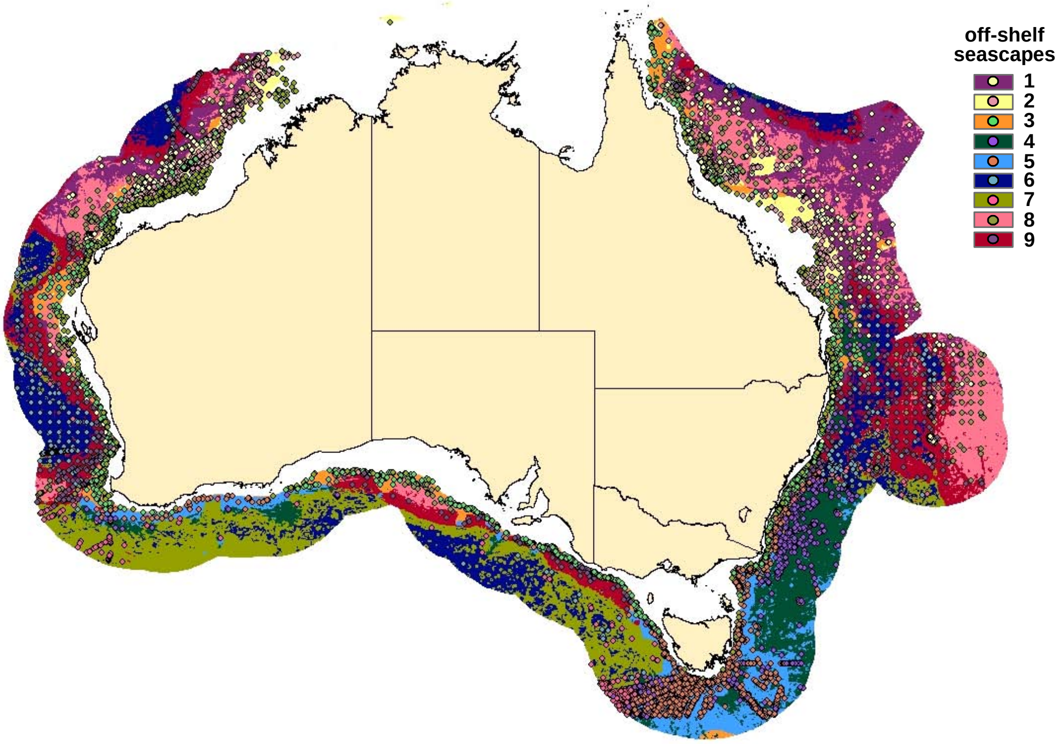


Figure 2.3 Location of OBIS records around Australia relative to the off-shelf national seascapes. Circles represent the location of OBIS records, while the colour of the circle and underlying polygons indicate the different seascapes.

To assess the predictive ability of the seascape classification at a national scale, we selected three key taxonomic groups that had representative genera in adequate data densities across the margin, and represented: 1) a habitat forming group of species (e.g. Scleractinian corals), 2) habitat modifiers (e.g. bivalves), and 3) habitat responders (e.g. Labridae). First, the order Scleractinia (stony hard-corals) was selected as this taxa is an important habitat former in both tropical systems—in which hermatypic or reef building corals dominate—and temperature systems in which ahermatypic or non-reef building corals are important. Second, the molluscan order Bivalvia (Bivalves) was chosen as it is ubiquitous around the Australian coastline, has representative genera in both hard and soft substratum, and can modify the complexity of these habitats. Finally, the fish family Labridae (Wrasses)—order Osteichthys—was chosen to represent a group of mobile organisms that also were distributed throughout Australia with representatives in a range of habitats.

The advantage of the OBIS dataset is that it is extremely large and covers a wide range of taxa across the AMJ (Table 2.2; Fig. 2.1). Importantly, many of these records coincide with the seascapes (Tables 2.3 & 2.4; Figs. 2.2 & 2.3). However, the OBIS data also have some important limitations. The main limitation is that OBIS records comprise presence-only data. This means that records are available for where an animal was found, but no information is available for when an organism was searched for but not found at a location. This is a common problem with these types of biogeographic data (Dormann *et al*., 2007), and causes data to be censored in a statistical way—i.e., it does permit the comparison of random zeros (animal looked for but absent) versus structural zeros (animal not looked for, so it is not know whether it was present or absent). This has important consequences for the interpretation and analysis of patterns. Lack of information on the sampling effort conducted at any given location causes problems in calculating species richness and diversity, which is dependent on sample size (Hurlbert, 1971; Magurran, 1988). Another important analytical consideration is that there is no information on what constitutes a sample station, so analyses that require a station × species data table cannot be carried out except by *post hoc* arbitrary gridding of the data.

2.3. ANALYSIS

OBIS data were analysed in a similar way to the GBR Seabed Biodiversity project data. In contrast with the GBR dataset, which had distinct replicate samples, the OBIS dataset consisted of a conglomerate of different data sources with no defined replicate sample stations and as such presented an analytical challenge. Consequently, data were gridded into 0.5° latitude and longitude blocks (~90 km^2) and each block was treated as a spatial replicate. Several grid sizes were examined, and a grid of 0.5° latitude and longitude was found to best balance the scale of spatial resolution, minimizing the number of empty replicates, and maximizing effective replication within any given seascape. The three taxonomic groups (Scleractinia, Bivalvia, & Labridae) were then summarised to occurrences of genera per 0.5° block. To reduce the effect of zeros in the data analyses only genera that occurred in >10% of samples were retained for analyses. Consequently, 56 Scleractinia (representing 551 stony hard-coral species), 21 Bivalvia (representing 66 bivalve species), and 25 Labridae (representing 157 wrasse species) genera were retained. Similarly, for each taxonomic level analysis, seascapes were only included where they contained >10 replicates per grid.

Statistical data distributions for the three taxa were examined with box-plots. All three taxa were right-skewed with strong variance-mean relationships, which were decoupled using $\log_{10}$ (Scleractinia, Labridae) and $x^{0.5}$ (Bivalvia) transformations. DFA ordinations were run on each of the three taxonomic groups using the SAS systems DISCRIM procedure, using 'Seascape' as a classification variable. However, initial analyses identified that the role of seascapes in predicting biological assemblages appeared to change in different biogeographic provinces. To examine the influence of biogeographic provinces on the predictive ability of seascape classifications at a national scale we first identified four provinces (Northwest, Northeast, Southwest, & Southeast) to typify national-scale geographic patterns with province boundaries selected based on established literature for a wide range of taxa: Cape Byron (latitude -28.5°, longitude 150°), Discovery Bay (latitude -38°, longitude 141°), Perth (latitude -32°, longitude 117°), and Weipa (latitude -12.5°, longitude 141.4°) (e.g., Veron, 1993; Veron & Marsh, 1988). Data were analysed with the seascape classification for both on-shelf and off-shelf datasets combined, but were presented separately for each province to examine the relative importance of seascapes per province and on-shelf versus off-shelf regions. Interpretation of the assemblages was based on the Discriminant Function Analysis (DFA), and genera responsible for differences between seascapes and provinces evaluated from the total structure coefficients (i.e. the correlation between the variables and the ordination axes).

2.4. RESULTS

The three taxonomic groups used to assess the predictive capability of seascape-classifications at a national-scale are key ecological taxa distributed Australia-wide with representative genera recorded from a diverse range of habitat types. The dominant signals in all three taxa examined were driven by temperate and tropical contrasts, with western and eastern provinces and on-shelf versus off-shelf zones distinct from each other to a lesser extent. Seascape classification contributed to predictive ability in some limited conditions.

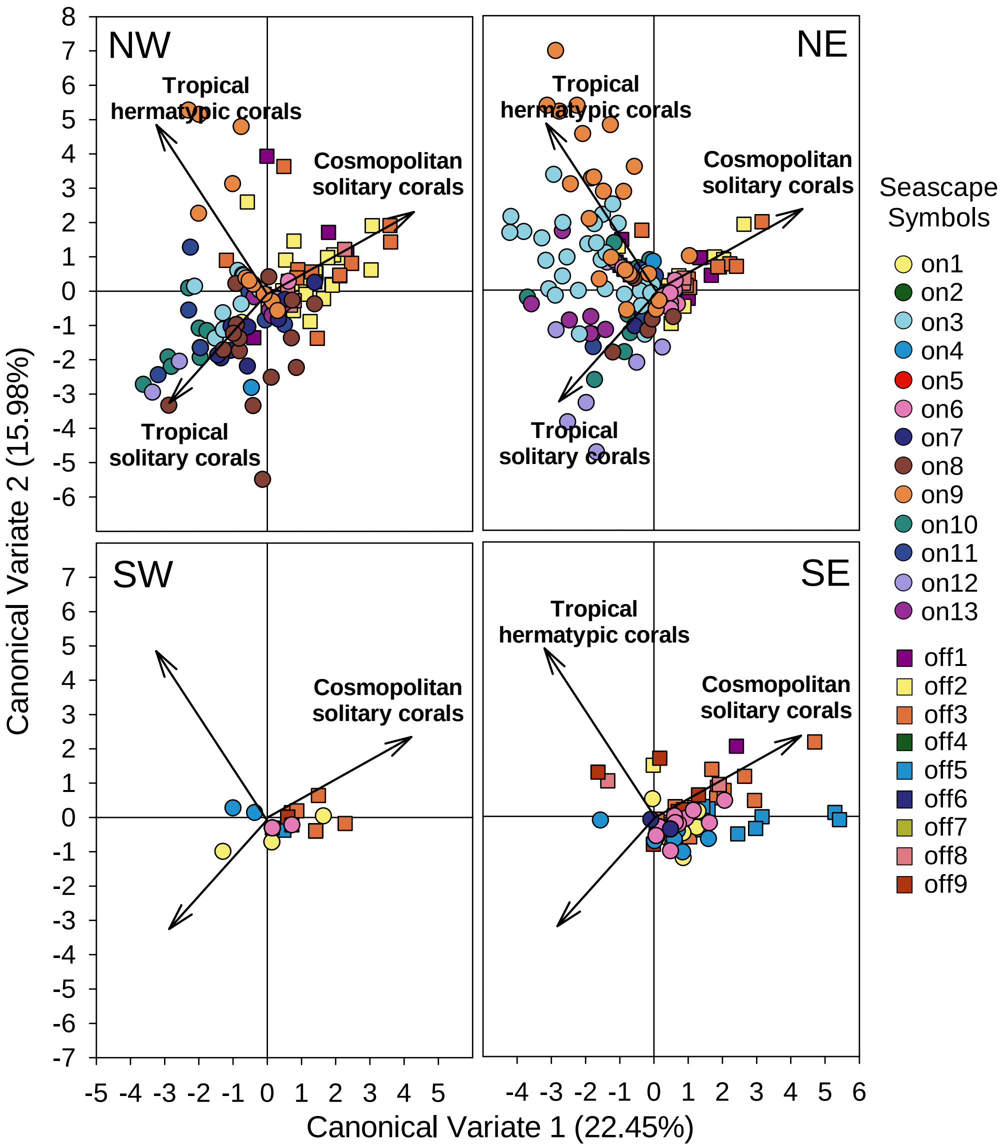


Figure 2.4 Discriminant Function Analysis (DFA) on Scleractinian hard corals (Order Scleractinia) from the OBIS data. The ordination was run on the entire Scleractinian coral dataset, but presented here by each province for clarity. The top left plot is the northwestern (NW) province, top right is the northeast (NE), bottom left is the southwest (SW), and bottom right is the southeast (SE) province. The vectors are stylised representations of the main trends of taxonomic differences, based on the structure coefficients (correlations between the variables and the ordination axes). Coloured circles = on-shelf seascapes (on1–on13), squares = off-shelf seascapes (off1–off9).

2.4.1.1. Scleractinian Coral Assemblages

At a national scale, two main patterns were evident in scleractinian coral assemblages, as follows:

1. Northern on-shelf seascapes contained a diverse range of hermatypic reef-building corals that were biologically distinct from southern and northern off-shelf and southern on-shelf seascapes (Fig. 2.4). Hermatypic coral distributions were aligned with both the 20°C isotherm and 100 m depth contour which reflected the limits of their physiological tolerance to temperature and light levels. Assemblages in the southern on-shelf and off-shelf seascapes were similar to each other, and were characterised by an absence of reef building hermatypic corals, and a less diverse fauna comprised of ahermatypic solitary cup coral genera from the families Caryophillidae and Flabellidae.

2. Seascape classifications in the southern provinces and northern off-shelf region were not as distinct compared with general province and on-shelf versus off-shelf classifications. However seascapes did contribute additional predictive ability in the northern on-shelf provinces (Fig 2.4). On-shelf seascapes 3 and 9 were characterised by a large array of reef-building hermatypic corals such as Acroporids, Poritids, and favids with more species in seascape 9. These seascapes were composed of gravelly seabed habitats (seascape 3) or reef and shoals (seascape 9) that provide hard substrata for corals to attach. In contrast, seascape 12 was characterised by the relative absence of these coral taxa and the presence of a tropical genus of ahermatypic solitary cup coral—*Truncatoflabellum*. Many of the species in this genus are free-living and do not require hard substratum for attachment, and are found in a range of inter-reef habitats (Veron, 1993). Seascape 12 occurred primarily in the northern-most region of Australia, in the Gulf of Carpentaria and Arafura Sea, and was characterised by low physical disturbance and gravelly sand habitats, which are likely to provide a range of suitable habitats for *Truncatoflabellum* species. In general, these three seascape patterns were more pronounced in the northeast province than in the northwest, probably due to the higher number of records from the GBR.

High misclassification rates were apparent and ranged from 46–100% (mean 77.7% ± 3.32 se). Within the seascapes that provided additional explanatory ability (i.e., seascapes 3, 9, & 12) misclassification rates were also high (75–85% range), indicating that these seascapes were not strong predictors of scleractinian coral assemblages at these scales.

2.4.1.2. Bivalve Assemblages

The primary pattern in the bivalve assemblage was a contrast between tropical genera on the left of the DFA ordination and temperate genera on the right (Fig. 2.5). This pattern was more pronounced in the east which comprised a more diverse range of genera than in the west. The second pattern was a contrast between hard bottom (e.g., reef, coral, and rubble habitats) that were positively associated with the second axis, and soft-bottom (sandy habitats) that were negatively associated with the axis. In the tropics hard-bottom regions were characterised by a range of genera including giant clams (*Tridacnea*), black-lipped oysters (*Pinctada*), *Gloripallium*, and *Lioconcha*, while soft bottom tropical regions were characterised by *Cryptopecten* and an absence of reef-associated genera. Temperate seascapes were characterised by a mixture of hard-bottom genera such as mussels (*Mytilus*), and a more diverse soft-bottom bivalve assemblage including commercial scallops (e.g. *Pecten*) and non-commercial bivalve genera (e.g., *Mimachlamys* and *Cyclochlamys*). No significant predictive ability was offered by the seascape classification and misclassification rates were high (mean 77.5% ± 3.6 se, range of 59–100%). However on-shelf seascapes 3 and 9 correctly described tropical hard-bottom bivalves, but the large spread of samples within these seascapes reduced their predictive ability.

2.4.1.3. Wrasse Assemblages

Amongst the wrasse family Labridae similar patterns were observed to the bivalve taxa. The tropical northeastern and northwestern off-shelf assemblages were diverse and varied and were characterised by a wide range of tropical genera, but assemblages did not systematically co-vary with seascape classification (Fig. 2.5). Overall, seascapes did not significantly add to the predictability of the wrasse assemblages at the national scale, and misclassification rates were high (mean 75.39% ± 5.57% se, range 41-100% misclassification rates). Seascapes in the north typically contained one of two assemblage types. A diverse

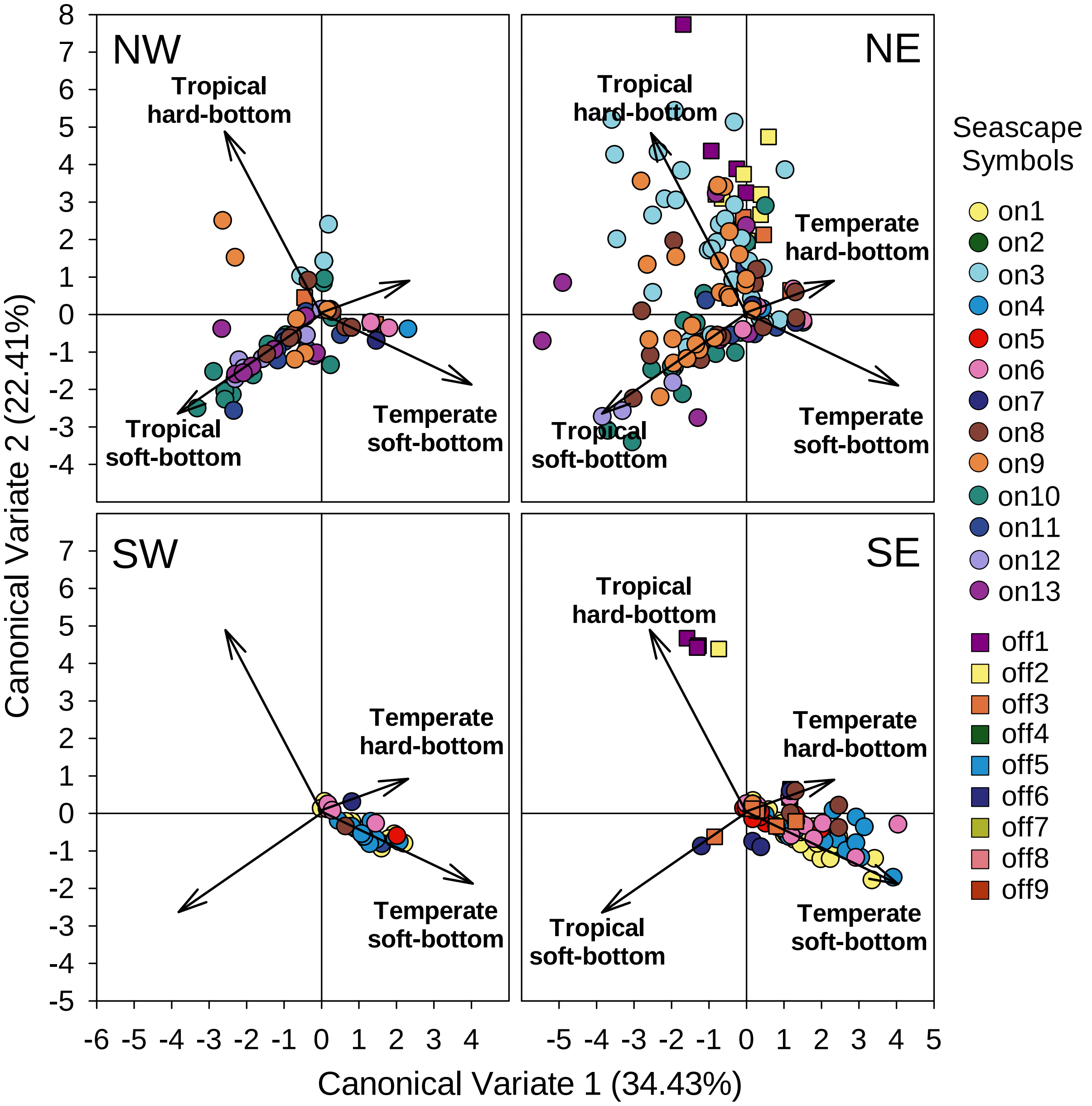


Figure 2.5 Discriminant Function Analysis (DFA) on bivalve genera (Order Bivalvia) from the OBIS data. The ordination was run on the entire bivalve dataset, but presented here by each province for clarity. The top left plot is the northwestern (NW) province, top right is the northeast (NE), bottom left is the southwest (SW), and bottom right is the southeast (SE) province. The vectors are stylised representations of the main trends of taxonomic differences, based on the structure coefficients (correlations between the variables and the ordination axes). Coloured circles = on-shelf seascapes (on1–on13), squares = off-shelf seascapes (off1–off9).

range of reef-associated tropical wrasse genera (e.g., *Cirrhilabrus, Thalassoma, Halichoeres, Coris*) were associated with both on-shelf and off-shelf seascapes in the northeast, and with off-shelf seascapes in the northwest. The presence of wrasse genera in off-shelf seascapes reflected shallow-water species that are associated with off-shelf emergent reefs such as Scott and Ashmore Reefs in the northwest, and Osprey and Bougainville Reefs in the northeast. Off-shelf emergent reefs were located within seascapes 2 and 3 on the northwest, and within a broad range of off-shelf seascapes—including seascapes 1, 2, 3, and 8—on the northeast, indicating significant overlap in the association of off-shelf wrasse assemblages on emergent reefs with the seascapes.

In contrast to reef-associated genera, in the northwest and, to a lesser extent the northeast, there was also a distinct on-shelf soft-bottom assemblage dominated by tuskfishes (*Choerodon*) and some razorfishes (*Iniistius*) (Fig. 2.6). Seascape 10 in particular, which occupied a large part of the continental shelf, appeared to be completely dominated by deeper water *Choerodon* species. However, samples from other seascapes also contained *Choerodon* species thereby reducing the predictive strength of this relationship. Little is known about the taxonomy and ecology of these deeper species, but both *Choerodon* and *Iniistius* are unusual among the wrasse family in that they are generally associated with featureless soft-bottom habitats in contrast with most other wrasses which are more characteristically associated with reefs. It is possible that this dominance of tuskfishes in these on-shelf seascapes may reflect sampling bias towards benthic trawl surveys targeting soft-bottom prawns and fishes than an absence of reef-associated wrasse genera in these regions.

Temperate assemblages were less diverse than tropical assemblages, and were characterised by on-shelf subtropical genera such as blue groupers (*Achoerodus*) and *Pictilabrus* as well as temperate genera such as *Notolabrus* (Fig. 2.6). On-shelf assemblages in the southeast were restricted to seascapes 1 and 4, which covered the majority of all on-shelf habitats in this province. Seascapes 1 and 4 predicted similar assemblage structure and differed only by the numbers of records. Their predictive ability was higher (58.3% and 31.8% correct, respectively) and they add a marginal predictive benefit beyond a simple southeast on-shelf classification. Off-shelf wrasse assemblages in the southeast were restricted to Lord Howe Island and were characterised by a mixed suite of shallow-water tropical, subtropical, and temperate wrasse species (47 wrasse species from 20 genera). These assemblages were represented in three off-shelf seascapes (seascapes 1, 2, & 9).

2.4.1.4. Summary of OBIS patterns

Dominant signals in all taxa examined were driven by temperate and tropical contrasts, with western and eastern provinces distinct from each other to a lesser extent. Seascape classification contributed to explanatory ability in some limited conditions—generally in the more heterogeneous environments of the northern on-shelf provinces. Overall, seascapes added marginally to the predictability of biological assemblages in the OBIS dataset; their explanatory power was confounded mainly due the relatively high amount of variability within a class in the DFAs, and the differences between tropical and temperate provinces and on-shelf and off-shelf zones. Province was an important predictor of biological pattern at the national scale, and the primary patterns in the three focal taxonomic assemblages reflected a tropical and temperate contrast in assemblage composition. Hermatypic scleractinian corals for example, had a non-linear or threshold association with temperature. They were present in waters that had a minimum winter temperature of ~20° (Cape Byron on the east, Houtman-Abrolhos on the west) but were practically absent outside these boundaries (cf., Veron, 1993). While the tropical-temperate contrast was captured in the seascape classification model, which included temperature, the non-linear response of these organisms to temperature was not captured in the seascapes. On-shelf and off-shelf patterns were also important predictors of biological assemblages, and the difference was conditional on which province the assemblages occurred in. For example on-shelf seascapes in the northern provinces were heterogeneous and supported a diverse on-shelf assemblage dominated by reef-building ahermatypic corals, while off-shelf seascapes and on-shelf seascapes in southern provinces were more homogeneous and supported a less diverse coral assemblage characterised by deep-water solitary corals. The presence of off-shelf emergent reefs (e.g., Lord Howe in the southeast, Scott Reef in the northwest, and Osprey Reef in northeast) were also important drivers of off-shelf patterns in fish distributions.

Once province and on-shelf/off-shelf patterns were identified, seascape classification

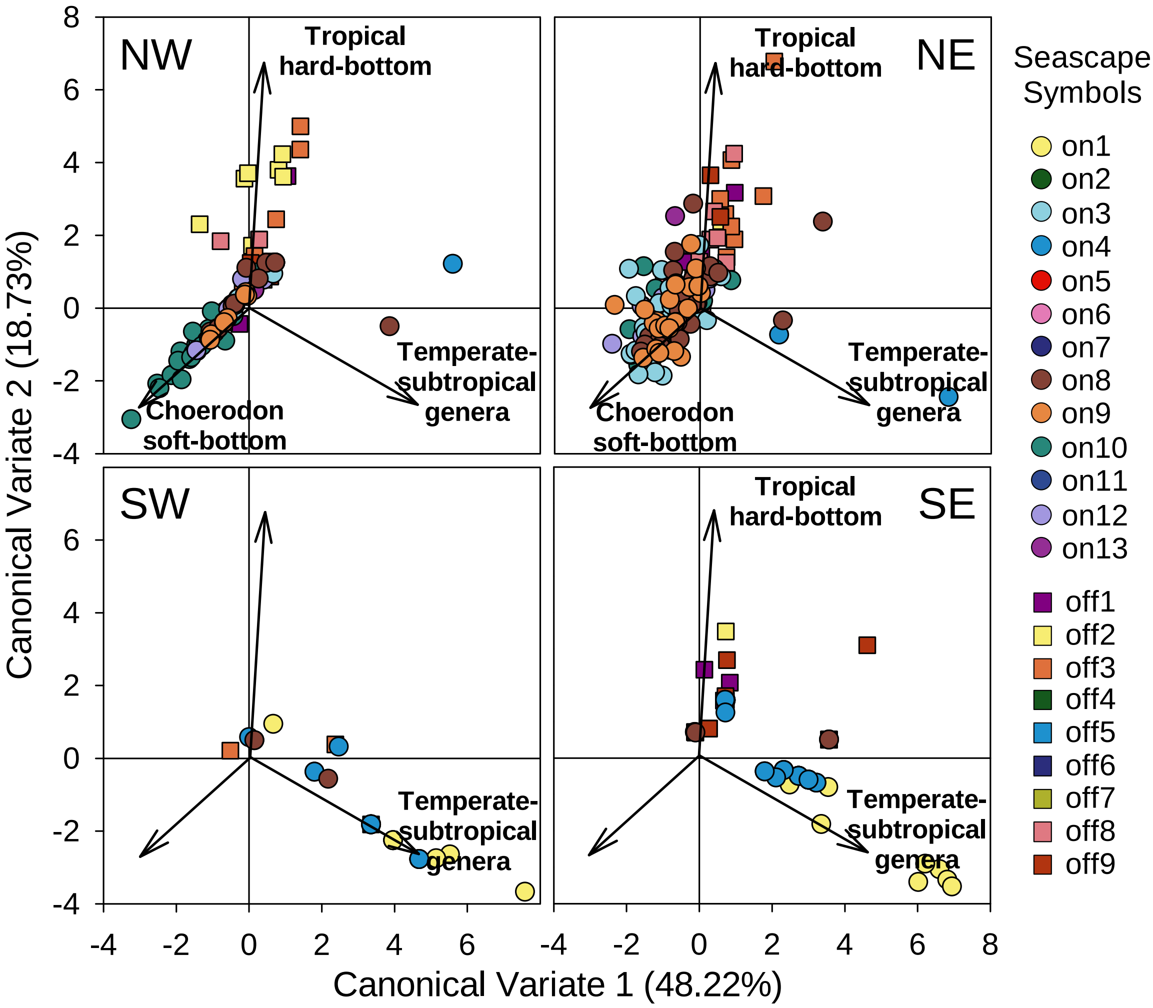


Figure 2.6 Discriminant Function Analysis (DFA) on wrasse genera (Family Labridae) from the OBIS data. The ordination was run on the entire wrasse dataset, but presented here by each province for clarity. The top left plot is the northwestern (NW) province, top right is the northeast (NE), bottom left is the southwest (SW), and bottom right is the southeast (SE) province. The vectors are stylised representations of the main trends of taxonomic differences, based on the structure coefficients (correlations between the variables and the ordination axes).

additionally explained minor differences in biological assemblage structure driven in part by differences in broad-scale substratum types. For example, the order of bivalves was subdivided into genera that were associated with soft substrata, and a set of genera that were associated with hard bottom substrata. Similarly, seascape 9 was characterised by reefs and shoals and were important descriptors of reef-building coral assemblages. Again, these patterns were conditional on the biogeographic province and the combination of within- and between-seascape variability for all three taxa hindered their overall predictive ability. While at the national scale seascapes provide some explanatory information it is clear that nesting them by biogeographic province, off-shelf/on-shelf zones, and at a finer-scale—habitat and substratum type—will increase their predictive power. While the present seascape classification captures physical characteristics of the environment very well, it is somewhat simplistic as a predictor of biological assemblages. Finer-scale incorporation of these regional-scale predictors along with substratum variable predictors are likely to be important and necessary additions to further iterations.

Finally, while OBIS is an impressive biogeographic database, there are major limitations and caveats to using these data for analysis. All OBIS results should be strongly tempered with caution. The east coast is more widely studied, so it is not clear whether the patterns identified in the present study are due to effects of sampling effort or represent the true biogeography. In addition, during the examination of the three taxonomic groups, we found strong indications of taxonomic bias which would only be evident to those familiar with these taxa. For example, in the wrasse data the most frequently recorded genus was *Choerodon*. The dominance of this genus appears to reflect a bias in sampling method due to higher number of benthic trawls sampled over soft bottom habitats compared to other collection methods in other habitat types. Consequently, the dominance by *Choerodon* may not necessarily reflect the true assemblage structure across the Labrid family. The prevalence of razorfish (*Xyrichtys*, *Iniistius*) in the assemblage, also characteristic of soft bottoms, supports this view. There was also a high occurrence of rare species in these OBIS data relative to more widespread species. This finding potentially identifies an additional bias towards museum collections rather than full species lists from field intensive surveys. For example, the genus *Wetmorella* is quite common in the OBIS data. This genus is very secretive, almost never seen by divers, and only collected by ichthyocide in targeted collections. In general well recognised species are less likely to be lodged with museum collections. These biases are important considerations because without taxonomic knowledge and experience, it is unwise to use the OBIS data at face value. However, in order to evaluate national scale patterns, large-scale compilations of biological data are all that are currently available. Any compilation of data will have inherent quality assurance and control issues that need to be carefully examined.

3. Correlation with Biological Data - Regional Scale

3.1. INTRODUCTION

In this chapter, we evaluate how well seascapes represent benthic biological assemblages at a regional scale. To do this we examine biological data from two regional biological datasets the Great Barrier Reef (GBR) and the Great Australian Bight (GAB). Firstly, we analyse seabed video footage and biota recovered from epibenthic sleds collected from the GBR during the Seabed Biodiversity project (Pitcher *et al.*, 2007), and secondly, biological and physical data from the GAB to investigate the utility of seascapes to differentiate benthic assemblages at a scale of hundreds of kilometres, hereafter referred to as regional scale.

3.1.1. Great Barrier Reef (GBR)

Our first approach to evaluating the national seascapes at a regional scale was to focus on a single region where data density was high, sample effort was known, and stations had been comprehensively sampled, so that biomass and percent cover of biological assemblages could be reliably determined and standardised by known sample effort. Six voyages were conducted across the GBR as part of the GBR Seabed Biodiversity Project, an inter-agency collaboration led by the CSIRO and the Australian Institute of Marine Sciences (AIMS) between September 2003 and November 2005 (Pitcher *et al.*, 2007). Although restricted to the on-shelf region of the GBR, this is the most comprehensive dataset collected at this scale for Australia. Pitcher *et al.* (2007) provide a full description of the scope of the survey, sampling design and methods, and preliminary findings. Using these two datasets, we examine the descriptive and predictive ability of the on-shelf seascape classes within the GBR region.

3.1.2. Great Australian Bight (GAB)

The GAB supports one of the world's most diverse soft-sediment ecosystems (Ward *et al.*, 2006), with exceptionally rich assemblages of benthic invertebrates, such as ascidians, nudibranchs, and bryozoans (Edyvane, 1998), although little is known about these invertebrate assemblages. An important component of the GAB Marine Park, is the Benthic Marine Protection Zone (BPZ), formed in 1998 as part of the Great Australian Bight Marine Park. The BPZ is a 20 nautical-mile wide north-south strip of seabed between 130° 28′E and 130° 51′E that runs across the shelf and slope to the outer limit of the AEEZ (200 NM). The objectives of the MPZ is to conserve ecosystems that are characteristic of the region (Great Australian Bight Marine Park, 2005), with specific protection to the benthic habitats and associated assemblages within this zone. The GAB also has low habitat heterogeneity making it a comparatively simple and therefore practical region to explore the biological utility of seascapes. Biological data from the GAB also spanned several seascapes, thus allowing us to compare biological assemblages among seascapes.

3.2. DATA SOURCES

3.2.1. Great Barrier Reef (GBR)

The GBR Seabed Biodiversity Project undertook broad-scale ship-based sampling at almost

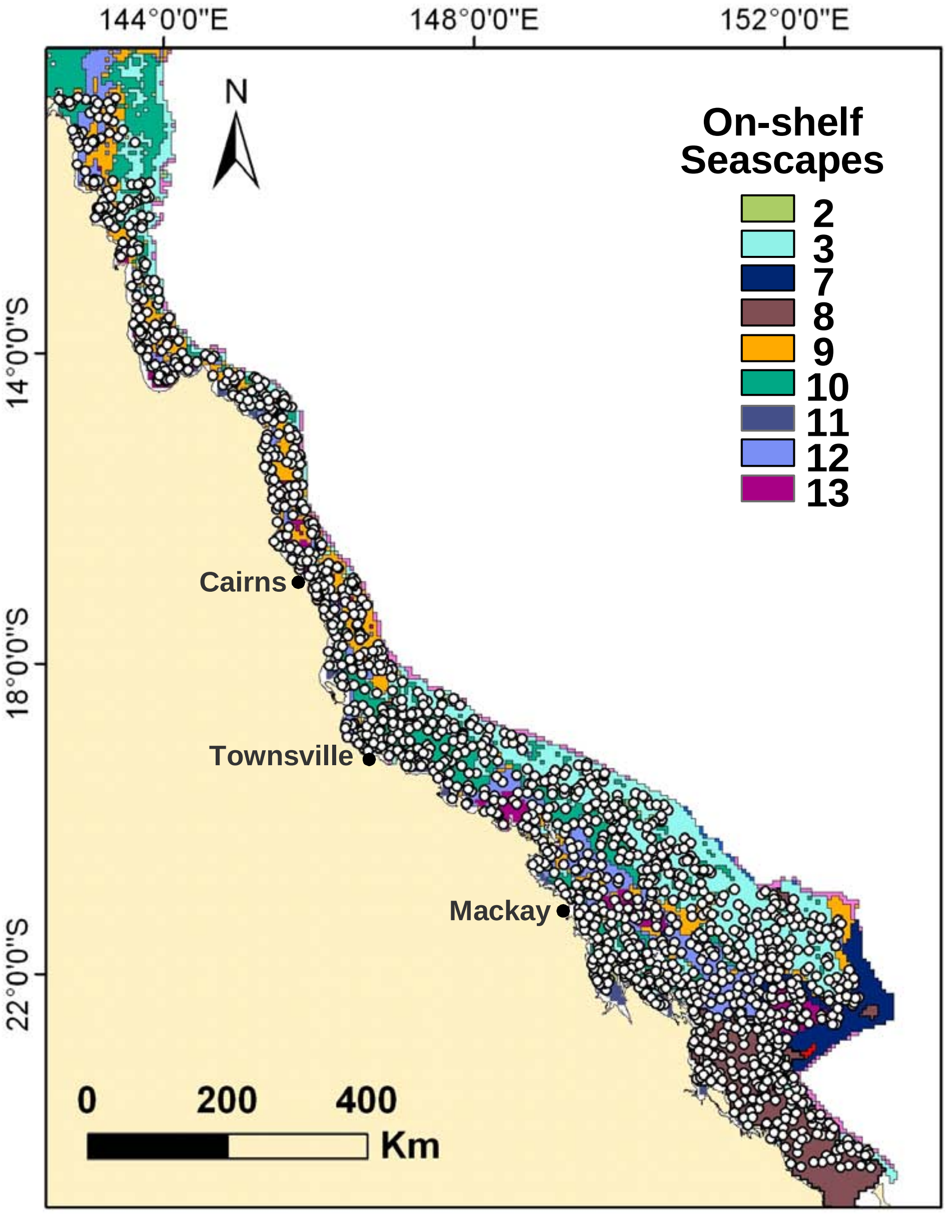


Figure 3.1. Distribution of GBR Seabed Biodiversity project epibenthic sled and seabed video sampling stations (white circles) relative to the GBR on-shelf seascapes. In general, seascapes were well sampled across the GBR with many stations sampled per seascape.

1,500 stations across the GBR lagoon (Figs. 3.1 & 3.2). At 1,219 of these stations a video camera system (Fig. 3.2A; Table 3.1) was towed 0.5 m above the seabed for a distance of ~500 m. Benthic cover was estimated from post-processing of the video footage (Pitcher *et al.*, 2007). Fauna and flora were classed into broad seabed habitat types: bioturbation, soft corals, gorgonian whips, sponges, hard corals, live-reef, flora, algae, *Halimeda*, *Caulerpa*, and seagrasses. At 1,194 stations an epibenthic sled (Fig. 3.2B; Table 3.1) was towed across the seabed for 200 m. All biota collected in the sled were sorted on deck into rough phylogenetic groups, namely: ascidians, bryozoans, cnidarians, crustaceans, echinoderms, fishes, molluscs, sponges, worms, seagrasses, algae (brown, green, & red), and remaining invertebrates (Fig. 3.2E), which were then weighed to provide biomass estimates for major biological groups (Pitcher *et al.*, 2007). These data were then used to produce benthic characterisations across the GBR (Fig. 3.3A, B). Only a subset of the full dataset has been used in this seascape evaluation.

Table 3.1. Data sources used for the national seascapes evaluation.

Data type	**Scale**	**No. data points**	***Biases***
GBR Seabed - sled	Regional	1,194 stations	*Sled - Biomass of dominant taxa **
GBR Seabed - video	Regional	1,219 stations	*Video - %cover of dominant taxa **

*Pitcher *et al*. (2007)

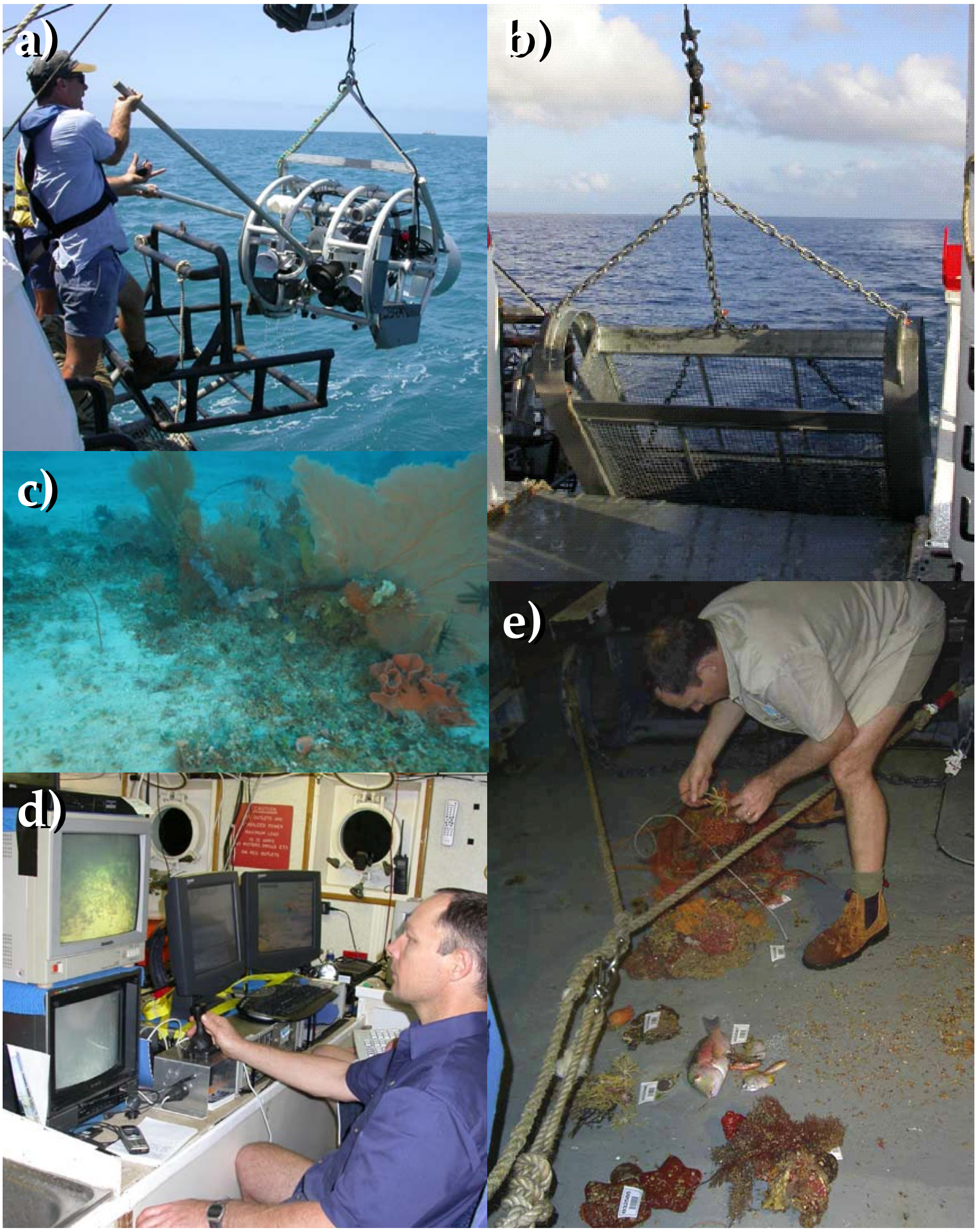


Figure 3.2. GBR Seabed Biodiversity Project - field sampling and processing. (A) Towed-video camera system used to characterise the seabed; (B) epibenthic sled used to sample benthic assemblages; (C) image of the seabed from the towed-video camera; (D) Characterising the seabed from real-time video footage of the seabed; (F) biological specimens captured in the epibenthic sled being sorted into rough phylogenetic groups. Photographs A, B, and D are copyright of the AIMS; photographs C and E are copyright of CSIRO and are used with permission.

Table 3.2. Summary data of the GBR Seabed Biodiversity project for sled and video data by on-shelf seascapes. On-shelf seascape 1 was not present on the GBR, while seascapes 4, 5, and 6 were either not sampled or were sampled at only a few stations.

On-shelf	2	3	4	5	6	7	8	9	10	11	12	13
Area (km^2)	2,783	68,305	405	199	6,303	10,748	28,087	35,265	92,605	5,391	36,523	14,105
Total area (%)	1	23	0.13	0.06	2	4	9	12	31	2	12	5
# Video stations	21	267	0	0	1	18	138	150	244	43	173	106
# Sled stations	31	206	0	0	1	22	142	127	253	52	185	118

Of the 13 on-shelf seascapes categorised for Australia, all but seascape 1 were present on the GBR. Of the total number stations 1,161 (96%) of the video stations and 1,137 (96%) of the epibenthic sled stations coincided with on-shelf GBR seascapes and were included in the analyses (Table 3.2). Although numerous stations were collected from most seascapes, no video or sled samples were collected from seascapes 4 and 5, and only 2 samples were collected from seascape 6 (Table 3.2). Consequently, these seascapes and stations were not included in analyses. Sample effort for the remaining seascapes varied between 31–253 stations for the sled survey, and 21–267 stations for the video survey (Table 3.2).

The advantages of the GBR Seabed Biodiversity project dataset are that it is the largest empirical dataset of its kind in Australia; it provides high density biological data over the extent of the GBR; and includes numerous stations for most GBR seascapes (Fig. 3.2). For this analysis we used the seabed video and epibenthic sled datasets, which recorded biomass and percent cover as continuous quantitative variables. One limitation is that while individual specimens were collected from the sleds, species-level data for all specimens from all samples are not yet available although some species-specific distributions are becoming available as they are processed (Pitcher *et al.*, 2007). Consequently, measures of biological taxa are presently available only as percentage cover (video) or biomass (sled) of dominant taxa rather than species-level information. Patterns of dominant taxa should provide adequate description of the seabed with each seascape however, species-specific patterns, when available, could be used to examine finer-scale distribution pattens in future.

3.2.2. Great Australian Bight (GAB)

Biological data spanning the on-shelf seascapes were obtained from Dr. Tim Ward at the South Australia Research and Development Institute (SARDI) and Geoscience Australia (GA). The SARDI biological data were collected from 500 m epibenthic sleds at 40 stations in October 2006 (Fig. 3.4) using the methods described in Currie *et al.* (2008). All 40 stations were located within or adjacent to the Benthic Marine Protection Zone (BPZ), with 30 stations in seascape 1, six stations in seascape 4, three stations in seascape 6, and one station in seascape 5 (Fig. 3.4a).

SARDI data were collected from a single survey during one month using the same sampling gear and protocol. Thus, real biological patterns are more likely to be detected because variation due to different people, sampling times, equipment, and methods is reduced. In addition, this survey targeted benthic marine invertebrates, which are likely to exhibit strong associations with benthic environmental variables. For each station at which SARDI biological data were collected, co-located grain-size data were obtained through the GA MARS database (www.ga.gov.au/oracle/mars), with the exception of Stations 26 and 45. For these stations, no MARS data were available, consequently, mud and gravel content were sourced from interpolated spatial layers as described below. Bathymetry was also recorded for each station during biological sample collection. The remaining physical factors

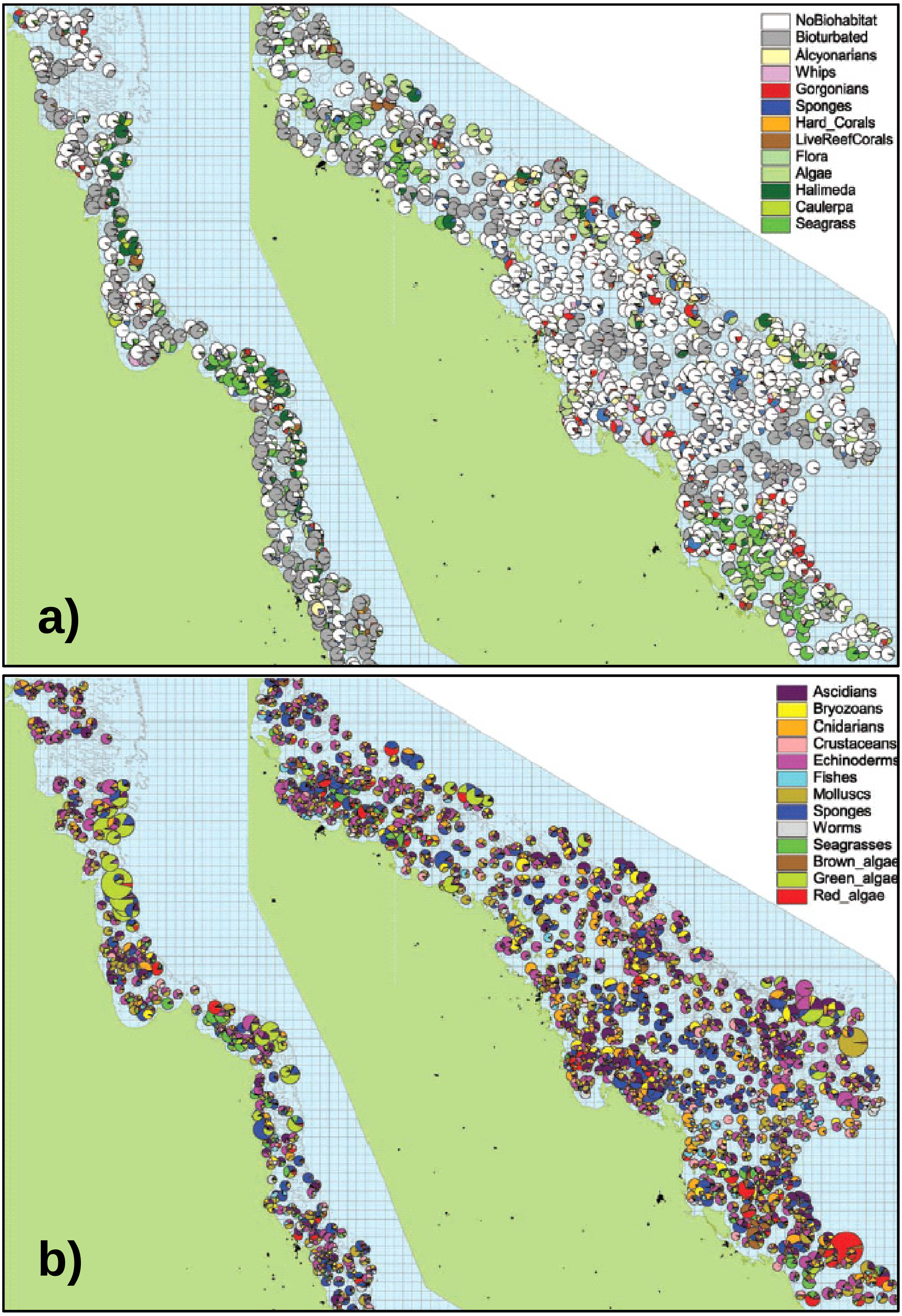


Figure 3.3. Map of the distribution of broad biological seabed habitat types observed during the GBR Seabed Biodiversity project over the extent of the GBR. (A) Towed-video stations; (B) Epibenthic sled stations. Reproduced from Pitcher *et al*. (2007) (p.54-55), "*The Great Barrier Reef: Biology, Environment and Management*" copyright CSIRO. Used with permission.

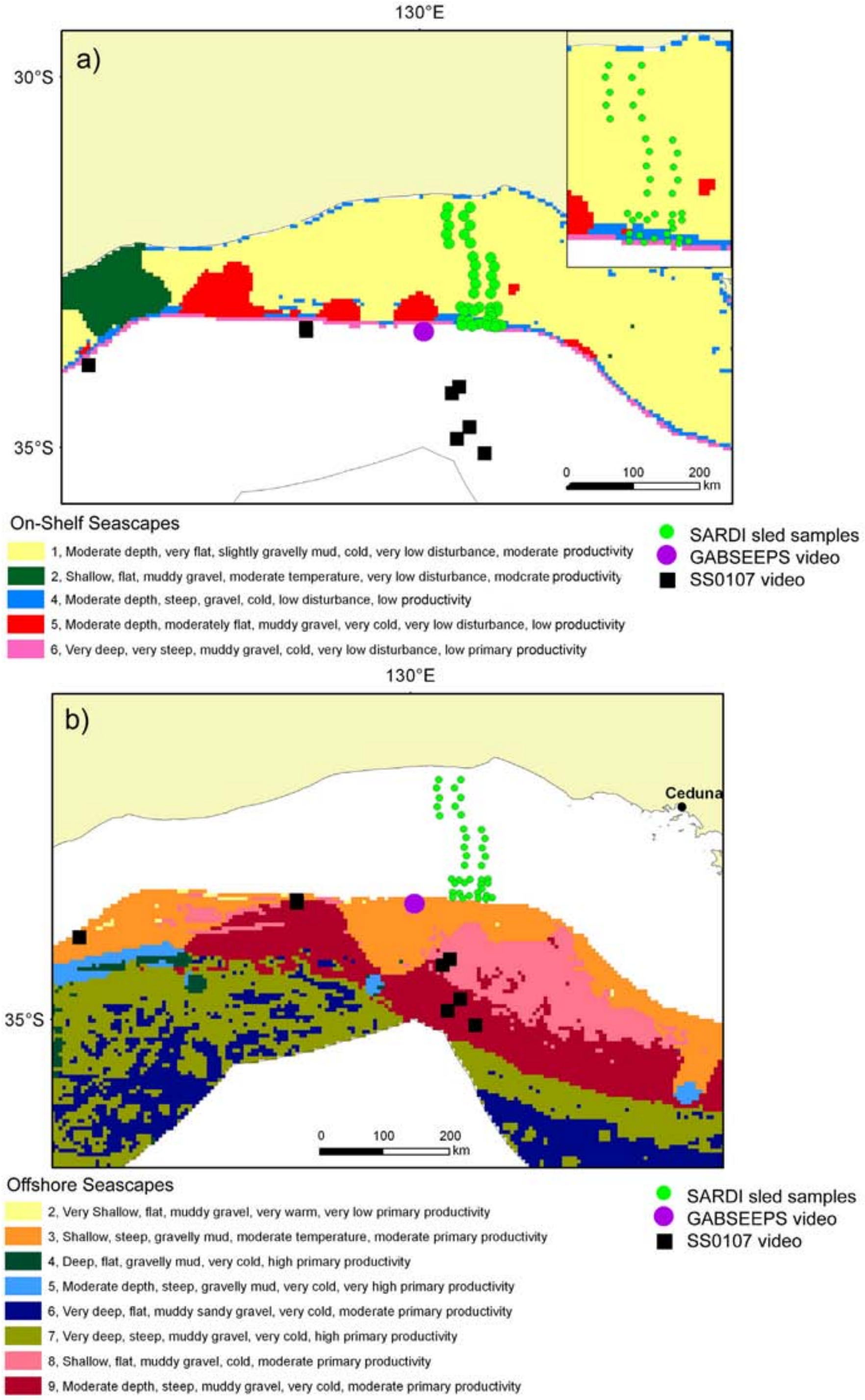


Figure 3.4. Location of biological data from the Great Australian Bight (GAB) overlaid on: (a) on-shelf and (b) off-shelf seascapes. Seascapes intersecting the GAB are also listed.

relevant to seascapes derivation were extracted from the respective interpolated spatial layers of the national on-shelf seascapes analysis using the Hawths Tools in ArcGIS (i.e., seabed temperature, slope, primary production, and effective disturbance).

Off-shelf biological data were characterised from seabed video footage of a single transect from GA's GAB-SEEPS survey in February 2001, and seven transects from the SS01/2007 survey in February–March 2007 (Fig. 3.4b) (Hughes *et al.*, 2009). Additional biological records (n=15) were sourced from OBIS, using a 0.5° grid-cell search where records overlapped with discrete seascapes in which video transects were located (Fig. 3.5).

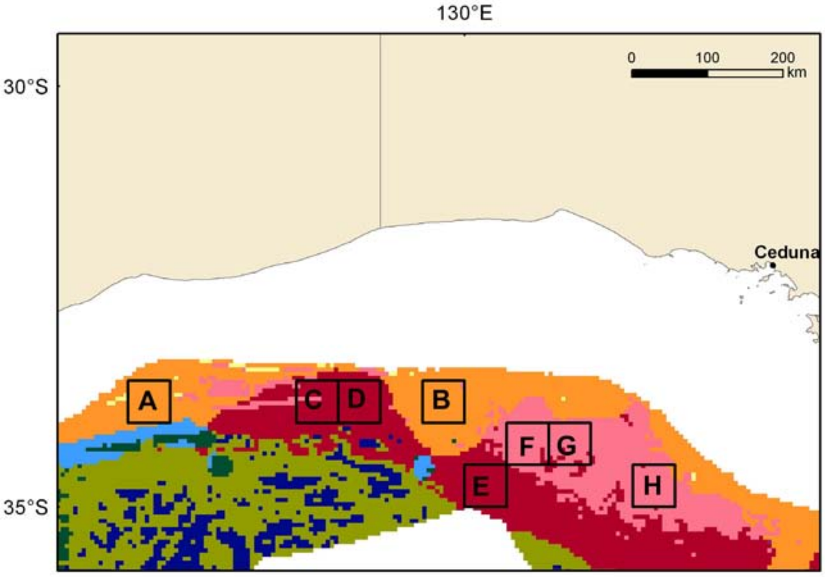


Figure 3.5. Map showing 0.5° grids searched in OBIS for species records.

3.3. DATA ANALYSIS

3.3.1. Great Barrier Reef (GBR)

To assess whether the seascape classifications as defined by the physical habitat characteristics were adequate predictors of the biological assemblage at the scale of the GBR we undertook two approaches on the data: Discriminant Function Analysis (DFA) and Classification Trees (CT). First, DFA uses a multivariate approach in which the position of a sample relative to the seascape centroid in multivariate space determines whether a sample is correctly classified. Second, the CT approach uses a divisive clustering algorithm to predict seascape classification. Both methods are complementary, and provide rates of correct and incorrect classification into different seascapes.

The sled data consisted of biomass data, which were log-normally distributed. A $\log_{10}$ transform was used to reduce both the skew of the data and the effect of large sled catches. Video data were measured as percent cover so an arcsin(√proportion) transform was used to reduce the skew in this dataset. Taxa correlations and the degree of redundancy within both the sled and video dataset were each examined using Principal Components Analysis (PCA). Variable correlations were generally low and no redundancy was found. The GBR Seabed Biodiversity project allocated sample stations without consideration/knowledge of the GA seascape classification and can be considered as unbiased samples of the GA seascapes. However, some of the GA seascapes were not present on the GBR (seascapes 1 & 5), while others were not adequately sampled by the GBR project (seascapes 4 & 6) due to small sample areas. These four seascapes were subsequently dropped from analyses.

DFA ordinations were run on both the sled and video data using SAS system (PROC DISCRIM) procedure. Initial DFA ordinations indicated no strong heterogeneity of variance-covariance matrices, and there were insufficient numbers to estimate within-group variance-covariances so a simple linear DFA was used in preference to a quadratic DFA, with equal prior probabilities. To evaluate how well the seascapes classified the biological assemblages in the DFA approach classification error rates (misclassification) were measured by cross-validation. The null probability of random allocation to a category assuming equal priors and a large number of samples was 11.1%, however this expectation is strongly influenced by sample size. To assess the likelihood of obtaining the observed probability for a given sample effort we generated 10,000 randomizations of a binomial process with random error and calculated the quartiles from the randomised distribution. Consequently we provide 75th, 90th, and 95th percentiles to give an indication of the 'significance' of the misclassification percentage. For example, a value above the 95th percentile would arise only 5% of the time due to chance for a given sample effort.

CT analyses were run on both the sled and video data, and calculated using the *rpart* function in the modelling software package R. For each dataset, we first generated a high-complexity tree then pruned the tree to the number of nodes that minimised the relative error (Venables & Ripley, 2002). To evaluate how well the seascapes classified the biological assemblages in the CT approach the relative error rate was estimated from the tree prediction. Finally, assemblages within each seascape and misclassification maps for both the sled and video data were plotted to evaluate the biological basis for dissimilarity between seascapes, and how these dissimilarities co-varied with space.

3.3.2. Great Australian Bight (GAB)

Among on-shelf seascapes, benthic assemblages were statistically analysed using the SARDI biological data and all co-located physical data. This was completed with non-metric multidimensional scaling plots (n-MDS) and analyses of similarities (ANOSIMs) for national seascapes. Biological data were transformed using presence/absence, as data for abundance were unavailable for many species.

Effects of taxonomic resolution and functional groups were evaluated using phyla, class, and species data, and mobility (sessile, mobile; trophic level- suspension feeder, scavenger, predator, deposit feeder, grazer). Functional groups are defined as a particular group of organisms sharing a similar biological or ecological function. N-MDS plots were derived and ANOSIMS were performed to compare the significance of seascapes across various taxonomic resolutions and functional groups. All multivariate analyses of species excluded station 7 because species at this station did not occur elsewhere and thus it represented an outlier in the data.

In order to identify taxa that may drive the observed patterns, the BVSTEP procedure in the computer software package PRIMER (v.6) was performed on the transformed SARDI biological data. In this approach, a stepwise algorithm is used to compare the original biological assemblage matrix with reduced matrices until an optimal reduced matrix is derived which includes the minimum number of taxa that account for 90% of the dissimilarity in the original data. The taxa remaining in this optimal reduced matrix are considered important drivers of the original trends (Clarke & Warwick, 2001). This procedure was applied to species, class, and phyla data to compare the effects of taxonomic resolution on the detection of biological drivers. In addition, stations across all seascapes, as well as stations within each seascape, were analysed to identify overall biological drivers and drivers that may be specific to each seascape. To examine the extent that the physical data explain the observed biological pattern (namely the similarity of benthic invertebrate assemblages between sites) the BVSTEP procedure was performed with the environmental data. The data were standardised to give each variable equal weighting. Assessment of the drivers was the same as for the biological dataset.

For offshore seascapes, benthic assemblages were qualitatively characterised using all available biological information, including Geoscience Australia seabed video (Fig. 3.4B), as well as available literature and OBIS.

3.4. RESULTS

3.4.1. GBR Seabed Biodiversity Patterns

3.4.1.1. Towed-video Data

The principal pattern in the video data was the contrast between high bioturbation and low percent cover of fauna and flora on the left of the DFA ordination, and no bioturbation and higher percent cover of fauna and flora on the right (Fig. 3.6). Five seascapes (7, 9, 11, 12, & 13) were characterised by high degrees of bioturbation and very low cover of fauna and flora (Figs. 3.6 & 3.7). In contrast, the four seascapes with little bioturbation (2, 3, 8, & 10) contained a range of benthic covers, albeit at low (<20%) levels, but were characterised by different suites of fauna and flora (Figs. 3.6 & 3.7). Seascape 8 was characterised by seagrasses and bivalve shells in addition to algae, gorgonians and *Halimeda*. Seascapes 2 and 3 also contained algae, gorgonians and *Halimeda*, but in contrast to seascape 8 were characterised by suspension-feeding invertebrates such as hard and soft corals, sponges, and gorgonian whips. Seascape 10 was variable and samples within this seascape could contain assemblages similar to seascape 8, 2 and 3, or 11. However within all seascapes these patterns were extremely variable, with considerable overlap indicated by the large standard deviations around the means (Fig. 3.6A).

The high variability within, and overlap between, seascapes in combination with the typically low percent cover of characteristic biota meant that the ability of the seascapes to predict assemblages was not very strong (Table 3.3). Seascape 7 had the highest classification success with 61.11% of samples being correctly classified, but was also frequently misclassified into seascapes 11 (22.22%) and 13 (11.11%). The five seascapes characterised by high bioturbation were as likely to be classified into the other four bioturbated seascapes as often as their own (Table 3.3). For example, seascape 12 samples could be classified as either 7 (23.70%), 11 (20.23%), or correctly into 12 (25.43%). This indicates that these five seascape classes contained a similar benthic assemblage.

The four seascapes that contained low levels of bioturbation with more flora and fauna were also relatively poor predictors of assemblage type. Seascape 8, characterised by seagrasses, was classified correctly 37.68% of the time, but was also frequently misclassified as seascapes 11 (20.29%) and 10 (14.49%) (Table 3.3). This misclassification may have occurred because seagrass was also present in seascapes 10 and 11, and biological assemblages of these three seascapes were very similar (Fig. 3.7). Similarly, seascape 10 was classified correctly only 21.72% of the time, but frequently misclassified as either seascapes 11 (24.18%), 8 (15.98%) or 3 (12.70%) (Table 3.3). Seascape 10 contained multiple assemblage types with some stations more similar to seascape 8, others more similar to seascapes 2 and 3, while more depauperate and bioturbated stations were similar to those in seascape 11 (Figs. 3.6 and 3.7). This within-seascape variability explains why seascape 10 was regularly misclassified into these other seascapes. Finally, we would have expected seascapes 2 and 3, which overlapped almost entirely in their assemblages (Fig. 3.6), to be equally misclassified as each other. However, while seascape 2 was frequently misclassified as seascape 3 (23.81% vs. 38.10% respectively), the reverse was not true (Table 3.3). In addition to being misclassified as seascape 3, seascape 2 was also misclassified as seascape 11 (23.81%). Seascape 3 on the other hand was correctly classified 29.59% of the time, and misclassified as seascapes 11 (22.10%) and 10 (14.23%), but not misclassified as seascape 2.

While misclassification rates among seascapes provide insight into the success of the seascape classification, understanding the reasons behind misclassifications is aided by

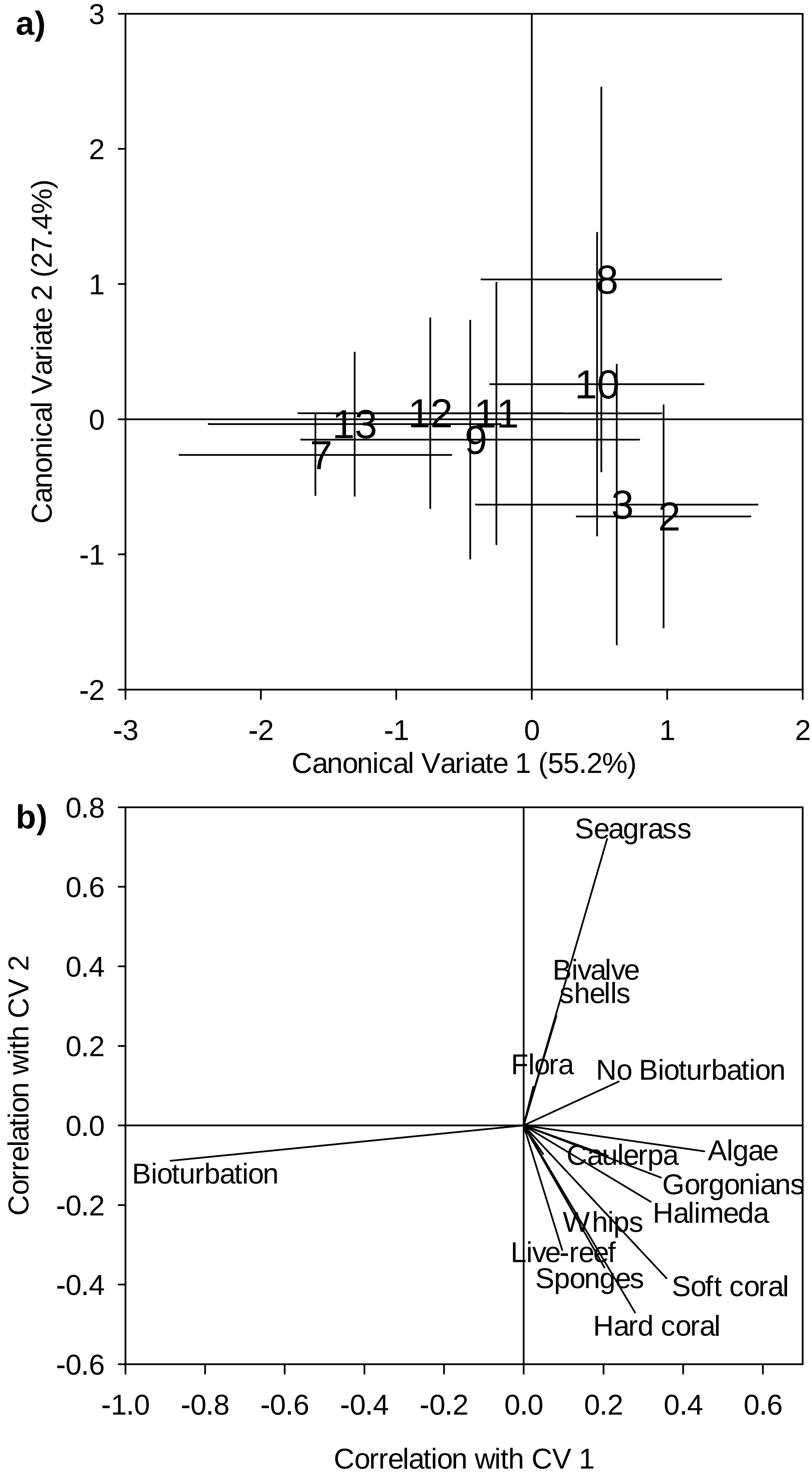


Figure 3.6. Discriminant Function Analysis (DFA) of the GBR video data. (A) Seascape mean centroids ± standard deviation; (B) correlation of video variables with canonical variate (CV) axes.

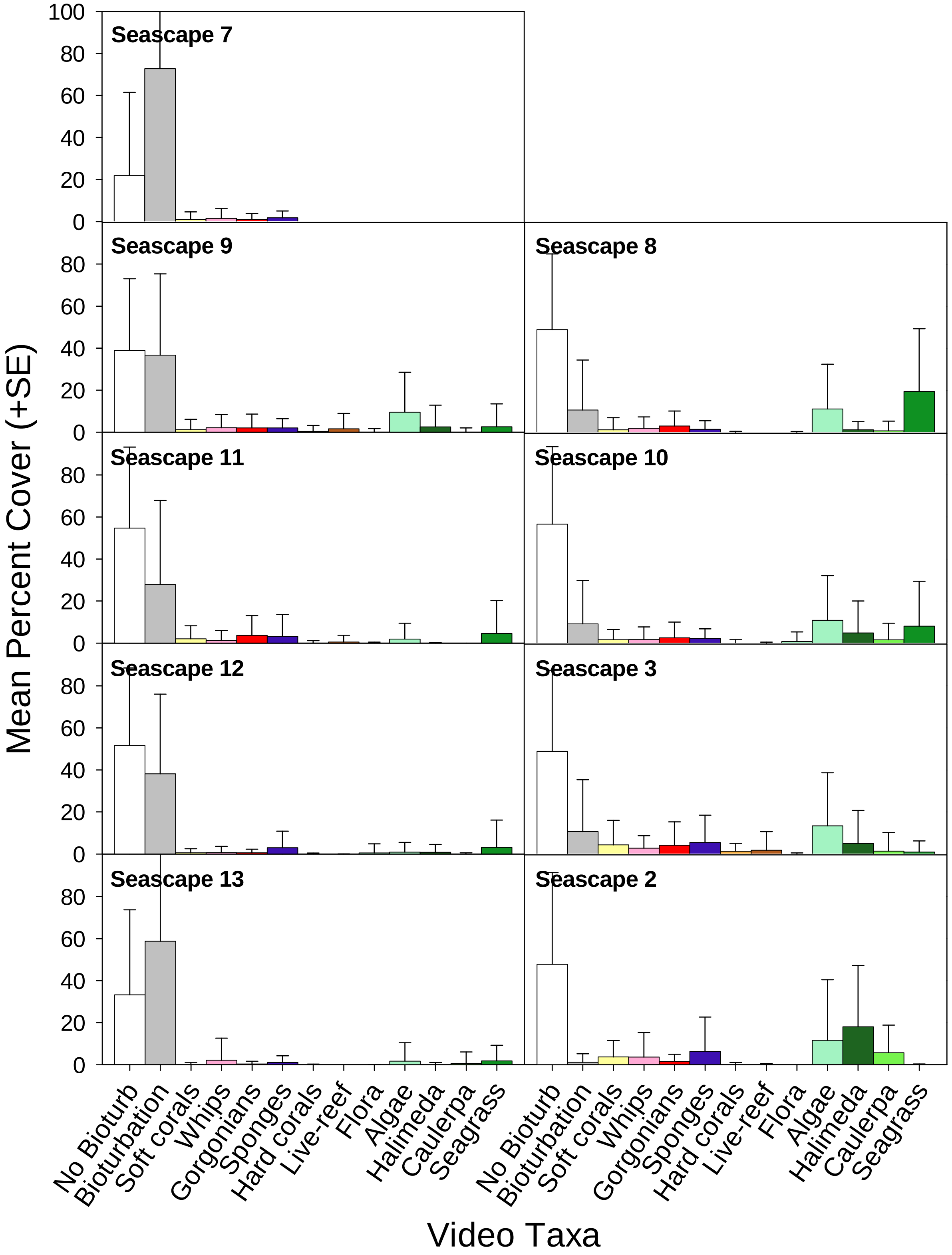


Figure 3.7. Seabed assemblages of the GBR video data relative to nine of the 13 on-shelf national seascapes found on the GBR.

Table 3.3. Discriminant Function Analysis (DFA) cross-validation misclassification rates and sample effort for GBR Video data. Blue text and light blue shading depict the percentage of samples that were correctly classified for a given seascape, while values in other columns in a given row indicate the percentage of samples misclassified into other seascapes. Shaded = 75th percentile; bold = 90th percentile; underlined = 95th percentile.

Seascape From	**% classified into**									***No. of stations***
	2	**3**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	
2	**23.81**	**38.10**	0.00	4.76	0.00	9.52	**23.81**	0.00	0.00	*21*
3	11.61	**29.59**	5.62	5.24	4.49	**14.23**	**22.10**	4.87	2.25	*267*
7	0.00	0.00	**61.11**	0.00	0.00	0.00	**22.22**	5.56	**11.11**	*18*
8	2.90	9.42	5.07	**37.68**	2.17	**14.49**	**20.29**	5.80	2.17	*138*
9	2.67	13.33	**24.67**	6.00	**12.67**	10.00	10.67	11.33	8.67	*150*
10	9.43	12.70	3.69	**15.98**	4.10	**21.72**	**24.18**	5.33	2.87	*244*
11	0.00	11.63	**20.93**	9.30	4.65	9.30	**34.88**	6.98	2.33	*43*
12	1.73	1.73	**23.70**	5.20	2.89	8.09	**20.23**	**25.43**	10.98	*173*
13	0.94	0.94	**50.00**	5.66	2.83	4.72	**19.81**	5.66	9.43	*106*

plotting the spatial position of correct and incorrect seascape classifications on the GBR, and evaluating the role of spatial position compared to random variability within categories, structural variability due to lumping of different biota into the same seascape, and redundancy in which multiple seascape classes describe the same biological assemblage. Several patterns emerge, as follows:

1. The better-predicted seascapes such as 7 and 8 were geographically restricted (Fig. 3.8). The localised spatial occurrence of these two seascapes, however, makes it difficult to determine whether the predictability is a function of the seascape characterization, a spatially autocorrelated feature of the local environment, or some combination of the two. Misclassification of both seascapes appeared to reflect a combination of within-seascape variability at this sampling scale, and a similarity with other seascape types. Seascape 8 was characterised by seagrasses. However, while seagrasses dominate the seabed within seascape 8, seagrass distribution is not limited to this seascape, but it is extremely broad—a pattern which is not reflected in any of the seascape classifications (Fig. 3.3A).
2. Seascapes that are frequently misclassified into each other—such as the highly bioturbated but otherwise relatively depauperate seascapes (7, 9, 11, 12, 13)—are typically widespread along the GBR with the exception of seascape 7 (Fig. 3.8). For these seascapes there appears to be no spatial influence in misclassification rates, but rather the misclassifications are due to between-seascape similarities—i.e., they each describe the same assemblage type (Fig. 3.7).

Seascapes 3 and 9, characterised by hard substrata (gravelly and reefal habitats respectively), differ in their ability to predict reef-associated assemblages. Stations in seascape 3 are broadly distributed and are located generally offshore around features such as the Ribbon reefs in the north and the Pompey's in the southern GBR, are characterised by gravelly substratum, and support a wide range of suspension-feeding invertebrates (Figs. 3.2, 3.7, and 3.8). This pattern corresponds well with the findings of Pitcher *et al.* (2007) who modelled these sites as high benthic stress areas positively correlated with exposed hard and gravelly substrata, and which support suspension feeding assemblages. However, high misclassification rates (Table 3.3) and the spatial position of errors indicate that fine-scale patchiness in assemblage structure within this seascape reduced predictive ability (Fig. 3.8). In contrast, seascape 9 was characterised by reefs and shoals in the seascapes-model,

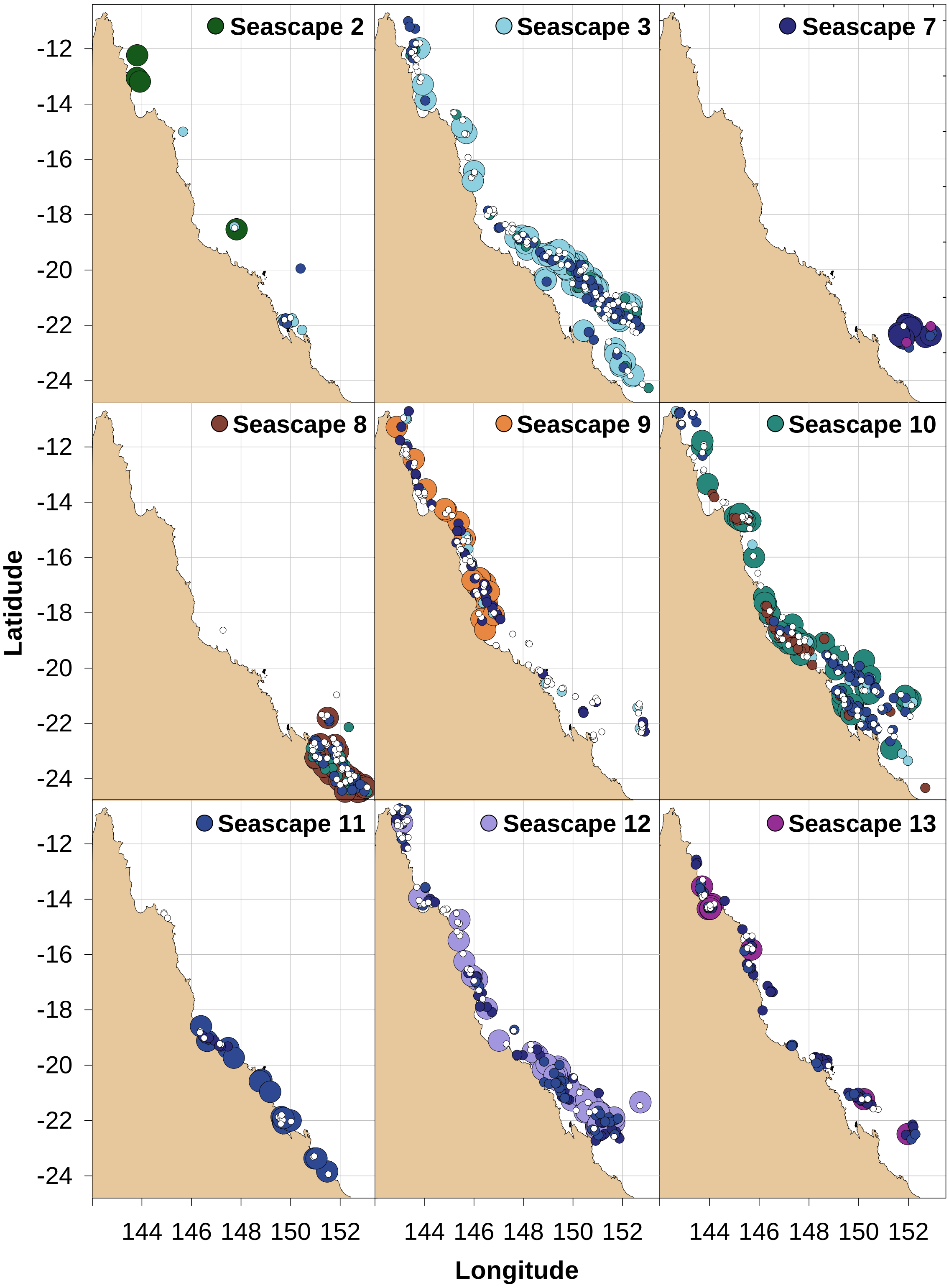


Figure 3.8 Misclassification maps for each seascape for GBR video data. Large circles in the colour of the seascape represent correct seascape classifications, smaller coloured circles depict high misclassification into other seascapes where the colour depicts the seascape it was misclassified with, small white dots depict lower misclassification rates into other seascapes.

which are generally characterised by suspension feeding invertebrates such as hard-and soft-corals, sponges, and gorgonians. However, the evaluation of seascape 9 against the GBR video data (and sled data) identified a depauperate sessile fauna and high levels of bioturbation, indicating muddy soft-sediment habitats rather than reef (Fig. 3.7). Seascape 9 was misclassified into other bioturbated seascapes (i.e. 7, 11, 12), but was rarely misclassified into other seascapes that were characterised by suspensions-feeders (i.e., seascapes 2 and 3), indicating that seascape 9 overall did not reflect either reefal or shoal habitats (Table 3.3). However, it is important to clarify that the GBR Seabed Biodiversity project did not sample shallow emergent coral reefs (<30 m depth), but rather aimed to survey deep inter-reefal habitats. Consequently, it is unclear what this effect had on the explanatory or predictive power of seascape 9.

The CT analysis provided an alternative way to evaluating the ability of seascapes to predict biological assemblages (Fig. 3.9, Table 3.4). In contrast to DFA, classification trees were better at predicting some seascapes, but worse at predicting others. Seascapes 3, 9, 10, 12, and 13 were better predicted by CT than DFA, however correct classification rates were still comparatively low (~50% or less). This improvement in predictive ability seemed to occur in seascapes with higher sample effort. In contrast, CT failed to predict seascapes 2, 7, and 11 when pruned to a level that minimised mean error (i.e., 8 nodes). These seascapes are less well sampled, but had been predicted—albeit with associated misclassification rates—in the DFA.

In contrast to DFA, which generally assigned misclassified samples to neighbouring seascapes in ordination space, CT generally misclassified samples into well sampled seascapes such as seascapes 3, 10, 12, and 13, and not necessarily the closest in overall assemblage structure. This is possibly due to CT using a divisive method to develop an ordered sequence of splitting rules rather than considering all variables simultaneously, and may result in this set of splitting rules being weighted in favour of those seascapes that are numerically dominant in the dataset.

The tree diagram (Fig. 3.9) provides some insight into both the differences between methods and the variability within seascapes. As with the DFA, the first split in the tree was based on the level of bioturbation. Subsequent splits are difficult to interpret biologically and were generally not informative. However, the end points (or leaves) of the tree indicate that there were multiple pathways or sets of biological assemblages that occurred within single seascape types. For example seascape 10, which consisted of a combination of assemblage types, could be predicted along four different pathways. Similarly, seascape 12 could be predicted along two pathways on opposite sides of the tree, which in turn implies that samples in seascape 12 could either be bioturbated or not.

3.4.1.2. Epibenthic-sled Data

Patterns in the sled data corresponded closely with those in the video data. The primary pattern was driven by the presence of biota and higher biomass on the right side of the DFA ordination (seascapes 2, 3, 8, & 10), and an absence of these biota on the left (seascapes 7, 9, 11, 12, & 13) (Figs. 3.10 & 3.11), which corresponds with the high bioturbation assemblages of the video data. Of the seascapes with biota, there was a contrast between seagrass and algal assemblages on the positive axis of Canonical Variate 2 (seascape 8) and suspension-feeding invertebrates such as sponges, ascidians, and cnidarians and benthic motile invertebrates such as echinoderms and crustaceans on the negative axis (seascapes 2 and 3). Seascape 10, as with the video data, fell between these two assemblage types indicating that some stations within this seascape contained seagrass and algal assemblages while others contained suspension-feeders.

Considerable overlap of the standard deviations around the means of each seascape indicates that the within-variability was again extremely high (Fig. 3.10A). This high variability within, and overlap between, seascapes in combination with the typically low percent cover of characteristic biota implies that the ability of the seascapes to predict assemblages is not very strong (Table 3.5; Fig. 3.12). Seascape 2 had the highest classification

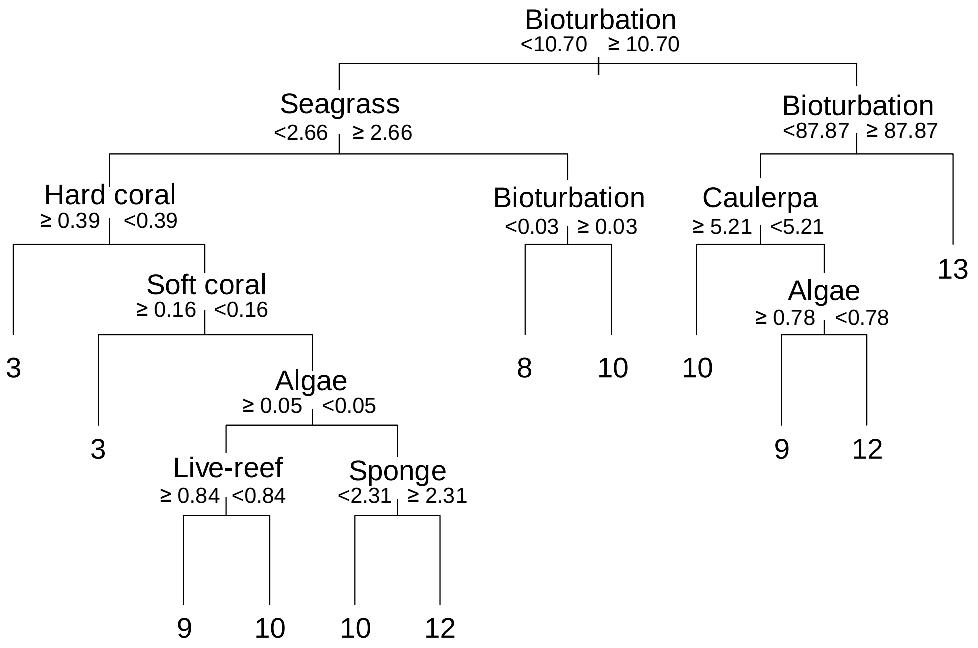


Figure 3.9 Classification Tree (CT) of the GBR video data relative to on-shelf seascapes. The trimmed tree predicted six of the nine seascapes sampled on the GBR.

Table 3.4. Classification Tree (CT) cross-validation misclassification rates and sample effort for GBR Video data. Blue text and light blue shading depict the percentage of samples that were correctly classified for a given seascape, while values in other columns in a given row indicate the percentage of samples misclassified into other seascapes. Shaded = 75th percentile; bold = 90th percentile; underlined = 95th percentile.

Seascape	**% classified into**									***No. of***
From	**2**	**3**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	***stations***
2	0.00	**42.86**	0.00	0.00	4.76	**42.86**	0.00	9.52	0.00	*21*
3	0.00	**55.06**	0.00	1.12	7.12	**24.34**	0.00	8.24	4.12	*267*
7	0.00	5.56	0.00	0.00	0.00	11.11	0.00	**27.78**	**55.56**	*18*
8	0.00	**14.49**	0.00	31.16	7.97	**27.54**	0.00	**15.22**	3.62	*138*
9	0.00	**18.00**	0.00	1.33	**21.33**	**15.33**	0.00	**26.67**	**17.33**	*150*
10	0.00	**27.05**	0.00	8.61	4.92	**48.36**	0.00	9.84	1.23	*244*
11	0.00	**25.58**	0.00	0.00	4.65	**34.88**	0.00	13.95	**20.93**	*43*
12	0.00	10.98	0.00	0.00	5.20	**17.34**	0.00	**47.98**	**18.50**	*173*
13	0.00	3.77	0.00	0.00	4.72	**22.64**	0.00	**21.70**	**47.17**	*106*

success with 51.61% of samples being correctly classified, but this seascape was also frequently misclassified into seascapes 3 (19.35%). As with the video data, the bioturbated seascapes were frequently misclassified as each other although to a much lesser degree. Seascape 7, for example, was correctly classified 45.45% of the time although its classification into seascape 13 was also high (31.82%). The similarity in misclassifications between the two data sets indicated they sampled the habitat comparably, but the better classification rates of the sled data indicated this would be a better sampling method. However, the sled data provided no further explanatory ability for seascape 9 which again did not characterise reefal assemblages (Fig. 3.11). The four seascapes that contained low levels of bioturbation but more flora and fauna were generally better predicted (Table 3.5). Seascape 8 was correctly predicted 48.59% of the time, and seascapes 2 and 3 which overlapped in ordination space

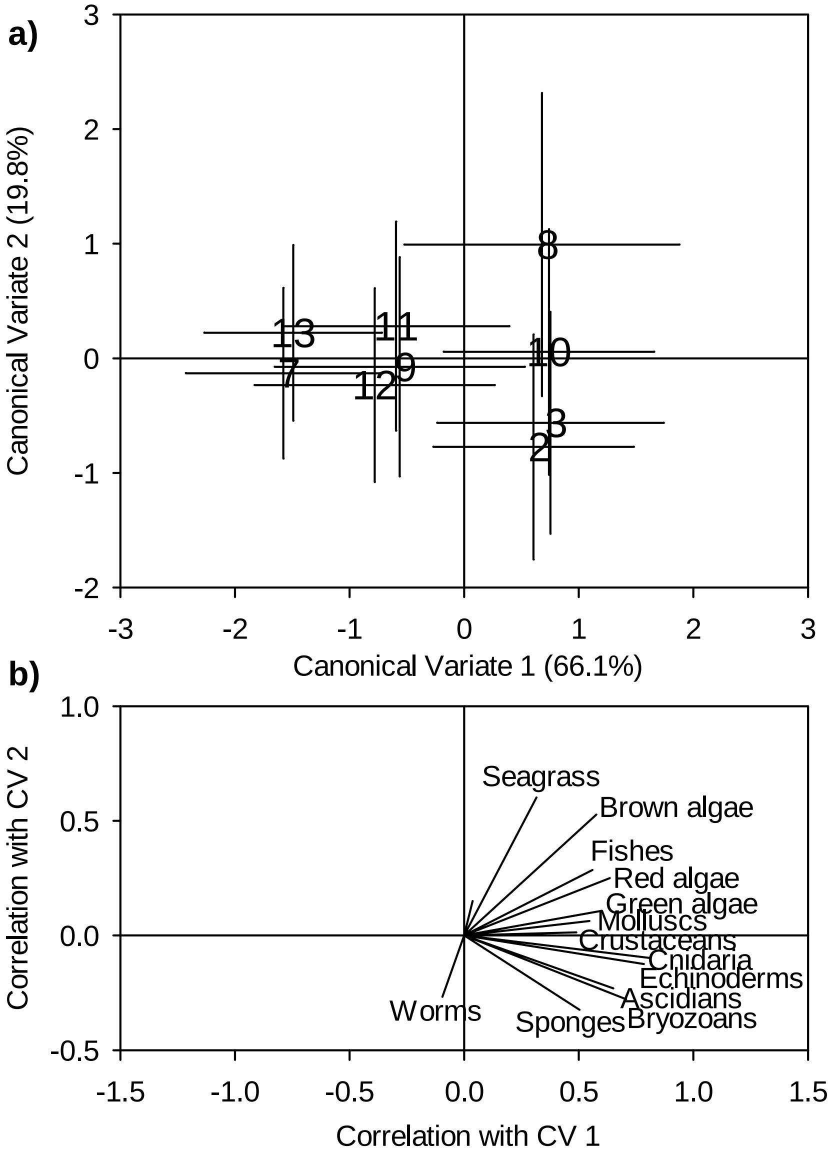


Figure 3.10 Discriminant Function Analysis (DFA) of the GBR Seabed Biodiversity project epibenthic-sled data. (A) Seascape centroids ± standard deviation; (B) correlation of sled variables with canonical variate (CV) axes.

were equally predicted as each other, indicating that when sampled by sled, their assemblages were indistinguishable. However these seascapes were rarely predicted as anything else. Seascape 10 was as frequently misclassified into seascape 3. Seascape 8 was correctly classified, reinforcing that this seascape contained a variety of different biological assemblages.

3.4.2. GAB Biological Assemblages and On-shelf Seascapes

Benthic invertebrate assemblages from the SARDI biological data were significantly different across the on-shelf seascapes in the BPZ (R=0.421, p=<0.001). Assemblages in seascape 1 were significantly different from assemblages in both seascapes 4 and 6 (Fig. 3.14). Seascapes 4 and 6 group together and the ANOSIM revealed no significant differences. Although, this may be due to the low number of samples in both seascape 4 (n=6 samples) and seascape 6 (n=3 samples), it also appears that seascape 4 may reflect a transitional assemblage along a narrow (5-17 km) but intermediate depth zone lying between the shallower depths of seascape 1 and the deeper depth zone of seascape 6.

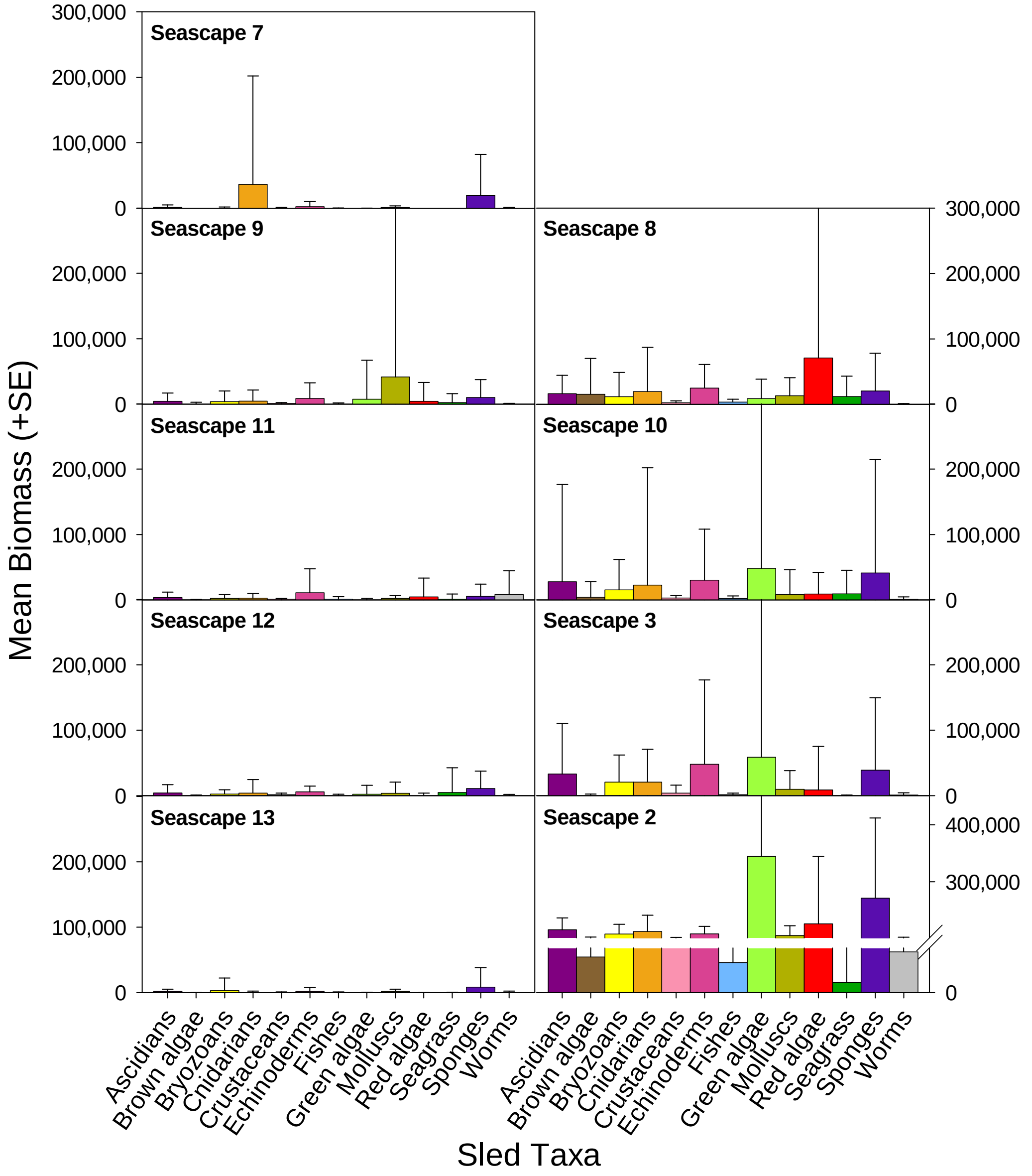


Figure 3.11 Seabed assemblage structure of the GBR Seabed Biodiversity project epibenthic-sled data relative to nine of the 13 on-shelf national seascapes found on the GBR.

Table 3.5. DFA cross-validation misclassification rates and sample effort for GBR Seabed Biodiversity project epibenthic-sled data. Blue text and light blue shading depict the percentage of samples that were correctly classified for a given seascape, while values in other columns in a given row indicate the percentage of samples misclassified into other seascapes. Shaded = 75th percentile; bold = 90th percentile; underlined = 95th percentile.

Seascape					To					No. of
From	2	3	7	8	9	10	11	12	13	Samples
2	**51.61**	19.35	0.00	6.45	3.23	6.45	0.00	9.68	3.23	31
3	**16.50**	**42.72**	1.94	9.22	3.88	13.11	4.85	4.85	2.91	206
7	9.09	0.00	**45.45**	0.00	0.00	0.00	4.55	9.09	**31.82**	22
8	9.15	11.97	7.75	**48.59**	2.11	5.63	4.23	2.82	7.75	142
9	9.45	9.45	11.81	9.45	**10.24**	4.72	14.17	**15.75**	14.96	127
10	10.67	**26.88**	2.77	**22.53**	4.74	**15.81**	7.91	7.11	1.58	253
11	1.92	1.92	11.54	**17.31**	13.46	3.85	**17.31**	**15.38**	**17.31**	52
12	4.86	8.65	**14.05**	5.41	10.27	5.41	11.35	**23.24**	**16.76**	185
13	2.54	1.69	**21.19**	0.00	5.93	0.00	11.86	13.56	**43.22**	118

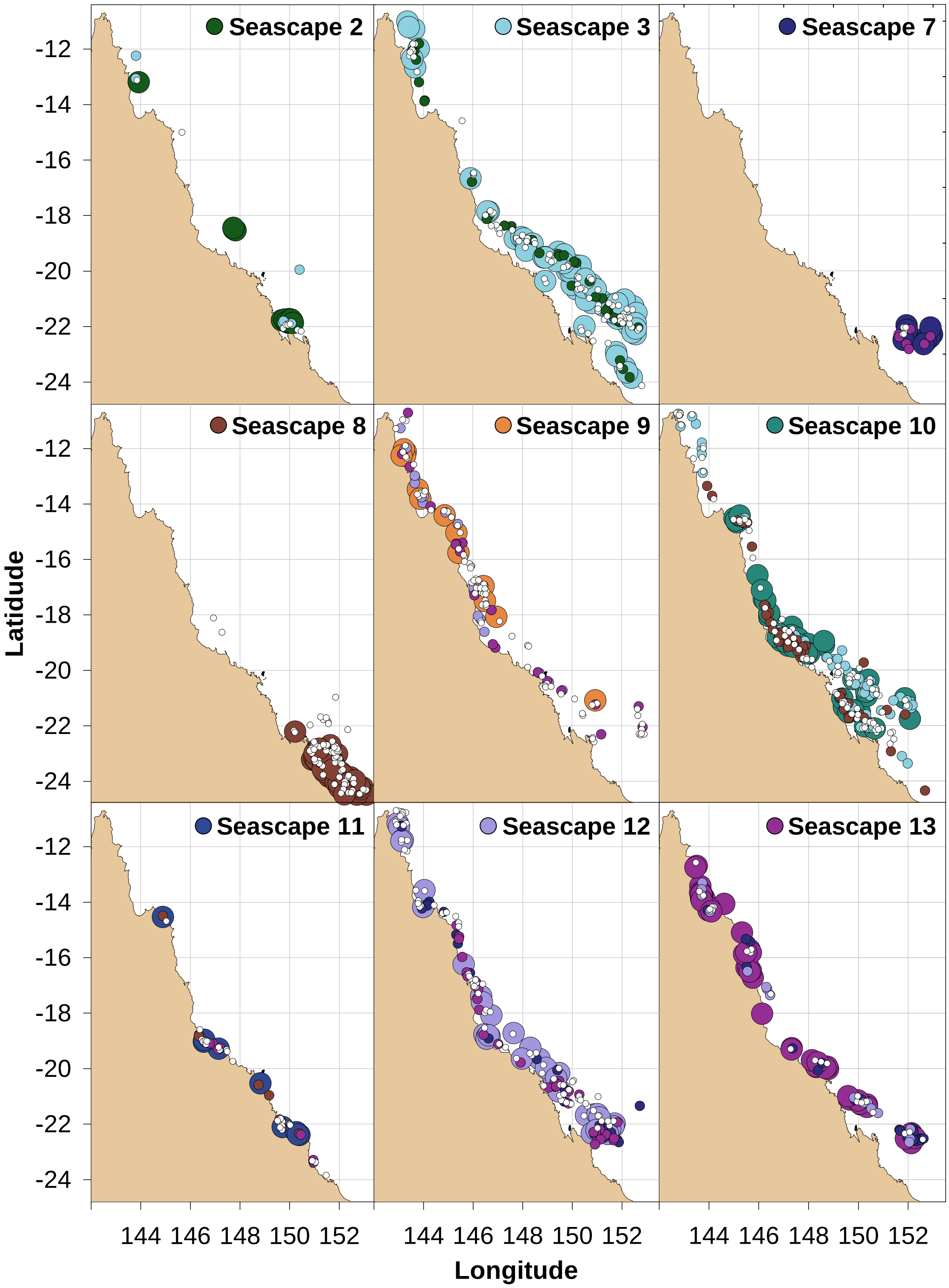


Figure 3.12 Misclassification maps for each seascape for GBR Seabed Biodiversity project epibenthic-sled data. Large circles in the colour of the seascape represent correct seascape classifications, smaller coloured circles depict high misclassification into other seascapes where the colour depicts the seascape it was misclassified with, small white dots depict lower misclassification rates into other seascapes.

3.4.2.1. Taxonomic Resolution

The ability to detect differences in biological assemblages among seascapes decreased with reduced taxonomic resolution. For species, relationships between biological assemblages and seascapes were highly significant ($p=<0.001$), with seascapes coinciding with 42% of the variation in biological assemblages (Fig. 3.15A). For class, these relationships were only moderately significant ($p=0. 031$), with seascapes coinciding with 19.4% of the variation in

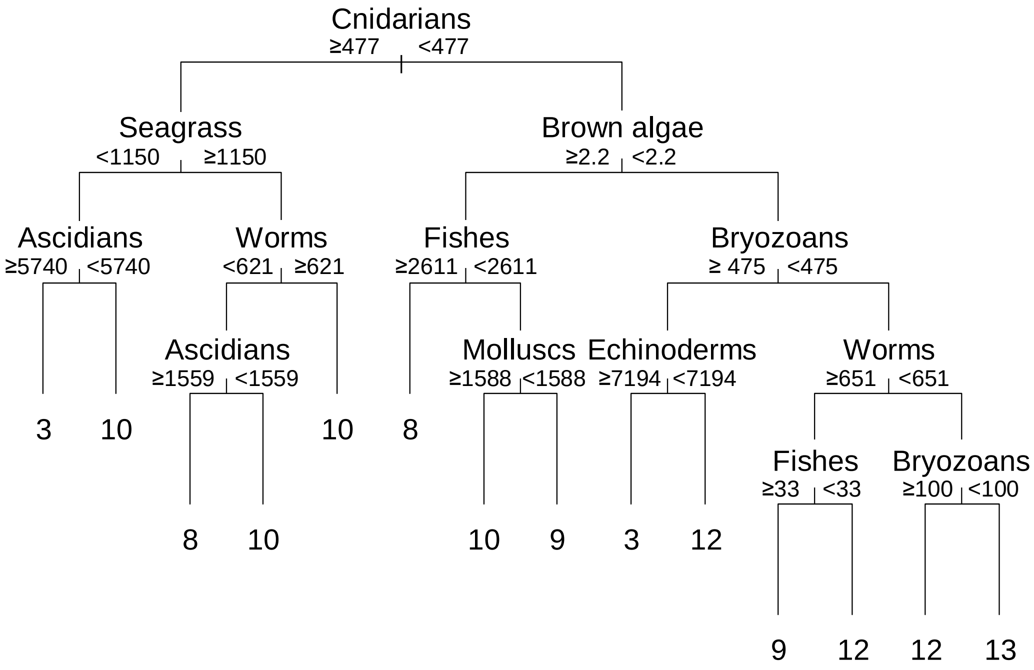


Figure 3.13 CT of the GBR Seabed Biodiversity project epibenthic-sled data relative to on-shelf seascapes. The trimmed tree predicted six of the nine seascapes sampled on the GBR.

Table 3.6. CT cross-validation misclassification rates and sample effort for GBR Seabed Biodiversity project epibenthic-sled data. Blue text and light blue shading depict the percentage of samples that were correctly classified for a given seascape, while values in other columns in a given row indicate the percentage of samples misclassified into other seascapes. Shaded = 75th percentile; bold = 90th percentile; underlined = 95th percentile.

Seascape	% classified into									***No. of***
From	**2**	**3**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	***stations***
2	0.00	**61.29**	0.00	0.00	0.00	**32.26**	0.00	3.23	3.23	*31*
3	0.00	**59.71**	0.00	2.91	4.37	**25.73**	0.00	4.85	2.43	*206*
7	0.00	9.09	0.00	0.00	9.09	13.64	0.00	**27.27**	**40.91**	*22*
8	0.00	**21.13**	0.00	**31.69**	5.63	**30.99**	0.00	3.52	7.04	*142*
9	0.00	9.45	0.00	1.57	**15.75**	**33.07**	0.00	**20.47**	**19.69**	*127*
10	0.00	**30.04**	0.00	5.53	1.98	**56.13**	0.00	5.14	1.19	*253*
11	0.00	13.46	0.00	1.92	**17.31**	**30.77**	0.00	13.46	**23.08**	*52*
12	0.00	11.89	0.00	1.08	3.78	**25.95**	0.00	**33.51**	**23.78**	*185*
13	0.00	4.24	0.00	0.00	5.93	11.02	0.00	**20.34**	**58.47**	*118*

biological assemblages and only weakly defined groups present in the n-MDS plot (Fig. 3.15B). For phyla, there was no significant relationship between seascapes and biological assemblages (p=0.247), with seascapes coinciding with only 6.8% of the biological variation and no groups evident in the n-MDS plot (Fig. 3.15C).

3.4.2.2. Functional Groups

Treatment of biological data as functional groups prohibited detection of differences among seascapes. The n-MDS plots revealed only a very slight grouping of biological assemblages coinciding with seascape 1 (Fig. 3.16). The ANOSIM detected no significant relationships between seascapes and trophic level (R=-0.07, p=0.795) or seascapes and mobility (R=-0.081,

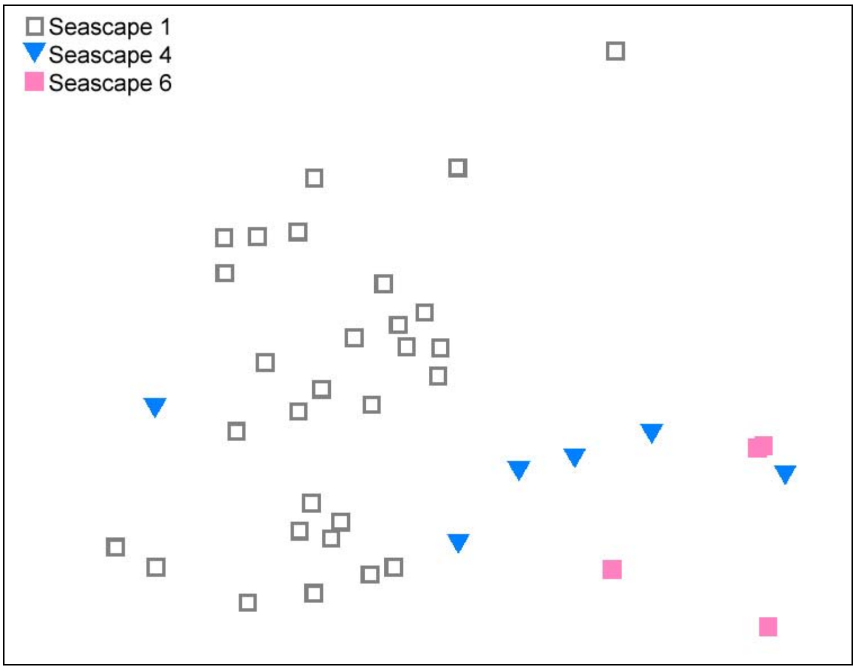


Figure 3.14 Non-metric multidimensional scaling plot (n-MDS) of benthic invertebrate species assemblages, with seascape as a factor. Each point represents the biological assemblage at a given station. The distance between points indicates the similarity among assemblages, with closer points denoting more similar assemblages than distant points. Stress = 0.09.

p=0.838). The distribution of animals among functional groups was highly uneven with 500 sessile animals and 87 mobile animals. A total of 507 animals were suspension feeders, 55 scavengers, nine predators, eight deposit feeders, and six grazers.

3.4.3. GAB Biological Assemblages and Off-shelf Seascapes

Much of the regional information about biodiversity in the GAB is derived from the shelf, and the paucity of data from deeper waters makes identification of biodiversity patterns for off-shelf seascapes problematic. The applicability of the on-shelf patterns listed below to deeper waters remains uncertain:

- *Feeding guild.* Suspension feeders may be more common than deposit feeders in some areas of the GAB, possibly reflecting a lack of terrigenous input to sediment, which limits the food available to deposit feeders (Ward *et al.*, 2006).
- *Distribution of sessile fauna.* As groups, sponges, ascidians, and bryozoans are broadly distributed on the shelf of the GAB, but individual species may have much more limited distributions (Ward *et al.*, 2006; Sorokin *et al.*, 2007), suggesting that differences across seascapes in the GAB are likely to only be detected using species-level information.
- *Substrate and sessile fauna.* The outer shelf and upper slope are often dominated by abundant bryozoan and sponge assemblages, which occur more frequently on hard substrate than soft. Rippled sandy bottoms have almost no epibenthos (Richardson *et al.*, 2005).
- *Biodiversity, depth, and grain size.* On the shelf, species richness and biomass decline with increasing depth and proportion of mud in the sediments, except for crabs and shrimp which increase with mud (Ward *et al.*, 2006). Smaller sessile species may be more prevalent in deeper waters with higher proportions of mud, as they may be able to better use fine sediments (Sorokin *et al.*, 2007).

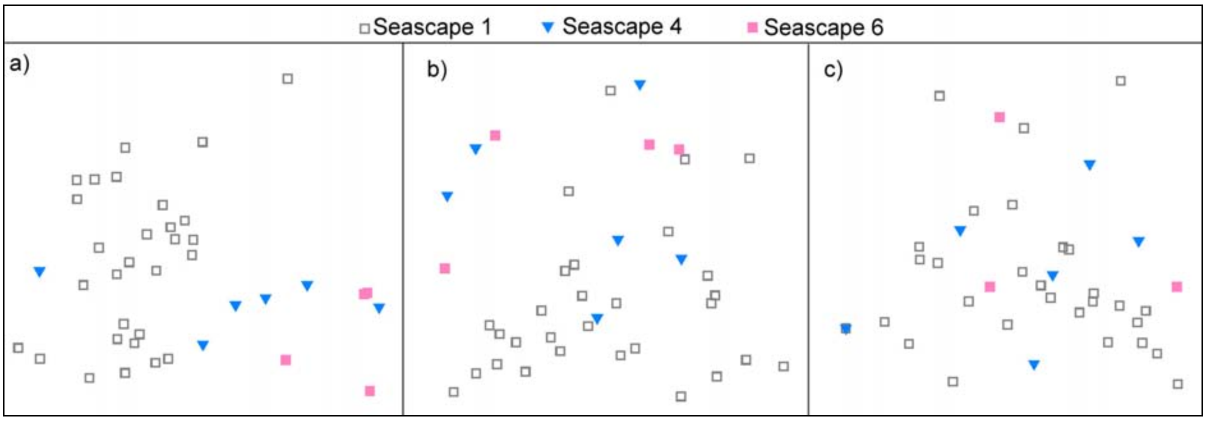


Figure 3.15 Non-metric multidimensional scaling plot (n-MDS) of benthic invertebrate species assemblages at different taxonomic resolutions: (A) Species (stress = 0.09), (B) Class (stress = 0.17), and (C) Phyla (stress = 0.15). Each point represents the biological assemblage at a given station. The distance between points indicates the similarity among assemblages, with closer points denoting more similar assemblages than distant points.

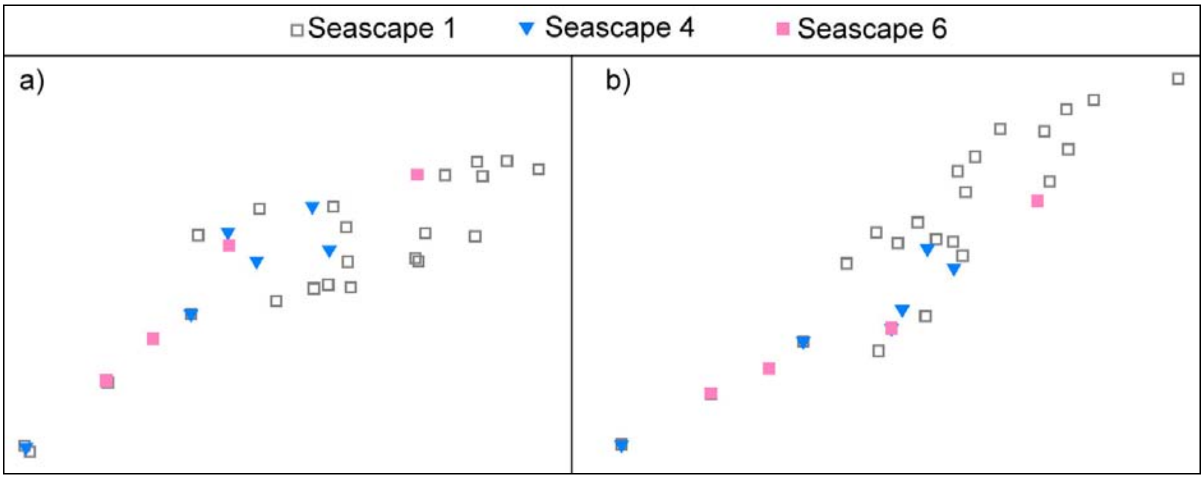
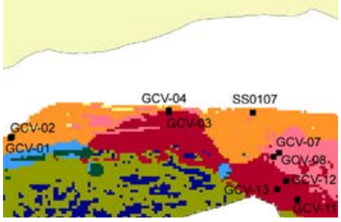


Figure 3.16 Non-metric multidimensional scaling plot (n-MDS) of benthic invertebrate assemblages using different functional groups: (A) trophic level (stress = 0.03) and (B) mobility (stress = 0.02). Each point represents the biological assemblage at a given station. The distance between points indicates the similarity among assemblages, with closer points denoting more similar assemblages than distant points.

Video transects from previous surveys provide some indication of biodiversity in these deeper waters for several seascapes. All video transects were undertaken in off-shelf areas, and descriptions are presented in Appendix B. The seabed was predominately bioturbated soft sediments with flat or low relief, with the exception of video transect GCV-12 in seascape 9 which revealed steep rock faces, interspersed with rocky moderate relief and flat muddy plains. This station also had the most diverse fauna, with the hard substrata supporting gorgonian gardens and other sessile organisms which provided habitat for numerous ophiuroids and crinoids, as well as other echinoderms, fish, and prawns (Table 3.4). No other station in seascape 9 had similarly diverse assemblages. At the national scale, seascapes did not differentiate the hard substrate on transect GCV-12 from the surrounding soft sediments shown in videos transects GCV-03, 04, 11, and 13.

There were no obvious associations with individual seascapes for most taxonomic groups examined, and large variations in presence and abundance occurred within seascapes (e.g., crinoids & brittlestars in seascape 3) (Table 3.7). An exception to this is the occurrence of pelagothurids, which were observed resting on the seabed or swimming along most transects from seascapes 8 and 9. Both of these seascapes are characterised by cold temperatures and muddy gravel substrates. In some transects, pelagothurids were extremely abundant. Dense herds were seen in video transects GCV-04, 07, and 08, with the last

Table 3.7. Relative abundance of organisms in off-shelf seascapes. Values are standardised for the duration of usable video in each transect, such that each value is the number of organisms occurring in an hour of video footage. The number of gorgonians, sea whips, soft corals, and associated crinoids and ophiuroids were estimated in transect GCV-12 due to the high abundance of these organisms. The inset map shows the location of the video transects in relation to off-shelf seascapes. Seascape 3 = orange; seascape 8 = pink; seascape 9 = red.

	**Seascape 3**			**S'scape 8**	**S'scape 8 & 9**	**Seascape 9**				
	SS01/07	GC01	GC02	GC07	GC08[1]	GC03[2]	GC04[2]	GC11	GC12	GC13
	727 m	615 m	632 m	1288 m	1427 m	957 m	897 m	2770 m	1624 m	2282 m
ECHINODERMS										
Brittlestar	0	51.5	18.9	4.0	0	0	0	0	1059	2.1
Starfish	0	0	3.6	2.0	1.4	0	0.6	0	0	2.9
Crinoid	0	0	184.0	0	0	2.1	0	0.8	353	2.9
Urchin	19.0	44.9	2.0	0.7	0	0	0	14.1	1.4	0
Holothurian (pelagothurid)	0	0	0	172.4	1079	23.5	136	0	14.1	12.9
Holothurian (other)	0	46.0	57.6	1.5	0	1.4	0	5.5	7.1	3.6
FISH										
Bony	25.0	16.3	19.9	39.6	73.7	44.8	94.7	7.9	38.8	10
Rays & Sharks	0	0	2.0	0	0	0	0	0	0	0
CRUSTACEANS										
Prawn/Scampi	2.5	0	8.2	9.5	1.4	8.5	26.7	15.7	3.5	2.9
Squat Lobster	0	0	0	0	0	0	0	48.8	0	0
Crab	0	0	0	1.5	0	0	0	0	0	0
CNIDARIANS										
Anemone	2.5	0	2.0	0	0	0	0	0.8	7.1	0
Sea Whip	0	0	0	0	0	0.7	0	0	70.6	0
Gorgonian	0	0	0	0	0	0	0	0	353	0
Soft Coral	0	0	0	0	0	0	0	0	70.6	0
WORMS										
Worm	0	0	0	0	4.1	0	0	0.8	0	0.7
UNKNOWN										
'Benthic jelly'[3]	0	0	0	6.5	37.2	0	0	0	0	0
'Dumbells'[3]	0	0	0	0	0	0	0	0	7.1	0
'Bi-lobed sessile'[3]	37.5	0	0	0	0	0	0	0	0	0

[1] Very close to seascape 8.

[2] Very close to seascape 3.

[3] See Appendix B for descriptions of these unknown animals.

transect containing approximately 500 animals over a period of five minutes. To our knowledge, this is the first record of such high densities of pelagothurids in Australian waters. By contrast, pelagothurids were absent for seascape 3 (Table 3.7), which is characterised by shallow waters, moderate seabed temperatures, and a steep gravelly muddy seabed compared to other offshore seascapes. Holothurians are known to have abrupt spikes in population density in response to nutrient input on the seabed (Uthicke *et al.*, 2009). It is possible that seascapes 8 and 9 represented habitats with higher nutrient availability while seascape 3 had lower nutrients. Alternatively, this species may have been linked to a depth-related variable such that the shallower environments of seascape 3 were unsuitable compared with the deeper habitats of seascapes 8 and 9.

OBIS returned very few records for the grids searched and all species listed were only

Table 3.8. Species records from OBIS in which 0.5° grids that overlapped discrete seascapes were searched. The grid letters represent the area defined in Figure 3.2. Data accessed 4 June 2009.

			Seascape 3		**Seascape 9**			**Seascape 8**		
Species	**Common Name**	**Taxa**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Bathysaurus ferox	Deepsea lizardfish	Fish	X							
Diretmichthys parini	Parin's spiny fin	Fish	X							
Paratrachichthys trailli	Common roughy	Fish	X							
Lucigadus nigromaculatus	Blackspotted grenadier	Fish		X						
Paraliparis lasti		Fish		X						
Ceratias holboelli	Deep sea angler fish	Fish							X	
Halosauropsis macrochir	Abyssal halosaur	Fish							X	
Remora remora	Common remora	Fish								X
Nototodarus gouldi	Gould's flying squid	Cephalopod				X				
Opisthoteuthis pluto	Octopus	Cephalopod					X			
Rossia australis	Squid	Cephalopod						X		
Pyroteuthis margaritifera	Squid	Cephalopod								X
Dendrobathypathes isocrada	Black coral	Cnidarian		X						
Parantipathes helicosticha	Black coral	Cnidarian							X	
Globicephala sp.	Dolphin	Cetacean		X						

Table 3.9. Species that accounted for 90% of variation among biological assemblages from the GAB.

Phyla	**Class**	**Name**	**No. Stations/Total Abundance**[1]
Bryozoa	Gymnolaemata	*Adeona* sp	15
Bryozoa	Gymnolaemata	*Amathia tortuosa*	3
Bryozoa	Gymnolaemata	*Cellaria* sp 1	6
Bryozoa	Gymnolaemata	*Lunularia capulus*	11
Bryozoa	Gymnolaemata	*Lunularia repanda*	8
Bryozoa	Gymnolaemata	*Orthoscuticella* sp. 139	5
Bryozoa	Gymnolaemata	*Orthoscuticella* sp. 206	8
Bryozoa	Gymnolaemata	*Triphyllozoon* sp. 1	9
Chordata	Ascidiacea	Ascidian sp. 89	7
Cnidaria	Hydrozoa	*Haplopteris glutinosa*	6
Porifera	Demospongiae	*Chondropsis* sp.178	6

[1] These values are the same number, as no more than a single specimen for each species occurred at a given station.

found once (Table 3.8). Thus, no species-level patterns could be determined. Of the two dominant groups (fish and cepholopods), cephalopods were not recorded from seascape 3, and fish were not recorded from seascape 9. Due to the low number of records and nature of OBIS as presence-only data no biological patterns were inferred in this region.

3.4.3.1. Biological Drivers

Across all seascapes, 11 out of 360 species accounted for 90% of the differences among

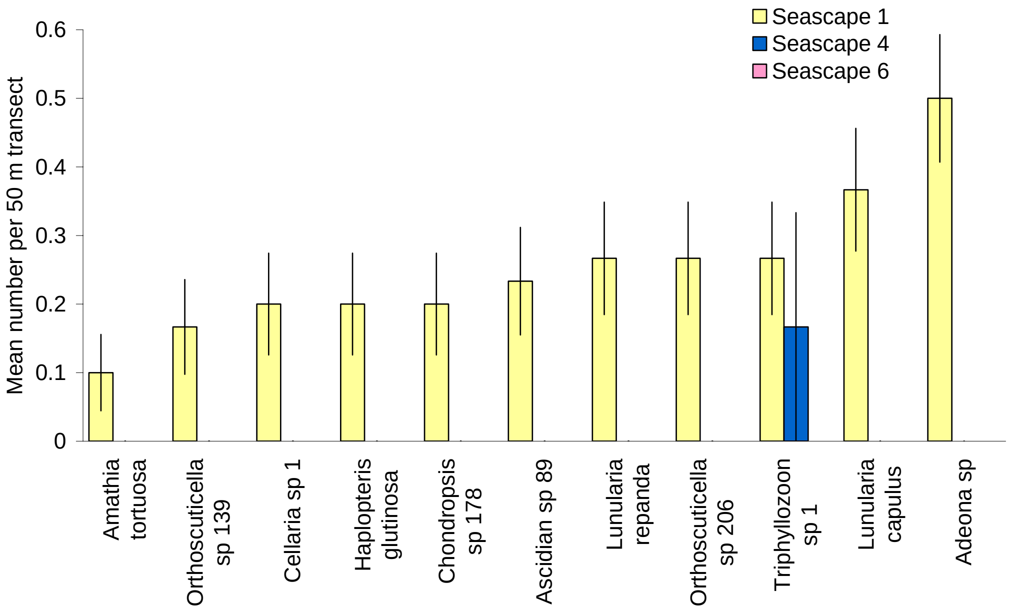


Figure 3.17. Abundance within each seascape of species identified as biological drivers. Error bars are standard error of mean; n = 30 for seascape 1, n = 6 for seascape 4, and n = 4 for seascape 6.

biological assemblages (Table 3.9). Only a very small percentage of the total species (3.6%) were driving the biological patterns. Analyses were performed at lower taxonomic resolutions, showed that four classes (Ascidea, Calcarea, Demospongiae, Gymnolaemata) and three phyla (bryozoans, chordates, sponges) were the main biological drivers.

None of the species identified as biological drivers occurred in seascapes 4 and 6, with the exception of a single *Triphyllozoon* sp.1 found in seascape 4 (Fig. 3.17). These species account for some of the differences in invertebrate assemblages between seascape 1 and the other seascapes. The large number of stations in seascape 1 compared to the other seascapes may also bias the taxa towards those prevalent in seascape 1.

When each seascape is analysed separately, different taxa emerge as contributing most to explaining the overall biological variation. In seascape 6, the gastropod *Cavolina* sp. and the sponge *Cribrochalina* sp. were dominant. In seascape 4, ascidian sp.14, bryozoan sp.3 and the sponge *Calcarea* sp.26 were dominant. In seascape 1, most of the species identified above (*Adeona* sp., ascidian sp. 89, *Haplopteris glutinosa*, *Lunularia capulus*, *Lunularia repanda*, *Orthoscuticella* sp. 139, *Orthoscuticella* sp. 206, and *Triphyllozoon* sp 1) also dominated the patterns within this seascape.

3.4.3.2. Physical Drivers

The strongest and most significant correlation to benthic invertebrate assemblages was from a combination of three environmental variables: depth, percent mud, and seabed temperature. These three variables contributed to almost 50% of the variation among biological assemblages (Spearman rank correlation (ϱ)=0.478, p<0.01). Taken individually, five environmental variables were significantly related to benthic invertebrate assemblages: depth (ϱ=0.453, p<0.01), percent mud (ϱ=0.452, p<0.01), seabed temperature (ϱ=0.450, p<0.01), and slope (ϱ=0.444, p<0.01). These variables exhibited strong individual correlations with biological data, each contributing over 44% to the biological variability. Primary production showed a weaker but still significant correlation (ϱ=0.152, p=0.01). The remaining two factors had no discernible relationship to biological data: percent gravel (ϱ=0.19, p=0.40) and effective disturbance (ϱ=-0.12, p=0.51).

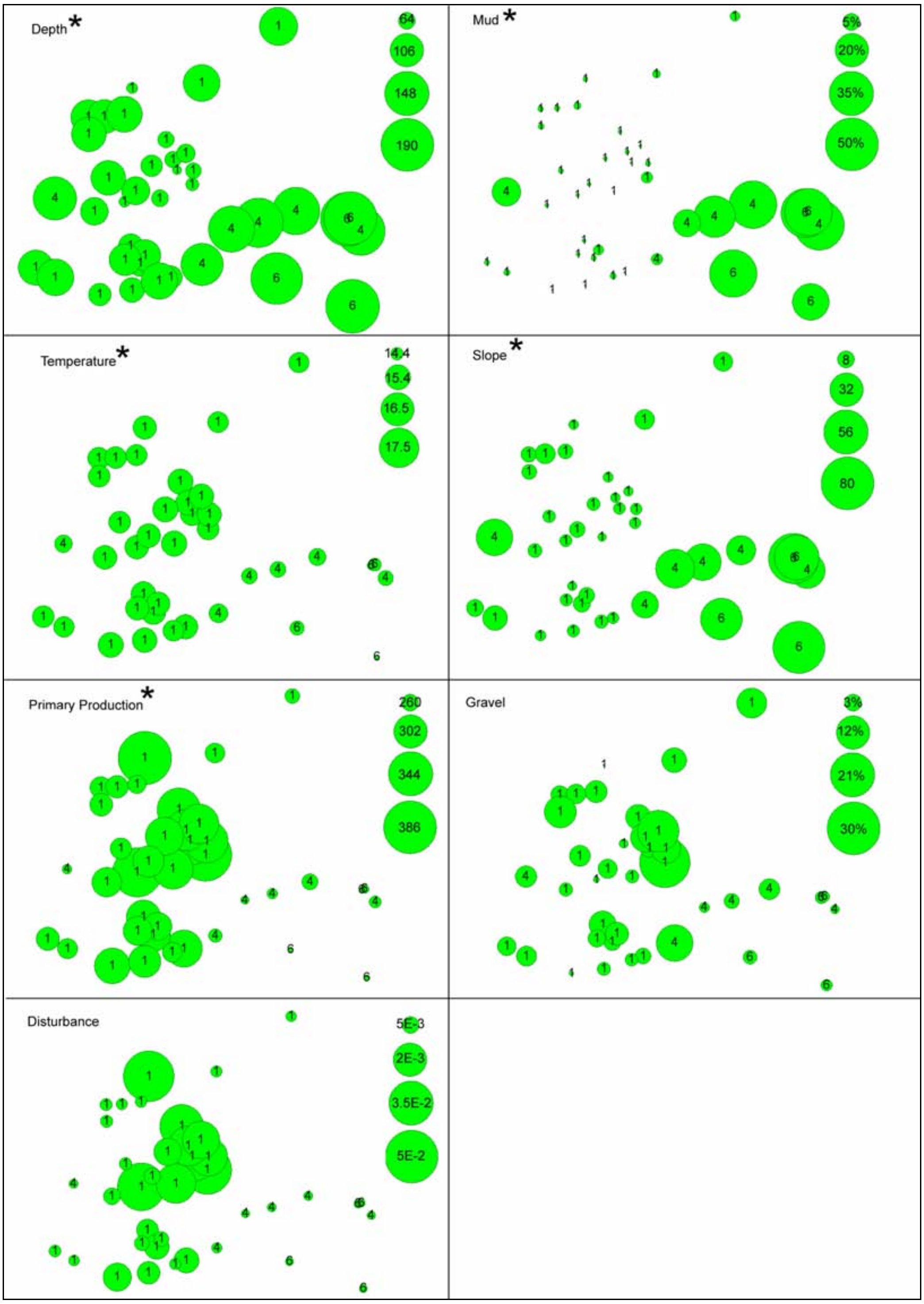


Figure 3.18 n-MDS ordinations with each bubble representing a station. The distance between the centers of bubbles illustrates the similarities of the associated invertebrate assemblages; the greater distance between the bubbles, the more disparate the invertebrate assemblages. The size of each bubble represents an untransformed environmental measurement, with the legend located in the upper right of each plot. Seascape numbers are overlaid on each point. Asterisks indicate significant relationships at α = 0.01. Stress = 0.09.

These relationships can be illustrated using bubble n-MDS plots, in which the size of a point indicates the contribution of a given factor (Fig. 3.18). The plots show that invertebrate assemblages are more similar at shallower sites (with lower percent mud and slope and higher seabed temperatures and primary production) than assemblages at deeper sites (with higher mud content and slope and lower seabed temperatures and primary production). This is illustrated by the clustering of similarly-sized bubbles in the n-MDS plots associated with these factors. In contrast, there was no clustering of similarly-sized bubbles in plots based on

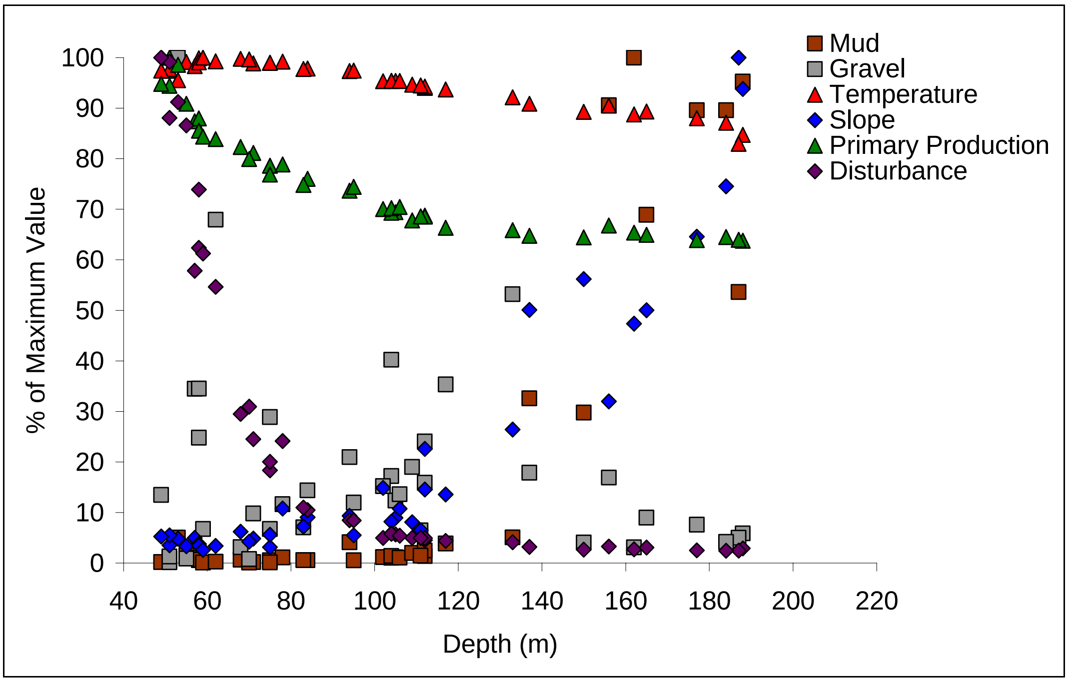


Figure 3.19 Relationship between water depth and all other environmental variables examined in the GAB. The y-axis represents the percent of the maximum value for a given environmental factor. Maximum values are as follows: percent mud = 42.57%, seabed temperature = 17.08°C, slope = 73.21, primary production = 385.50, percent gravel = 25.95%, and effective disturbance = 04.

percent gravel and effective disturbance. Similar assemblages located in comparatively shallow sites coincide with seascape 1 on the left side of the plots, while different assemblages located in deeper sites coincide with seascapes 4 or 6 on the lower right side of the plots.

Environmental variables are likely related, as suggested by the similar patterns across most environmental variables in the bubble plots (Fig. 3.18). When the percentages of maximum values for each environmental factor are plotted against depth, clear relationships can be seen (Fig. 3.19). Percent mud and slope both show a positive relationship with depth while seabed temperature, primary production, and effective disturbance show a negative relationship. Percent gravel was the only environmental factor not to have any discernible relationship with depth.

3.5. SUMMARY

3.5.1. GBR Seabed Biodiversity

Seascapes on the GBR in general were not strong predictors of biological pattern with generally less than 50% prediction success. Three main patterns were observed to describe this low predictive ability:

1. Seascape 10 included at least three different benthic assemblages. This combination of biological assemblages within a single seascape meant that sample variability within this seascape was high. In addition, these assemblages were also present to some degree in other seascapes, which resulted in frequent misclassification of seascape 10 with other seascapes (e.g., 3, 8, & 11).
2. Several seascapes were not biologically distinct based on the available data. Seascapes 7, 12, 9, and 13, for example, were each characterised by high bioturbation with a depauperate epibenthic assemblage, identifying that they functioned as a single biological classification. Seascapes 2 and 3 were also not biologically distinct,

with both seascapes characterising a gravelly seabed that supported a similar suspension-feeding assemblage.

3. The location of misclassified samples in and around correctly classified samples (e.g., seascape 3) indicates that local patchiness of physical habitats and/or biological assemblages was not well modelled in the national seascapes. Although modelling fine-scale patchiness may be an unrealistic at a national scale, this scale of patchiness was an important contributor in the reduced predictive ability of the seascapes model.

Finally, for seascapes to be useful predictors of biological assemblages in complex regions such as the GBR, there should be no redundancy of seascapes, but a rather each seascape should correspond with a single biological assemblage. However, biological systems are inherently variable, consequently while physical variables may provide strong predictive ability, the relatively coarse classification of the national seascapes may not necessarily provide the level of resolution required to capture all of this variability.

3.5.2. GAB Seabed Biodiversity

Seascapes were biologically meaningful in the GAB, although the significance and magnitude of their relationships with biological assemblages varied among the three seascapes and according to biological data quality. Among on-shelf seascapes, analysis of high quality species data revealed differences in benthic invertebrate assemblages. As taxonomic resolution was reduced, the significance of these relationships declined. Species level identification was ideal to detect differences across seascapes; class was only slightly useful; and phyla failed to detect any significant relationships. Functional groups did not show differences across seascapes.

Although a robust biological dataset was used, several limitations may have reduced the effectiveness of this dataset at revealing biological drivers or differences among seascapes. First of all, the data was highly unbalanced among seascapes, with seascape 1 containing 30 stations and the other seascapes containing only a total of 10 stations. This low sample size may have precluded identification of significant relationships (e.g., different biological assemblages between seascape 4 and 6). In addition, abundance data were unavailable. This essentially limits the dataset to only presence-absence and excludes abundance data, possibly decreasing the chances of detecting significant relationships. Despite these potential limitations, significant differences in biological assemblages between seascape 1 and the other on-shelf seascapes were detected, thereby strengthening the biological utility of seascapes for the GAB.

It is unknown if seascapes would be similarly associated with invertebrate biological assemblages in other regions of Australia's shelf. In contrast to the GBR region, where epibenthic biological patterns are relatively heterogenous, the GAB is relatively homogenous. Ideally, future research would also include datasets with a range of abundances and more equitable numbers of stations among seascapes.

Among off-shelf seascapes, qualitative analysis of video transects revealed no differences in most taxonomic groups. However, data from these video transects are only represented by coarse taxonomic levels, mostly phylum, as it was impossible to differentiate most animals to finer taxonomic levels. Thus, results from the off-shelf seascape analysis corroborate those from the on-shelf seascape analysis in that there is no detectable difference in biological assemblages among seascapes at the level of phylum. Indeed, the one species of pelagothurid that did show variation among off-shelf seascapes was distinctive and therefore easily identified in all of the video transects as the same or a very similar species.

Only 3.6% of species were classed as on-shelf biological drivers, mostly bryozoans. All but one of these species occurred in seascape 1, likely due to the large bias of animals from this seascape due to its comparatively large number of stations.

Five of the seven environmental variables were significantly correlated to on-shelf benthic invertebrate assemblages, including: depth, percent mud, seabed temperature, slope, and primary productivity. Interestingly, several of these (percent mud, depth and slope) have been shown to predict benthic biological assemblages in the very heterogenous GBR (Pitcher *et al.*, 2007). Moreover, all of these environmental variables have been linked to predicting biological assemblages in other similar studies (e.g., Thouszeau *et al.*, 1991; Greene *et al.*, 1995; Kostylev *et al.*, 2001; Post, 2008). Only percent gravel and effective disturbance showed no relationship to biological data in the GAB study. The best correlation was achieved with a combination of depth, mud, and temperature. These results can be explained by the relationship between depth and most environmental factors. The factors that were significantly correlated to biological assemblages (depth, percent mud, seabed temperature, slope, and primary productivity) are more or less linearly related to depth. In contrast, the factors that were not correlated to biological data showed complex or no relationship with depth. Thus, depth-related factors comprising the seascapes appear to be the principal environmental factors contributing to the observed variation among benthic invertebrate assemblages in the GAB.

4. Integration of Biological Data – Local Scale

4.1. INTRODUCTION

The seascapes have been derived from physical factors that have established biological links and although a national-scale assessment has been completed that provides further insight to the 'ecological-meaningfulness' of the seascapes, the lack of available standardised biological data for the AMJ precludes the integration of biological layers into their derivation. However, by focusing at a local scale (tens of kilometres) available robust and consistent biological data can be incorporated into the derivation of the seascapes. Following this, an assessment can be made as to their ability to capture the distribution of smaller-scale seabed habitats, namely geomorphology, which can then be used to extrapolate to the larger (national) scale. In this section we integrate biological data into new derivations of 'local-scale' seascapes and compare the results from seascapes derived without these data in an assessment of their ability to represent seabed geomorphology (Glomar Shoals, NW-shelf).

4.1.1. Aims

By deriving new seascapes at the local and regional scale, our aims were to:

- Characterise demersal fish biodiversity in the Glomar Shoals area;
- Investigate and compare the effects of integrating biological data into seascape derivations at a local and regional scale;
- Identify taxa driving biological patterns at a local scale; and
- Identify environmental factors driving biological patterns at a local scale.

4.1.2. Glomar Shoals

Shoals are defined as areas of elevated seabed composed of unconsolidated material (Heap & Harris, 2008). In Australia, 488 banks/shoals have been identified covering a total area of 51,010 km^2 or 0.57% of the total area (Heap & Harris, 2008). The northwest Australian margin contains by far the largest number of banks and shoals with 276 (Heap & Harris, 2008).

Glomar Shoals are located 150 km north of Dampier on the Rowley Shelf (Jones, 1973) and cover approximately 200 km^2 is the shoals are a submerged feature 26–70 m below the present sea level. Sediments mostly consist of skeletal material of marine organisms and are characterised by a relatively high (>90 %) carbonate content. Sediment samples from Glomar Shoals are distinguished from surrounding seabed by a much higher gravel content and presence of coarse sands of weathered coralline algal and shell material. The accumulation of coarse carbonate sand at Glomar Shoals indicates a high energy environment subjected to strong seabed currents (McLoughlin & Young, 1985).

Relatively little physical data are available for the Glomar Shoals (Falkner *et al.,* 2009), considering the shallow depth of this feature and associated ease of sampling compared to deeper neighbouring areas. However, more data are available for the surrounding area reflecting an intense sampling effort along the 125 m isobath.

Glomar Shoals was used as the subject of investigation of the seascapes on a local scale because a large number of robust and consistent biological data points were available from the *Berg-3* survey in 1967. More importantly, this dataset comes from a single survey, thereby eliminating variation due to sampling times, gear, and target taxa. Finally, the region represents an area of relatively high habitat complexity, with a large range of water depths and substrate types (Falkner *et al.,* 2009). National seascapes were designed to

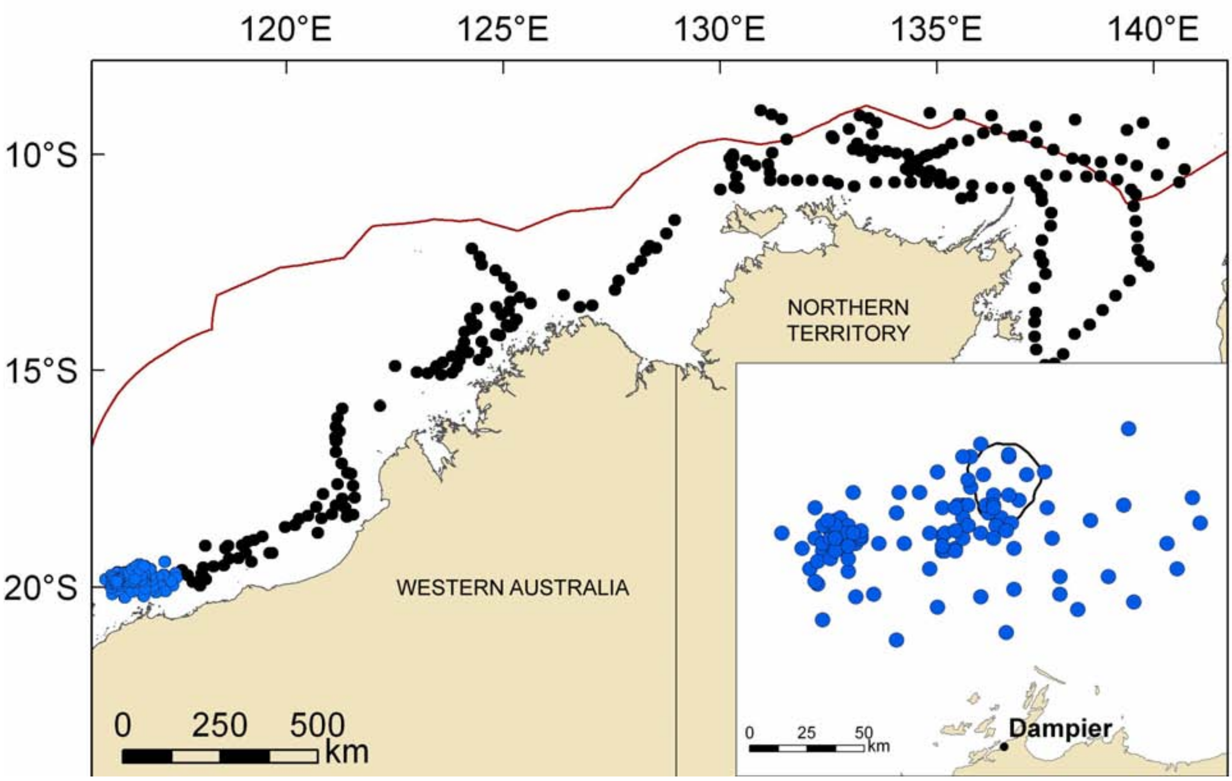


Figure 4.1. Location of demersal fish data from the *Berg-3* 1967 survey. The black circles indicate all samples from the survey, while the blue circles represent samples designated as part of the Glomar Shoals area (inset). The outer boundary of the Australian EEZ is denoted by the red line. Inset: the black outline represents Glomar Shoals.

focus at a larger scale than that examined here, and therefore seascapes have been derived at the local scale albeit using the same datasets used to derive the national on-shelf datasets (see Table 1.1).

4.2. METHODS

4.2.1. Data Sources

CSIRO maintain a biological database containing biological data collected in Australian water by Soviet researchers in the 1990s. Subsequently, CSIRO have confirmed taxonomic identifications where possible and compared these against known distributions for the species concerned and loaded these into the database (Koslow *et al.*, 1999). The biological dataset used here is from the CSIRO database and comes from a survey of the Russian fishery research vessel *Berg*-3 undertaken between May and July 1967. The survey yielded catch composition from 354 demersal trawls on the Northwest Shelf, Timor and Arafura Seas and Gulf of Carpentaria. For our local seascape derivations, we only used data from the Glomar Shoals and surrounds, restricting the dataset to 113 demersal trawls (Fig. 4.1). These trawls returned 152 fish species, of which 106 occurred in numbers of <100 individuals and a further 33 species of <1,000 individuals.

In addition to the biological data, water depth, effective disturbance, percent gravel and mud, slope, primary production and seabed temperature were used to derive the local-scale seascapes. The source of these physical data and derivations of the associated interpolations are described in section 1.

4.2.2. Biodiversity at Glomar Shoals

The full multivariate assemblage data was reduced into two univariate diversity indices using the statistical computer software package PRIMER (v.6). These diversity indices were: The Shannon index (*H′*) and Simpson index (Magurran, 2004). For each index, values were then interpolated as a spatial layer in ArcGIS using the same method as used for the other physical variables and as described in Whiteway *et al*. (2007). Both biodiversity indices were used to determine whether there were any significant differences in diversity on and outside Glomar Shoals and among the local-scale seascapes derived both with and without the integration of biological data.

4.2.3. Seascape Derivations

To investigate whether integrating biological data contributes to the derivation of local-scale seascapes, the following six analyses were undertaken:

1. Seascapes for the Glomar Shoals region without the integration of biological data;
2. Seascapes for the Glomar Shoals region with the addition of a biological layer derived from the Shannon index;
3. Seascapes for the Glomar Shoals region with the addition of a biological layer derived from the Simpson index;
4. Seascapes for the Glomar Shoals region with the addition of a biological layer derived from randomly generated data;
5. Seascapes for the entire region covered by the *Berg-3* survey, excluding biological data; and
6. Seascapes for the entire region covered by the *Berg-3* survey, including the addition of a biological layer derived from the Shannon index.

The additional biological layer created using random data was derived using the random algorithm function in Microsoft Excel. This was undertaken to separate true biological effects from effects solely due to the addition of an extra layer in the new seascape derivations.

To compare the effects of integrating biological data into seascape across local and regional scales, seascapes were also derived for the entire region covered by the *Berg-3* 1967 survey data. Biological data was interpolated to 50 km around each station, rather than the 25 km interpolation used in the local seascape derivations. This larger radius was used because the biological data spread was greater at the regional scale than the local scale; maintaining the 25 km radius at the larger scale would result in a highly irregular and discontinuous result. Seascapes and focal variety analyses were performed both with and without the integration of biological data using the methods described in section 1.

4.2.4. Biological Drivers

In order to identify taxa that may dominate the observed patterns in the Glomar Shoals region, the BVSTEP procedure was performed in the statistical computer software package PRIMER (v.6) on the entire dataset with square-root transformation to allow less weighting of the very abundant species (see sub-section 3.2.3 for further details about BVSTEP).

These species were then investigated further to isolate any taxa that may contribute to observed differences across seascapes and seabed geomorphology. For each species identified by the BVSTEP procedure as an important biological variable, two Kruskal-Wallis rank sum tests were performed. The first test was performed on data from across the seascapes and the second test was performed on data from between stations from Glomar Shoals and stations outside the shoals. The R statistical computer software package (v.2.7.2) was used to undertake these analyses.

4.2.5. Physical Drivers

4.2.5.1. Univariate analysis

To identify environmental factors associated with the univariate measure of demersal fish biodiversity, a multiple regression was performed in R. Environmental data were extracted from the respective interpolated spatial data layers of the local seascapes analysis (excluding the biological layer) using the Hawths Tools in ArcGIS. Environmental data available for the statistical analysis were bathymetry, percent gravel, percent mud, seabed temperature, slope, primary production, and effective disturbance. Data remained untransformed, as all residuals were normally distributed and met the regression assumptions.

4.2.5.2. Multivariate analysis

To identify environmental factors driving the multivariate measure of fish assemblages between sites, the biological and physical data were analysed using the BIO-ENV procedure in PRIMER. The analysis of the biological pattern was based on a reduced, square-root transformed dataset. Prior to statistical analysis, rare species were removed to increase the chances of an interpretable ordination result. Species were considered rare when they contributed less than 4% of the total abundance of any sample, as confirmed by the SIMPER routine (Clarke & Warwick, 2001). This routine converts Bray-Curtis similarities between all pairs of samples into percentage contributions from each species.

The resulting reduced data matrix consisted of 70 species, which is comparable to the recommended number of species for this type of analysis (Clarke & Warwick, 2001). The abundance data of these remaining species were square-root transformed to allow less weighting of the very abundant species. The environmental data were extracted using the method outlined in sub-section 3.2.4.1. Environmental data were standardised to give each variable equal weighting and individually transformed to achieve a normal distribution (Clarke & Warwick, 2001). Specifically, slope was log transformed; seabed temperature, primary production, and effective disturbance were ranked; and bathymetry, percent mud, and percent gravel were not transformed.

The BIO-ENV procedure is based on deriving similarity matrices that differ to match the form of data that underlie both datasets. In this case, Bray-Curtis similarity coefficients were used for the biological data, and Euclidean distances were used for the environmental data (Clarke & Warwick, 2001). The Spearman coefficient was used because it is appropriate for comparing similarity matrices derived from different types of coefficients.

4.3. RESULTS

4.3.1. Biodiversity for Glomar Shoals Region

The diversity of demersal fish varies across the region, as shown by interpolation of the Shannon and Simpson indices (Fig. 4.2). The Glomar Shoals and areas immediately to the east and southeast are characterised by high diversity. The area adjacent to the western margin is characterised by very low diversity. Interpolations across the region are similar between Shannon and Simpson indices, with only areas of moderate diversity showing differences between the two indices.

The diversity of demersal fish was significantly higher at Glomar Shoals than the surrounding region (Fig. 4.3), as confirmed by ANOVAs using the univariate Shannon index (df=1, F=9.7487, p=0.0023) and the Simpson index (df=1, F=8.4348, p=0.0044).

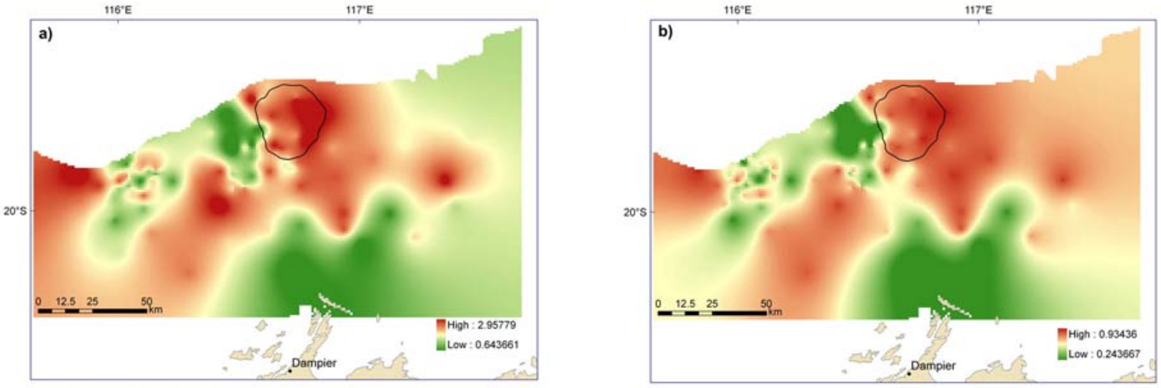


Figure 4.2. Diversity indices interpolated as spatial layer to include into new seascapes analyses using (A) Shannon index and (B) Simpson index. Glomar Shoals is outlined with the black line.

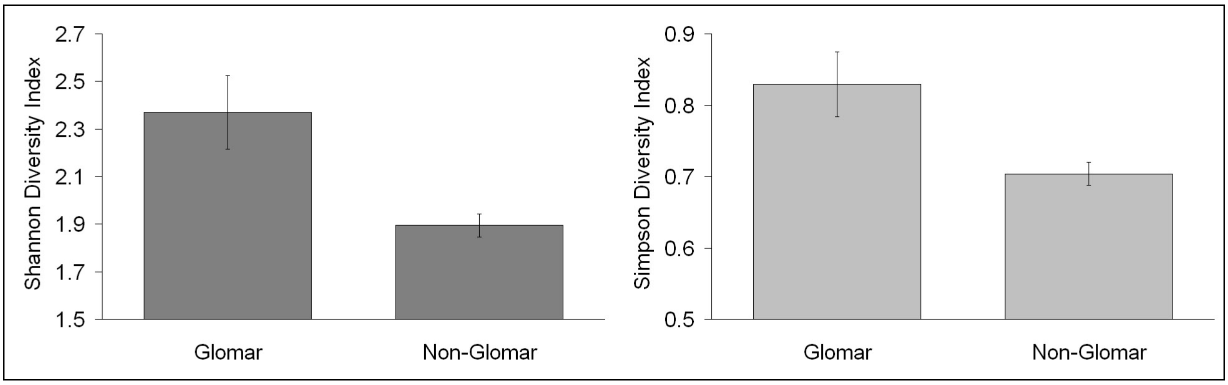


Figure 4.3. Demersal fish biodiversity at Glomar Shoals (n = 12) and surrounding region (n = 101) using (A) the Shannon index, and (B) the Simpson index. Error bars are standard error of mean.

There is no significant difference in biodiversity among seascapes using the Shannon index (df=5, F=1.0384, p=0.399) or Simpson index (df=5, F=0.9027, p=0.4823) for the local seascape derivations excluding the biological layer (Fig. 4.4).

4.3.2. Seascape Derivations and Focal Variety Analyses

4.3.2.1. Local seascapes excluding biological data

A total of 10 seascape classes were produced for Glomar Shoals excluding biological data (Fig. 4.5), with the Glomar Shoals itself coinciding mainly with seascape 7. This seascape has a depth range of 33 to 77 m with a mean of 58 m and is also characterised by the 3rd-lowest gravel content, the highest mud content and the 3rd-highest seabed temperatures. However, seascape 7 extends west and southwest beyond the margins of Glomar Shoals. The eastern margin of Glomar Shoals also includes three other seascapes: seascape 9, which ranges in depth between 1 and 90 m and is characterised by the highest slope values; seascape 2, which ranges in depth from 50 to 81 m and is characterised by the lowest effective disturbance and primary productivity values; and seascape 1, which ranges in depth from 39 to 77 and is characterised by the lowest gravel content and seabed temperatures.

The focal variety analysis showed that much of Glomar Shoals overlaps the area of highest habitat heterogeneity in the region, particularly the eastern margin (Fig. 4.6). In contrast, the western margin and the centre are areas of comparatively low habitat heterogeneity, similar to most other areas in the region.

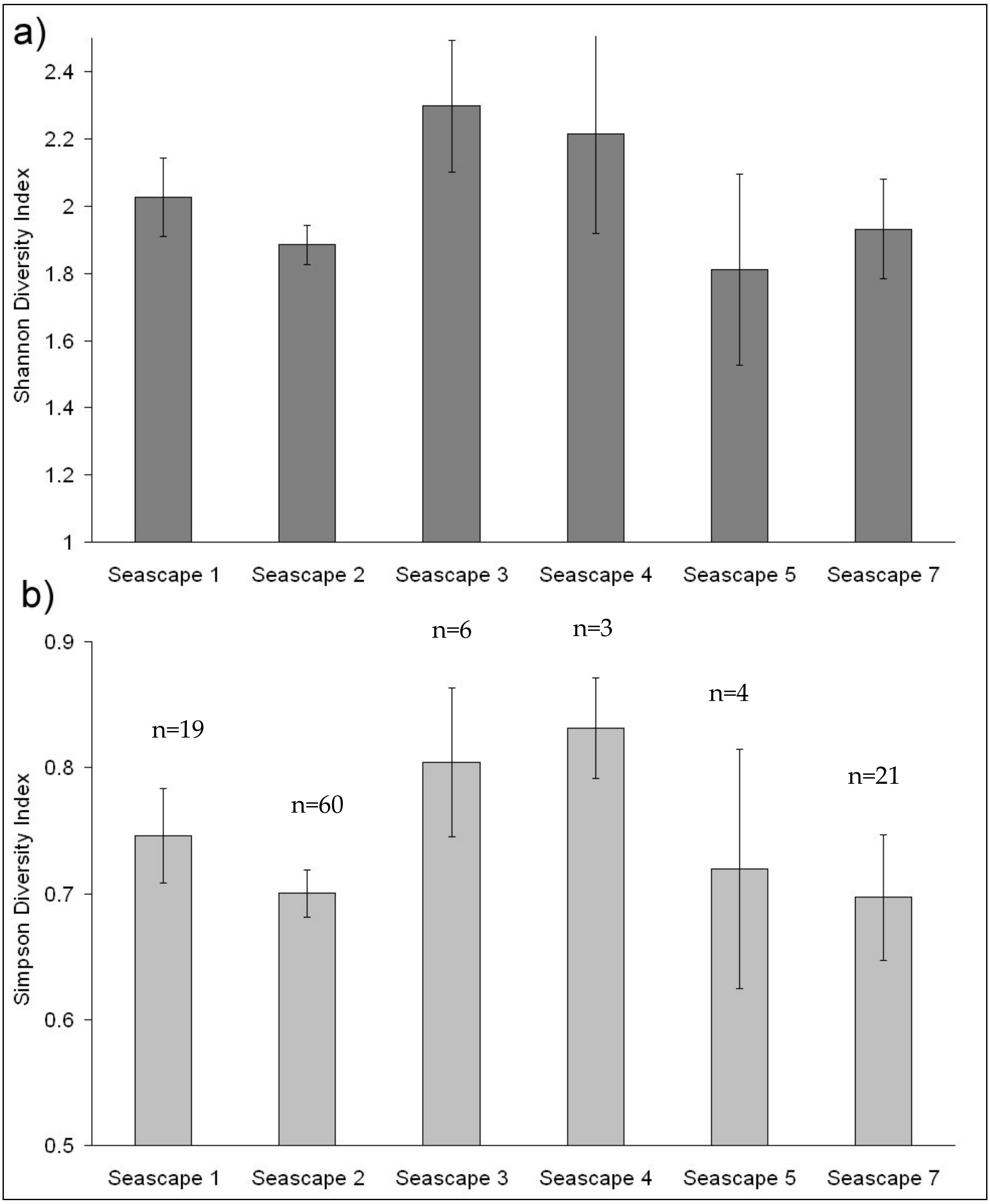


Figure 4.4. Demersal fish biodiversity by seascape from local derivation (excluding biological layer) using (A) the Shannon index, and (B) the Simpson index, +- standard error bars.

4.3.2.2. Local seascapes including biological data

Shannon Index:— A total of 11 seascape classes were produced for Glomar Shoals using the Simpson index as an additional layer (Fig. 4.7). Interestingly, Glomar Shoals coincides closely with seascape 11, which is not found in the adjacent areas. Seascape 11 ranges in depth from 32 to 71 m with a mean of 46 m and is characterised by the 2nd-highest diversity index values and the 3rd-highest gravel content and seabed temperatures. Seascapes 4, 10 and 11 also cover parts of the shoal, margin, and immediate surrounds. Overall, these seascapes are characterised by high diversity and low primary productivity, whereas seascapes coinciding with areas closer to the coast are characterised by relatively low diversity and high primary productivity and seabed temperatures (seascapes 6–9).

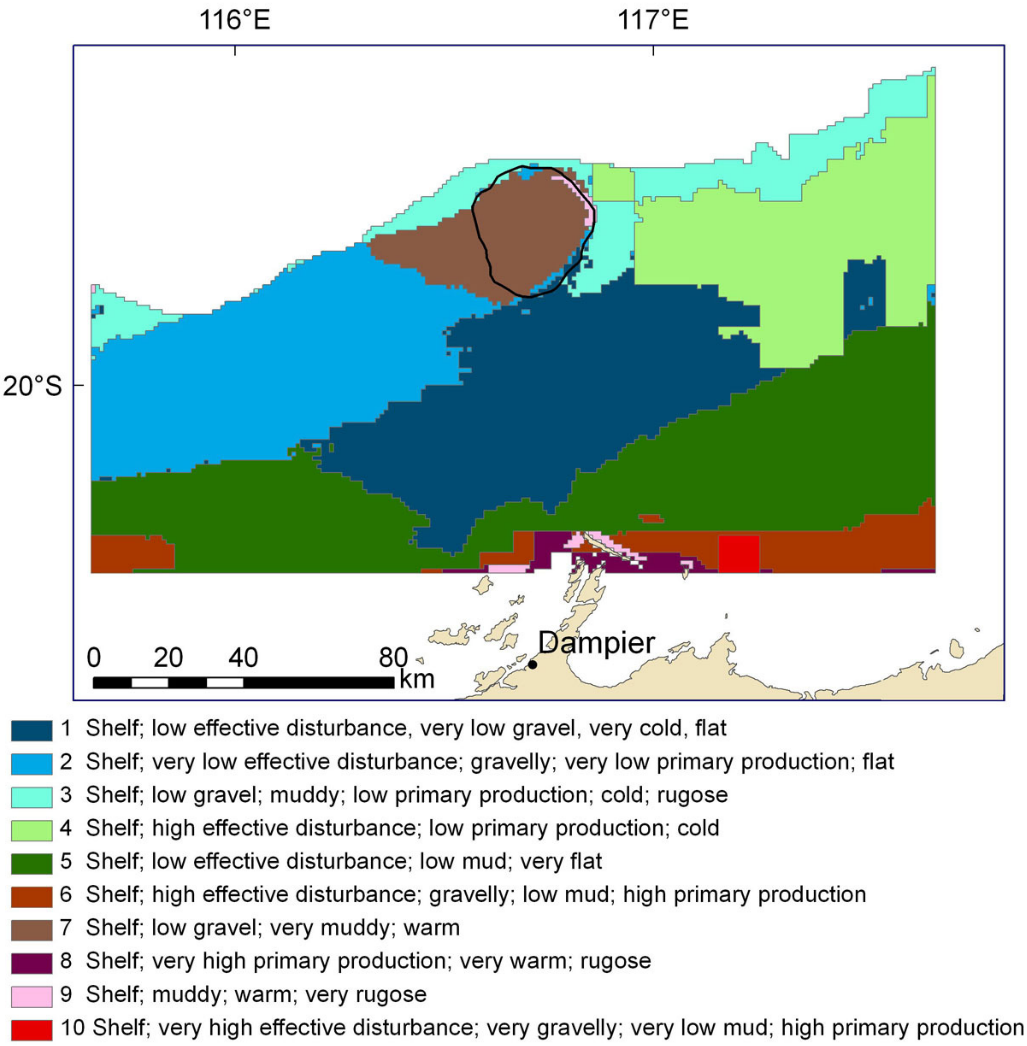


Figure 4.5. Map of the seascapes for Glomar Shoals and surrounds, excluding biological data layer. Glomar Shoals is marked with a black outline.

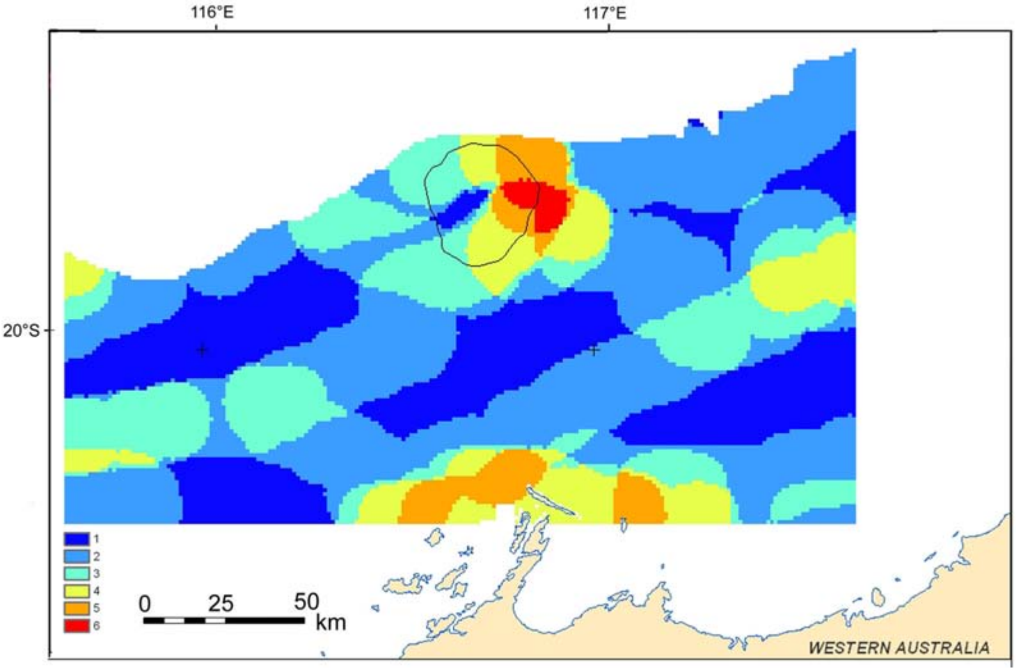


Figure 4.6. Map of focal variety indices for Glomar Shoals and surrounds, excluding the biological data layer. Higher index values represent higher habitat heterogeneity.

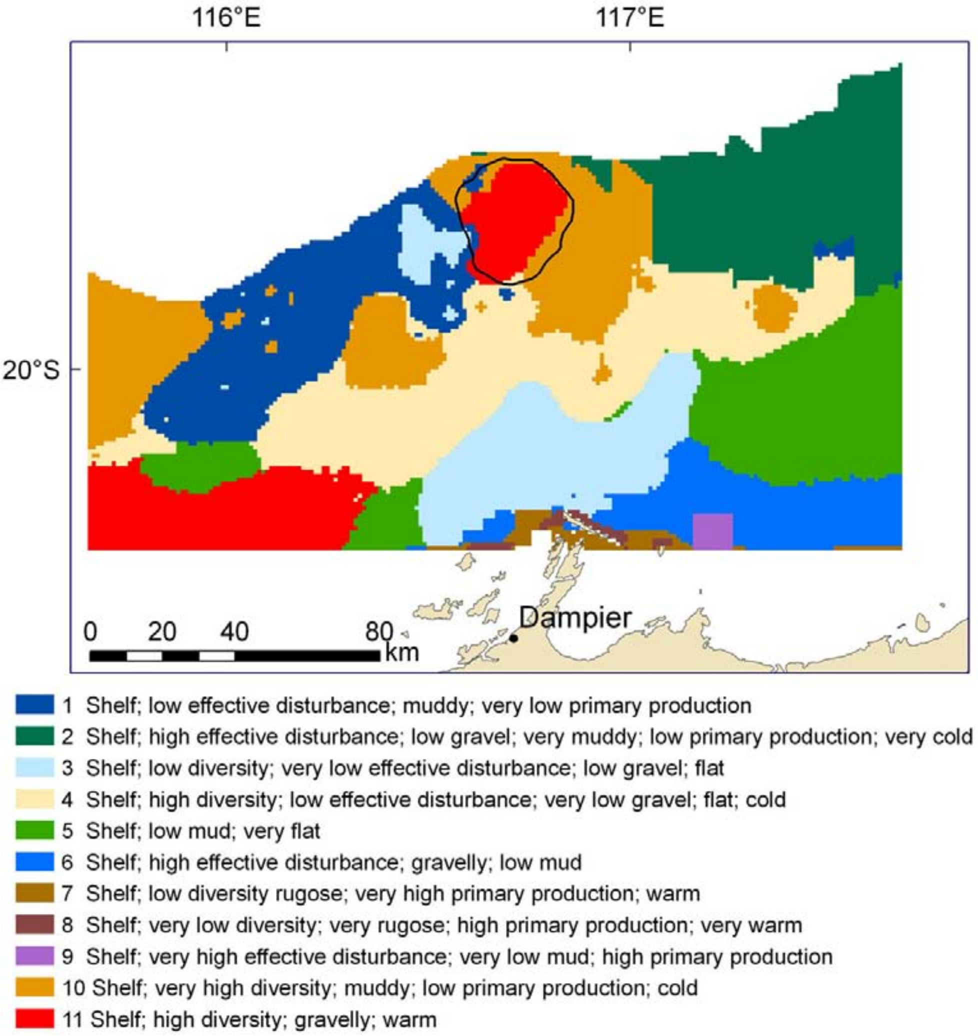


Figure 4.7. Map of the seascapes for Glomar Shoals and surrounds, including the Shannon index as a biological data layer.

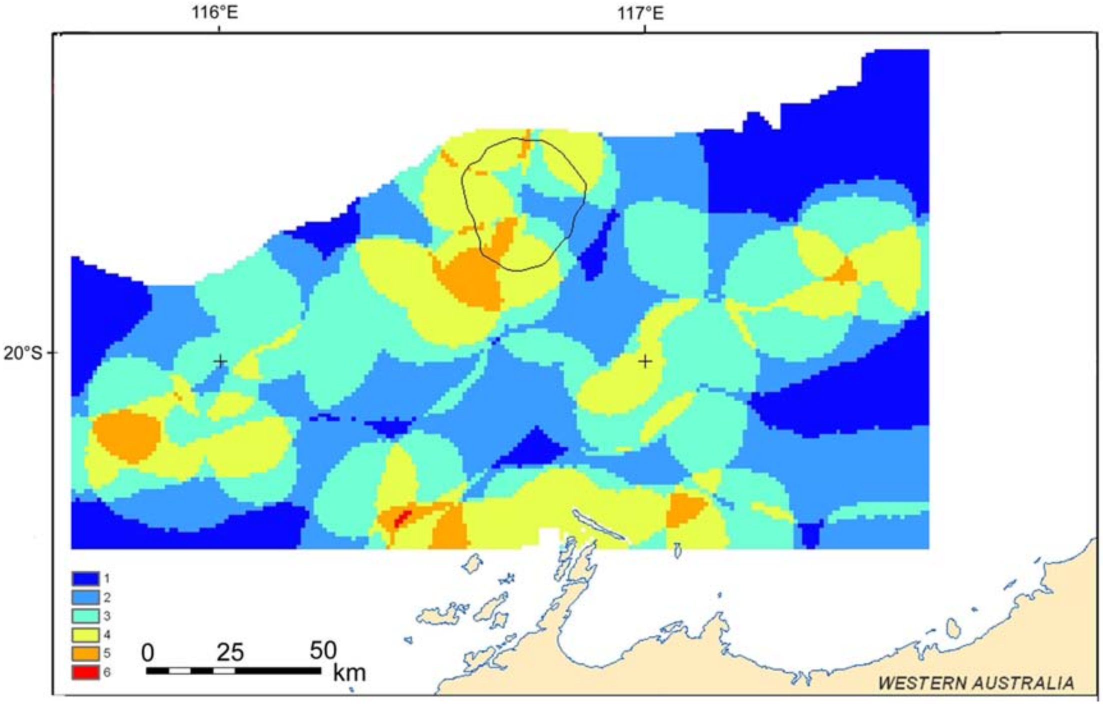


Figure 4.8. Map of focal variety indices for Glomar Shoals and surrounds, including the Shannon index as a biological data layer. Higher index values represent higher habitat heterogeneity.

The focal variety analysis of seascapes derived using the Shannon index biology layer indicates that the western shoal margin and areas west of Glomar Shoals are high in habitat heterogeneity (Fig. 4.8). This is in direct contrast to the analysis excluding the biological data in which the eastern shoal margin had a higher focal variety index. The shoal centre is homogenous, similar to the previous analysis.

Simpson Index:— A total of nine seascape classes were produced for Glomar Shoals using the Simpson index as an additional layer (Fig. 4.9). The Glomar Shoals overlaps quite closely with seascape7, which is not found in the adjacent areas. Seascape 7 ranges in depth from 22 to 59 m with a mean of 40 m and is characterised by the highest diversity and mud content, the 2nd-lowest gravel and primary production, and the 2nd-highest slope and temperature. Other seascapes also cover parts of the shoal, margin, and immediate surrounds, all of which are characterised by relatively low temperatures (seascapes 1, 3, & 4). Seascapes 1 and 3 are further characterised by high diversity and low primary productivity and seascape 4, near the western margin of Glomar Shoals, is characterised by low diversity.

The focal variety analysis with the integration of the Simpson biology layer indicate that the western margin of Glomar Shoals and areas further west are areas of high habitat heterogeneity (Fig. 4.10). Areas of highest habitat heterogeneity occur near the coast, with other areas in the region comparatively homogenous, including the shoal centre.

Randomly-Generated Data:— A total of eight seascape classes were derived for Glomar Shoals using randomly-generated data as an additional layer (Fig. 4.11). Glomar Shoals primarily overlap with seascapes 3 and 5. Seascape 3 occurs on the southeastern margin and is the principal seascape to occur near the coast. It is characterised by the highest diversity and lowest slope. Seascape 5 occurs only over Glomar Shoals, but also extends beyond the western margin. It is characterised by low diversity and the highest mud content. Seascape 1 also overlaps the margins of Glomar Shoals and is characterised by moderate diversity and the lowest disturbance and gravel content.

The focal variety analysis with integration of randomly-generated data indicates that the eastern margin and areas beyond have the highest habitat heterogeneity (Fig. 4.12). Similar areas of very high habitat heterogeneity occur near the coast, with other areas in the region comparatively homogenous, including the shoal centre.

4.3.2.3. Regional seascapes excluding biological data

A total of nine seascape classes covering the entire *Berg-3* survey region were derived excluding the biological data (Fig. 4.13). Spatial gradients were observed, with benthic habitats in the southwestern area of interest being relatively homogenous, as illustrated by the large and continuous area of each seascape. Northern and northeastern areas show relatively high habitat heterogeneity, with smaller seascapes and higher patchiness. Several seascapes also showed specificity to these areas. Seascapes 3-5 were confined mostly to the southwestern regions and are characterised by high effective disturbance and gravel content, and low mud content. Seascapes 7 and 9 were confined mostly to the western area and are characterised by low effective disturbance, high mud content, low gravel content, rugose seabed, and warm seabed temperatures. Seascapes 1 and 8 occurred mostly in the northern area and are characterised by low primary production.

The regional focal variety analysis, excluding biological data, indicates that the southern area, including Glomar Shoals, has lower habitat heterogeneity than the rest of the region (Fig. 4.14). In contrast, the Kimberley coast, the area northwest of Melville Island, and a small area north of Arnhem Land are characterised by highest habitat heterogeneity.

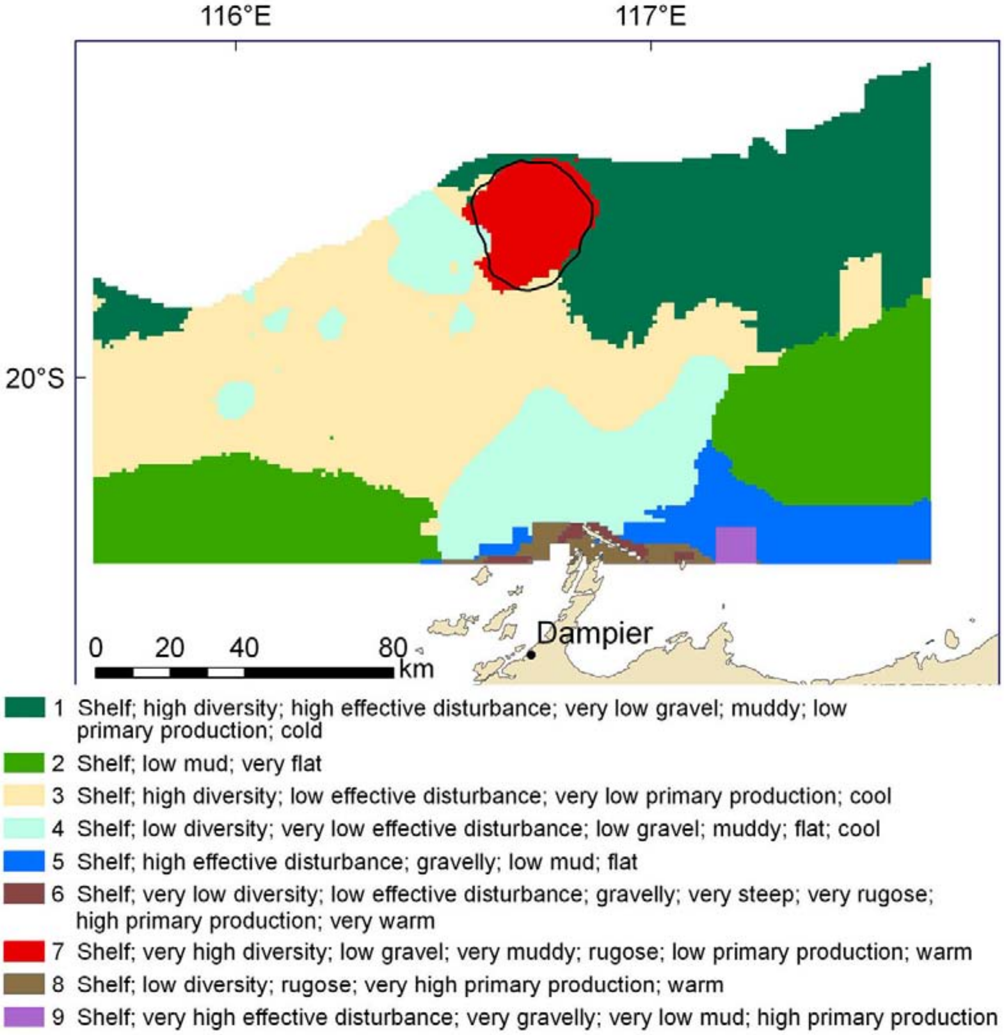


Figure 4.9. Map of the seascapes for Glomar Shoals and surrounds, including the Simpson index as a biological data layer.

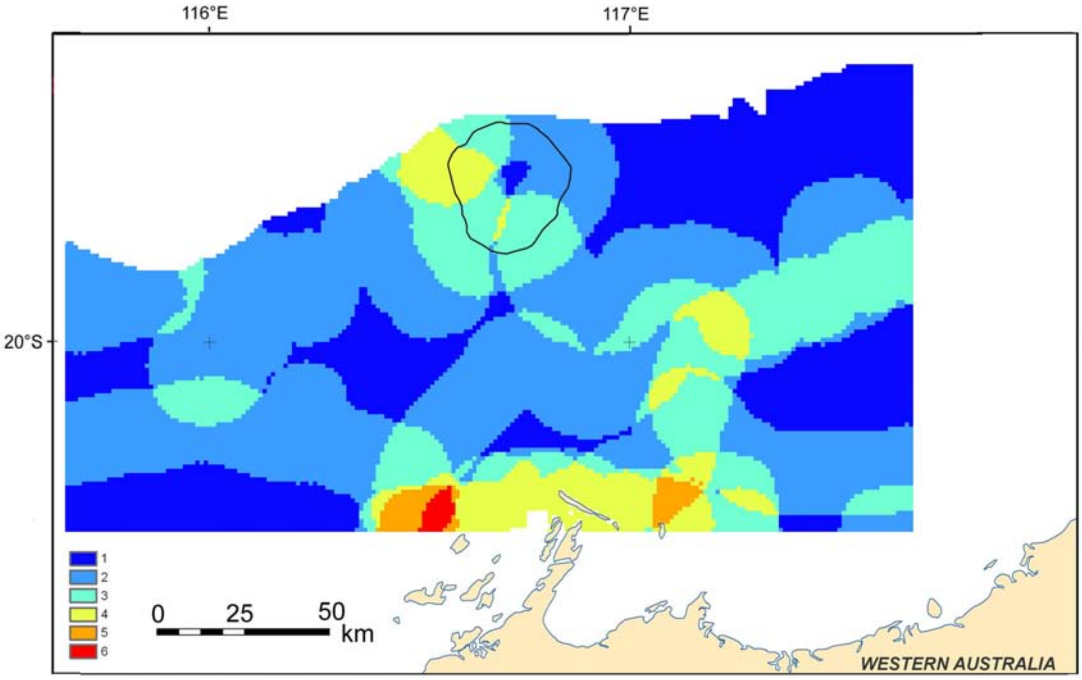


Figure 4.10. Map of focal variety indices for Glomar Shoals and surrounds, including the Simpson index as a biological data layer. Higher index values represent higher habitat heterogeneity.

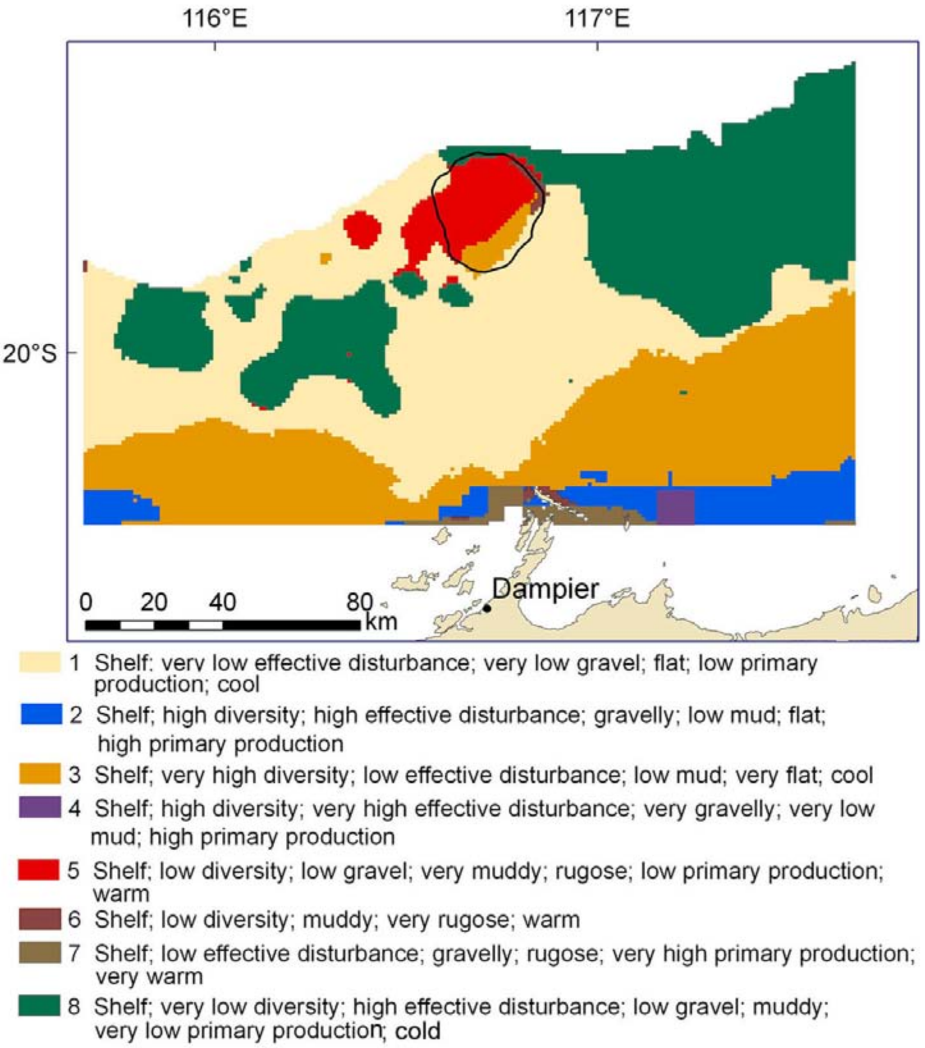


Figure 4.11. Map of the seascapes for Glomar Shoals and surrounds, including randomly-generated data as an additional layer.

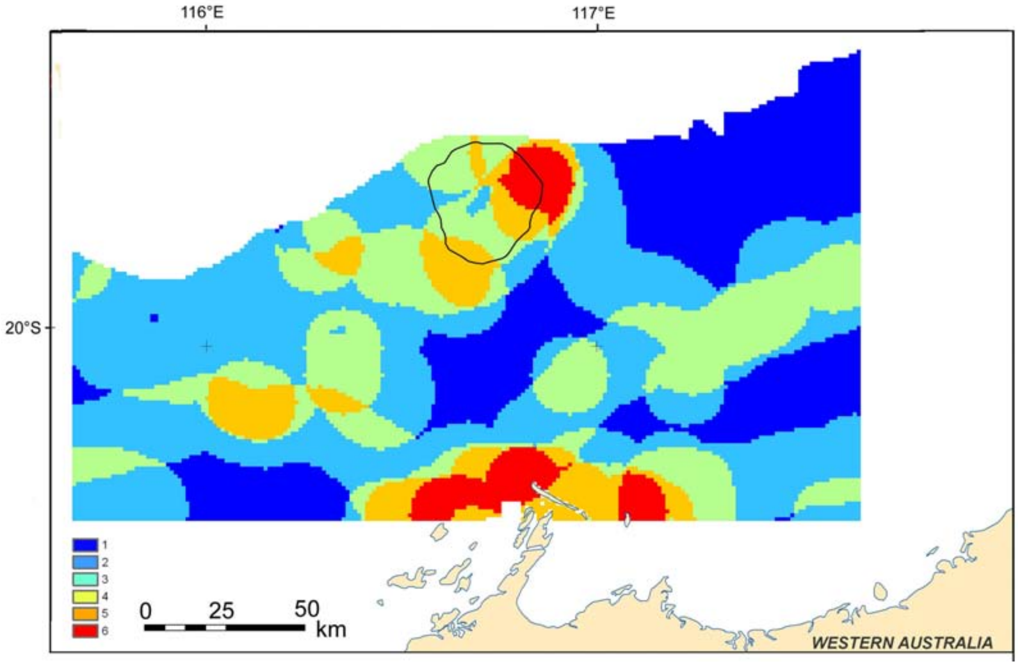


Figure 4.12. Map of focal variety indices for Glomar Shoals and surrounds, including randomly-generated data as an additional layer. Higher index values represent higher habitat heterogeneity.

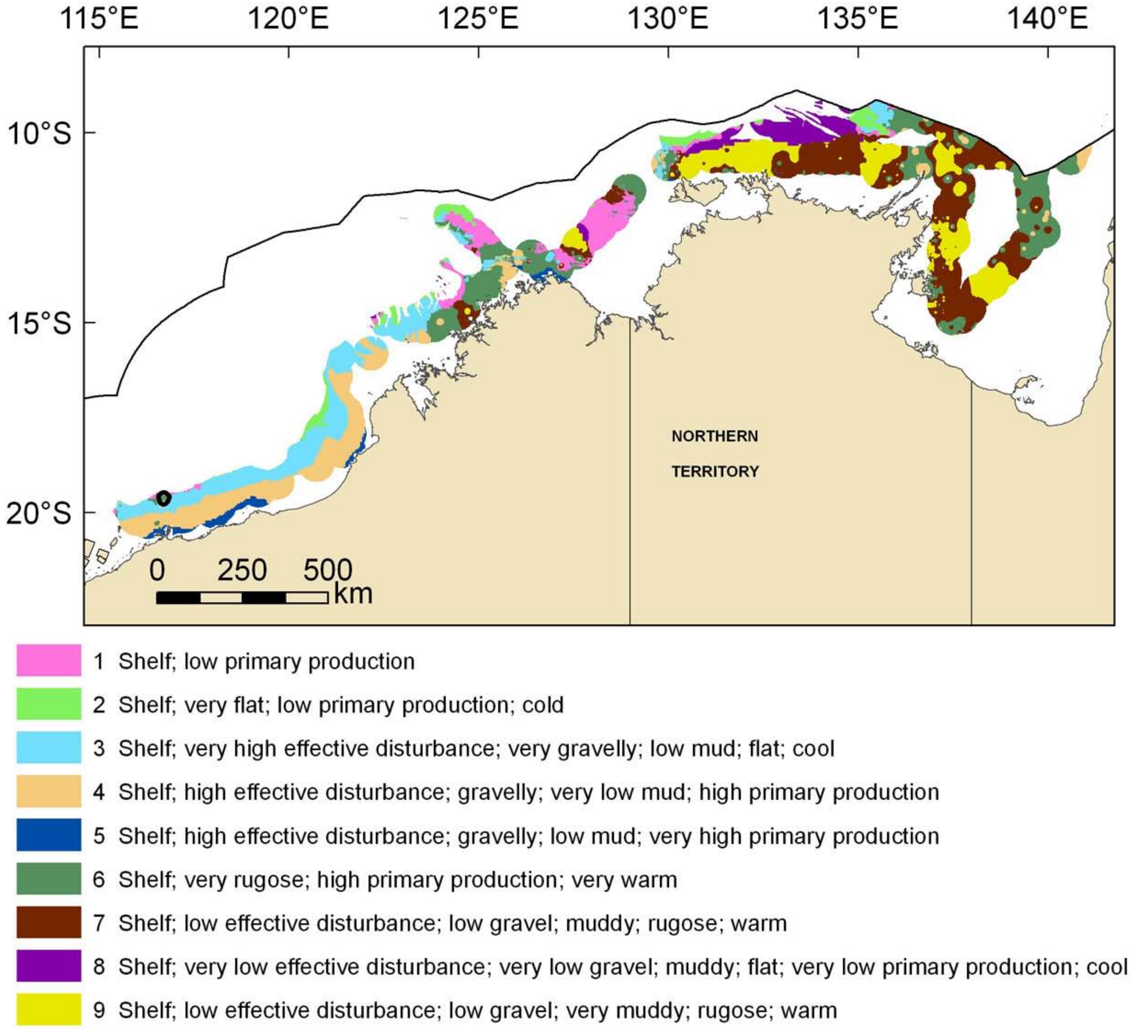


Figure 4.13. Map of the seascapes for the region encompassing all *Berg-3* survey locations, excluding biological data. The thick black circle in the lower left represents Glomar Shoals, and the thin black line is the outer boundary of the Australian EEZ.

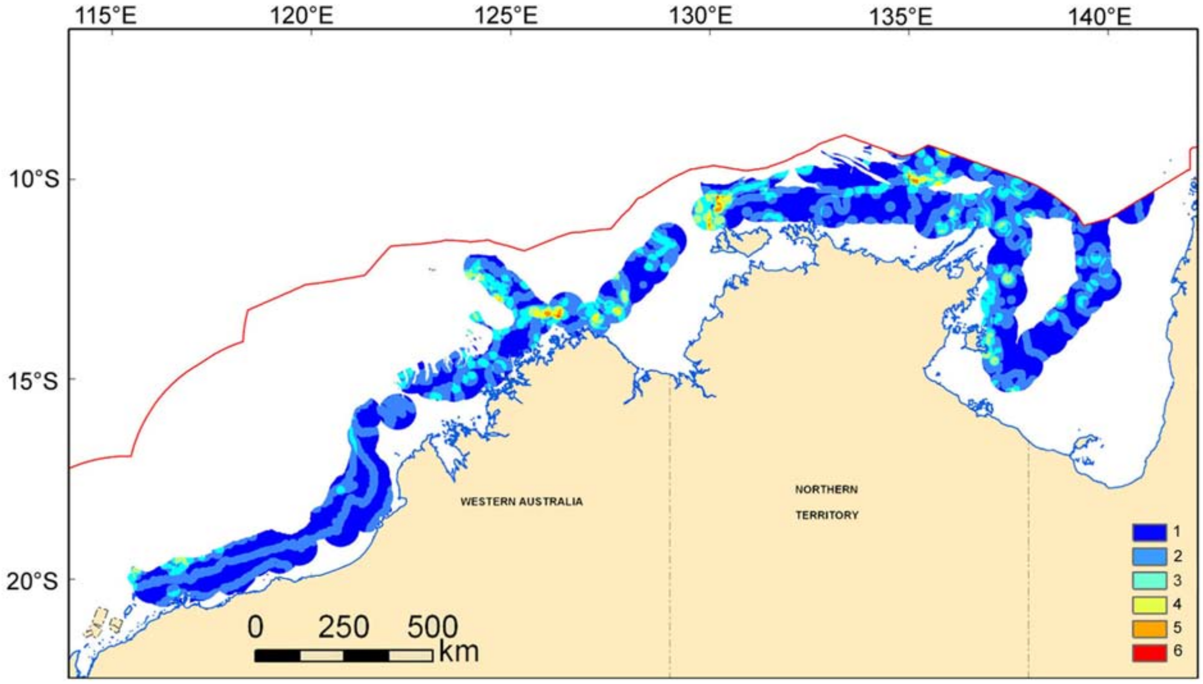


Figure 4.14. Map of focal variety indices for the region encompassing all *Berg-3* survey locations, excluding biological data. Higher index values represent higher habitat heterogeneity.

4.3.2.4. Regional seascapes including biological data

A total of 13 seascape classes were derived covering the entire *Berg-3* survey region after including the biological data (Fig. 4.15). Due to the many classes in this derivation, it was difficult to identify any local scale patterns. The southern area had larger and more continuous seascapes, while seascapes in the northern and northeast areas were smaller and patchy by comparison.

The regional focal variety analysis, including biological data, indicates that with the exception of the area around Glomar Shoals, the southern area is relatively low in habitat heterogeneity compared to the rest of the region (Fig. 4.16). Glomar Shoals and the immediate surrounds represent highly heterogeneous habitats. Other areas of high habitat heterogeneity are the Kimberley coast, the area north of Melville Island, and north of Arnhem Land.

4.3.3. Comparative Analysis

4.3.3.1. Biodiversity and focal variety analyses

Biodiversity was highest on the western side of Glomar Shoals (Fig. 4.17A), which corresponds to the part of the shoals that also has the highest focal variety (Fig. 4.17B). A roughly circular area of higher diversity to the west of Glomar Shoals also coincided with high focal variety indices. Since this pattern reflects the underlying demersal fish data, habitat heterogeneity indicated by high focal variety indices may be a suitable proxy for biodiversity. However, this relationship was not consistent across the area. An example occurs in the southwest part of the study region where relatively low biodiversity coincided with higher focal variety indices.

Focal variety analyses can be useful in representing spatial biodiversity at a local scale in situations where there are no robust biological data. Specifically, focal variety analyses can reveal areas in which biodiversity may be high due to the proximity of a range of habitat types. However, not all areas of high focal variety will necessarily have high biodiversity. This is because other factors also have a large influence such as dispersal and recruitment.

4.3.3.2. Comparison of seascapes with Shannon and Simpson biological layers

When integrated into the seascape derivations, the Shannon and Simpson indices resulted in similar habitat maps. In both derivations, Glomar Shoals was centred on one seascape characterised by high diversity and warm temperatures and immediately to the west of Glomar Shoals a seascape characterised by low diversity and effective disturbance (seascapes 3 & 4, respectively) (Fig. 4.18). On the western and southern sides of the study region, the seascape boundaries were almost identical, likely due to the low density of biological samples in these areas (Fig. 4.1).

Despite the similarities around Glomar Shoals, small differences are apparent in the derivations from between the analyses. The most notable difference is revealed is in the number of seascapes, with 11 being evident using the Shannon index compared to 9 using the Simpson index. Thus, the derivations based on the Shannon index showed more habitat heterogeneity than those based on the Simpson index, particularly to the west and southwest of Glomar Shoals where density of biological data was highest (Fig. 4.18). Differences in the classification of physical data were also detected, including with the naming of the seascape overlapping Glomar Shoals. In the derivation using the Shannon index, this seascape (seascape 11) had the 3rd-highest gravel content in the area, but in the derivation using the Simpson index, this seascape (seascape 7) had the 3rd-lowest gravel content in the area.

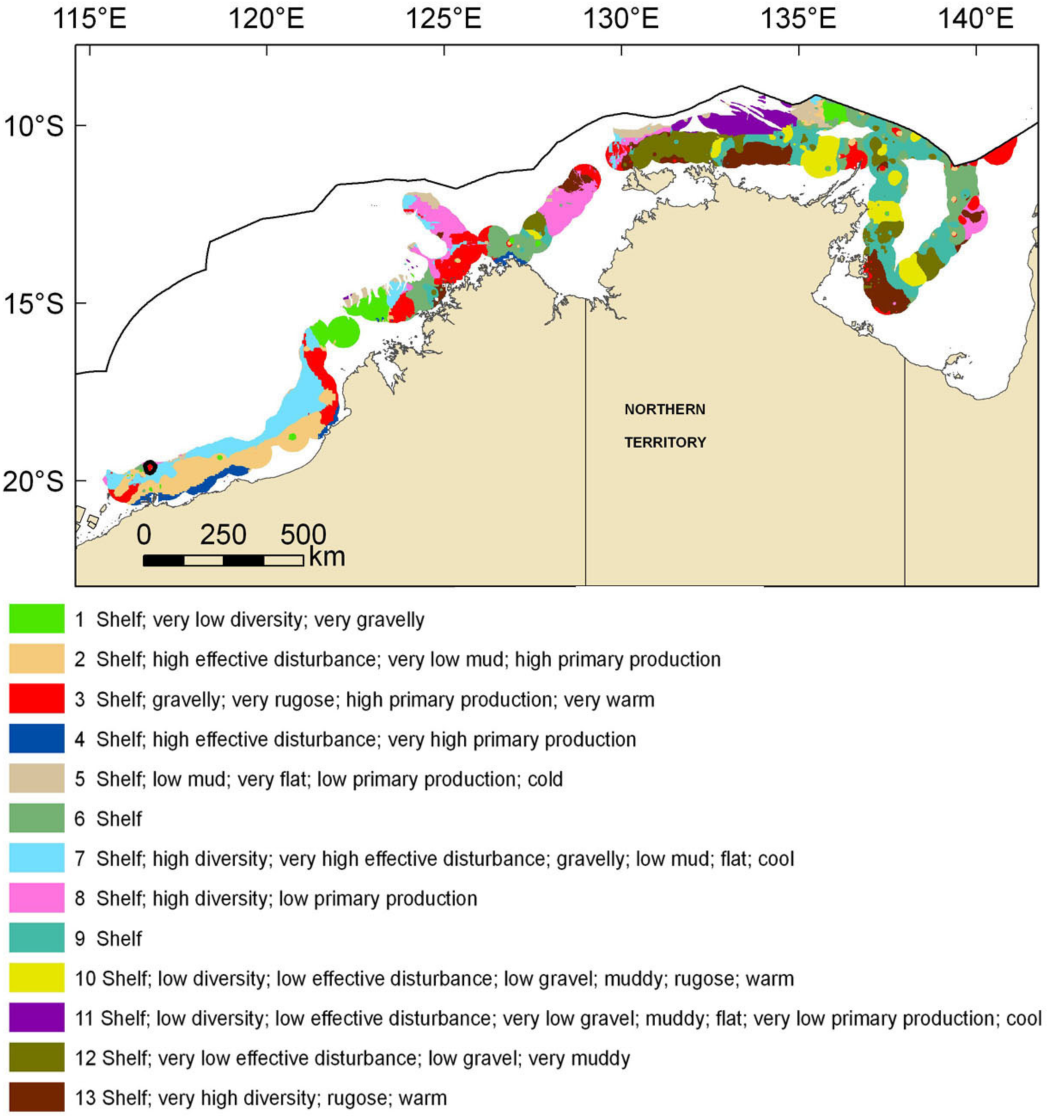


Figure 4.15. Map of the seascapes for the region encompassing all *Berg-3* survey locations, including the Shannon index as a biological data layer. The thick black circle in the lower left represents Glomar Shoals, and the thin black line is the outer boundary of the Australian EEZ.

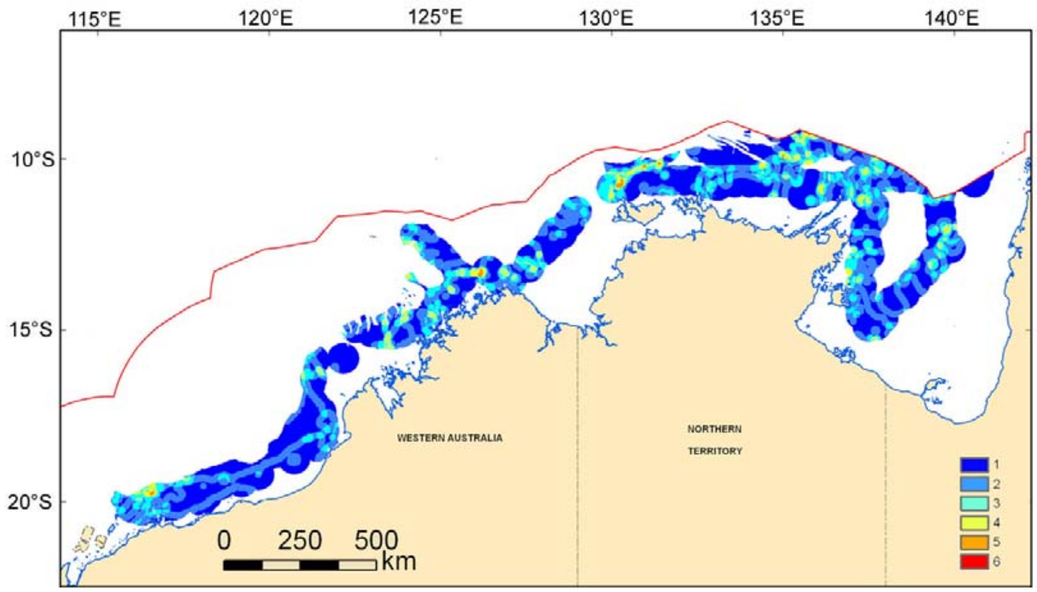


Figure 4.16. Map of focal variety indices for the region encompassing all *Berg-3* survey locations, including the Shannon index as a biological data layer. Higher index values represent higher habitat heterogeneity.

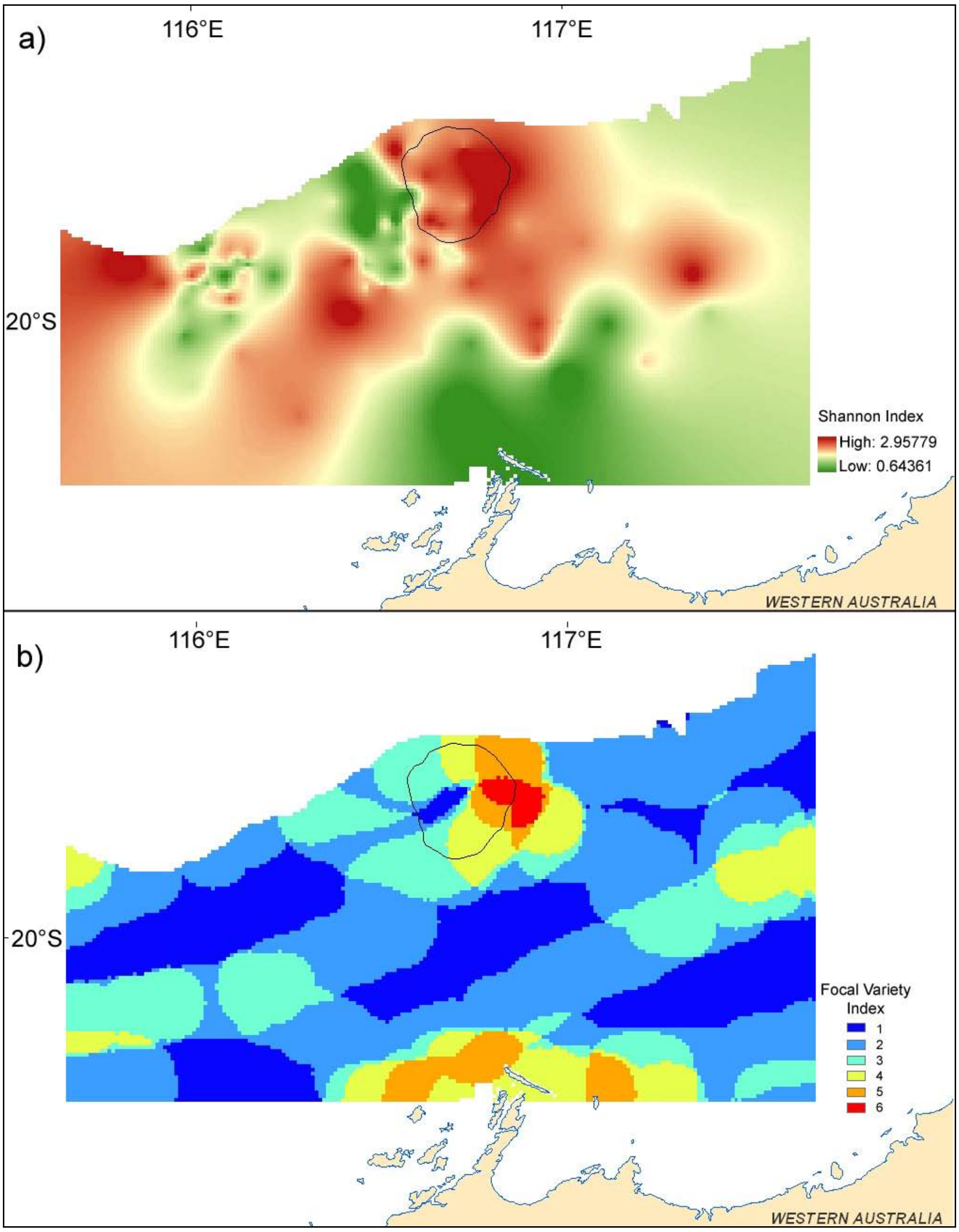


Figure 4.17. Comparison of: (A) interpolated biodiversity with the Shannon index and (B) focal variety analyses (excluding the biological layer) at Glomar Shoals and surrounding region. The black line denotes the outline of Glomar Shoals.

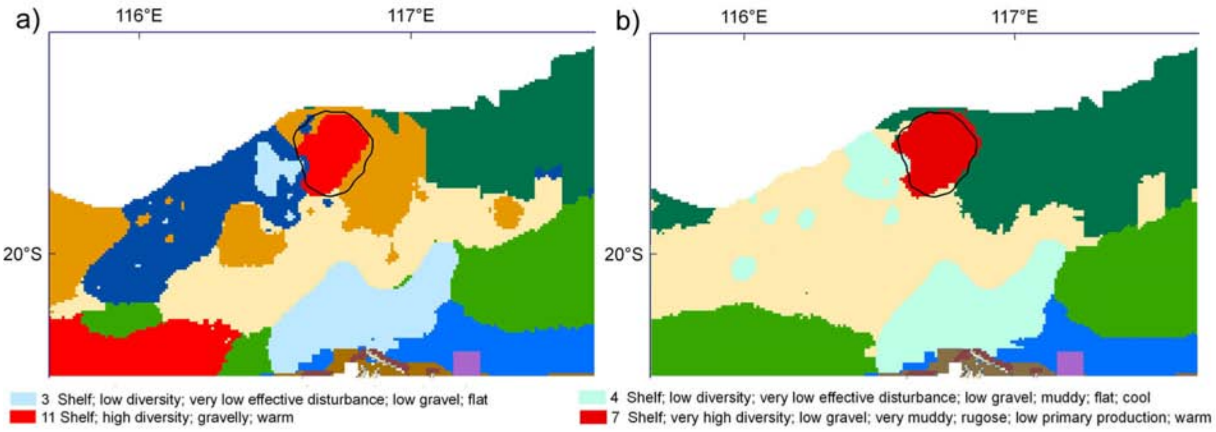


Figure 4.18. Comparison of local seascapes from analyses including a biological layer based on: (A) the Shannon index and (B) the Simpson index. The black line denotes the outline of Glomar Shoals.

4.3.3.3. Comparison of seascapes with and without biological data

The geomorphology of Glomar Shoals and immediate surrounds was used to compare seascape derivations with and without the integration of biological data. In all the seascape derivations undertaken, Glomar Shoals more or less corresponded with a single seascape characterised by relatively higher seabed temperatures (Fig. 4.19). However, the coincidence of this seascape with Glomar Shoals varied between the different derivations (i.e., the boundary of the seascape did not necessarily adhere to the boundary of Glomar Shoals in each case). Although Glomar Shoals is an ideal case for such an analysis because it represents a distinct geomorphic feature type surrounded by relatively homogenous geomorphology, variability in the seascape position and extent is expected because of the variable interactions between the different combinations of the data layers.

When the biological data layer is excluded, seascape 7 overlaps almost all of Glomar Shoals, but it extends approximately 20 km beyond the shoals into the surrounding area to the west (Fig. 4.19A). Similarly, when randomly-generated data is included as an additional layer, seascape 5 overlaps much of Glomar Shoals but also extends to the west (Fig. 4.19B). In contrast, when biological data are incorporated, this area immediately west of Glomar Shoals coincides with a different seascape and is characterised by low diversity (seascape 3 in Fig. 4.19C; seascape 4 in Fig. 4.19D). Importantly, the seascape derivations incorporating biological data more closely match the geomorphology of Glomar Shoals than the derivations excluding biological data or that incorporating random data. This result indicates that the inclusion of robust biological data can produce a more accurate seascape derivation that represents the underlying geomorphology.

4.3.3.4. Comparison of seascapes at local and regional scales

A regional seascape derivation was undertaken to assess whether the broader-scale geomorphology could be discerned by including biological data. The regional seascape derivation did not match the regional geomorphology to the same degree as the local scale analysis. Regional seascape derivations produced several seascapes that overlapped large portions of Glomar Shoals (Fig. 4.20A-B), whereas local seascape derivations produced single seascapes overlapping Glomar Shoals (Fig. 4.20C-D). However, integration of biological data into the regional-scale seascape derivations had a similar effect to that of the local derivations with the seascapes overlapping Glomar Shoals more closely matches the boundaries of the shoal (Fig. 4.20B, D).

In order to determine whether the integration of biological data produces more accurate seascapes at the regional scale the derivations were assess against other distinct geomorphic features in the region, including the Rowley Depression and West Londonderry and Sahul Rises. These features were chosen based on moderate density of biological data from the *Berg-3* survey and because they represent other distinctive geomorphic features.

The Rowley Depression did not coincide with any unique seascape, with or without the integration of biological data (Fig. 4.21). However, the seascapes derived with the additional biological layer more closely matched the geomorphology of the western side of the Rowley Depression (Fig. 4.21B) than those derived without biological data (Fig. 4.21A). Two seascapes covered the Rowley Depression in the derivation integrating the biological data compared to three in the derivation without.

The West Londonderry and Sahul Rises coincided with multiple seascapes (Fig. 4.22). In each case, the seascapes are not confined to the boundaries of the feature. In relation to the accuracy of delineating geomorphic features, there was no discernible difference between seascape derivations with and without the integration of biological data.

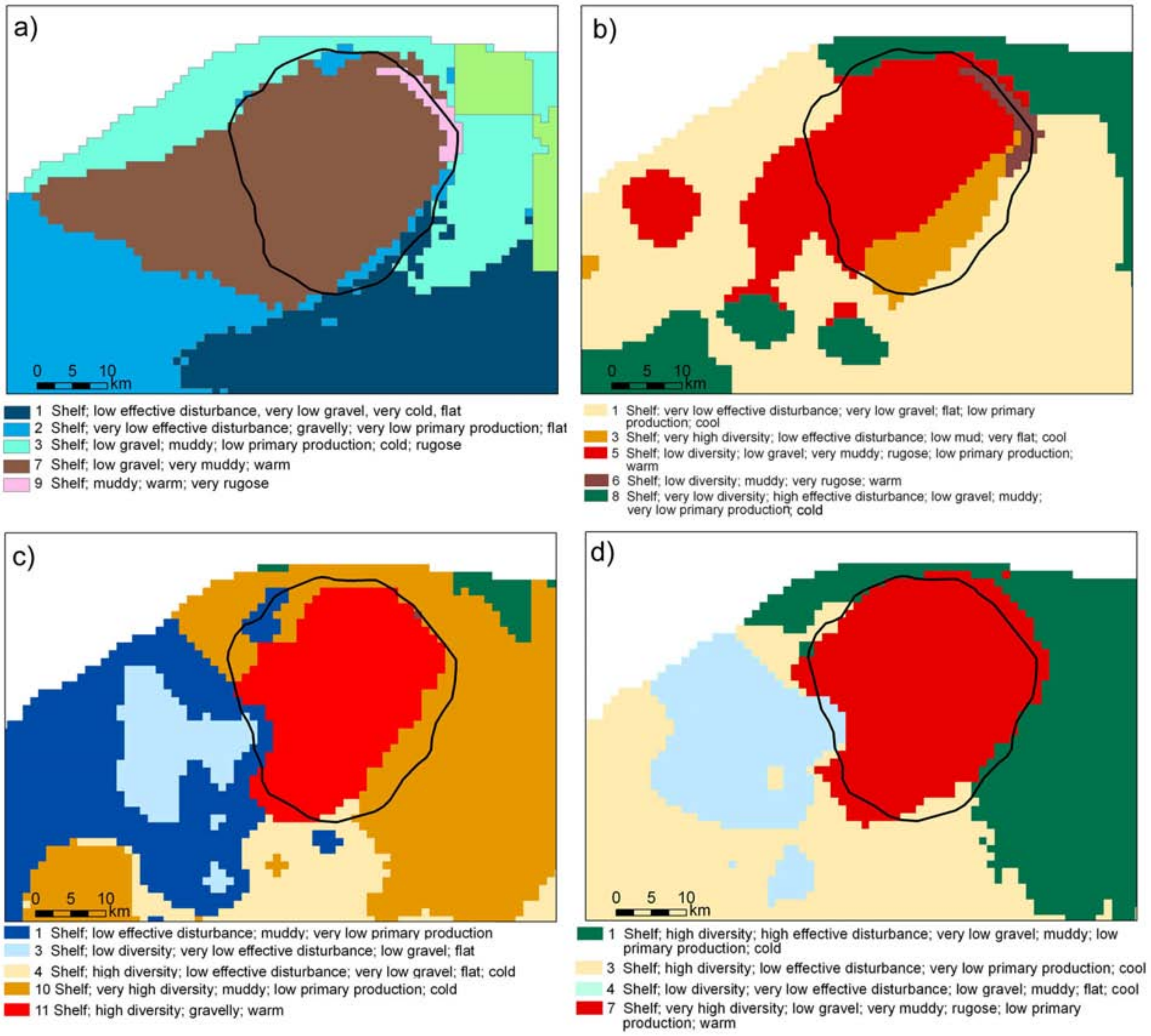


Figure 4.19. Comparison of local seascapes from an analysis: (A) excluding biological data, (B) including an additional layer based on randomly-generated data, (C) including an additional layer based on the Shannon index, and (D) including an additional layer based on the Simpson index. Black line denotes Glomar Shoals, and the names of seascapes intersecting the shoals are listed.

4.3.4. Biological Drivers

Eight out of 152 demersal fish species recorded from Glomar Shoals contributed more than 90% of the similarities of demersal fish assemblages among sites. These eight species (King soldier bream *(Argyrops spinifer),* Emperor fish *(Lethrinus* sp.), Malabar blood snapper *(Lutjanus malbaricus),* Brownstripe red snapper *(L. vitta),* Oblique banded snapper *(Pristipomoides zonatus),* Gracile lizardfish *(Saurida gracilis),* Yellowstripe scad *(Selaroides leptolepsis),* and Rabbitfish *(Siganus oramin))* are commercially-important. Several species showed slight variation in abundance across the seascapes. For example, *Saurida gracilis* was abundant at stations in seascapes 2 and 7, but this species was less abundant in seascape 1 (Fig. 4.23). However, no statistically significant differences in abundance were detected across seascapes for any of these species.

Several species were more abundant at Glomar Shoals than other areas (Fig. 4.24). Other species such as *S. leptolepsis* and *L. malabaricus* were not present at Glomar Shoals, but were moderately abundant at stations from the surrounding region. Despite differences in species presence, no significant differences in abundance were detected between Glomar Shoals and other locations for any species (except *S. leptolepsis* which was unable to be

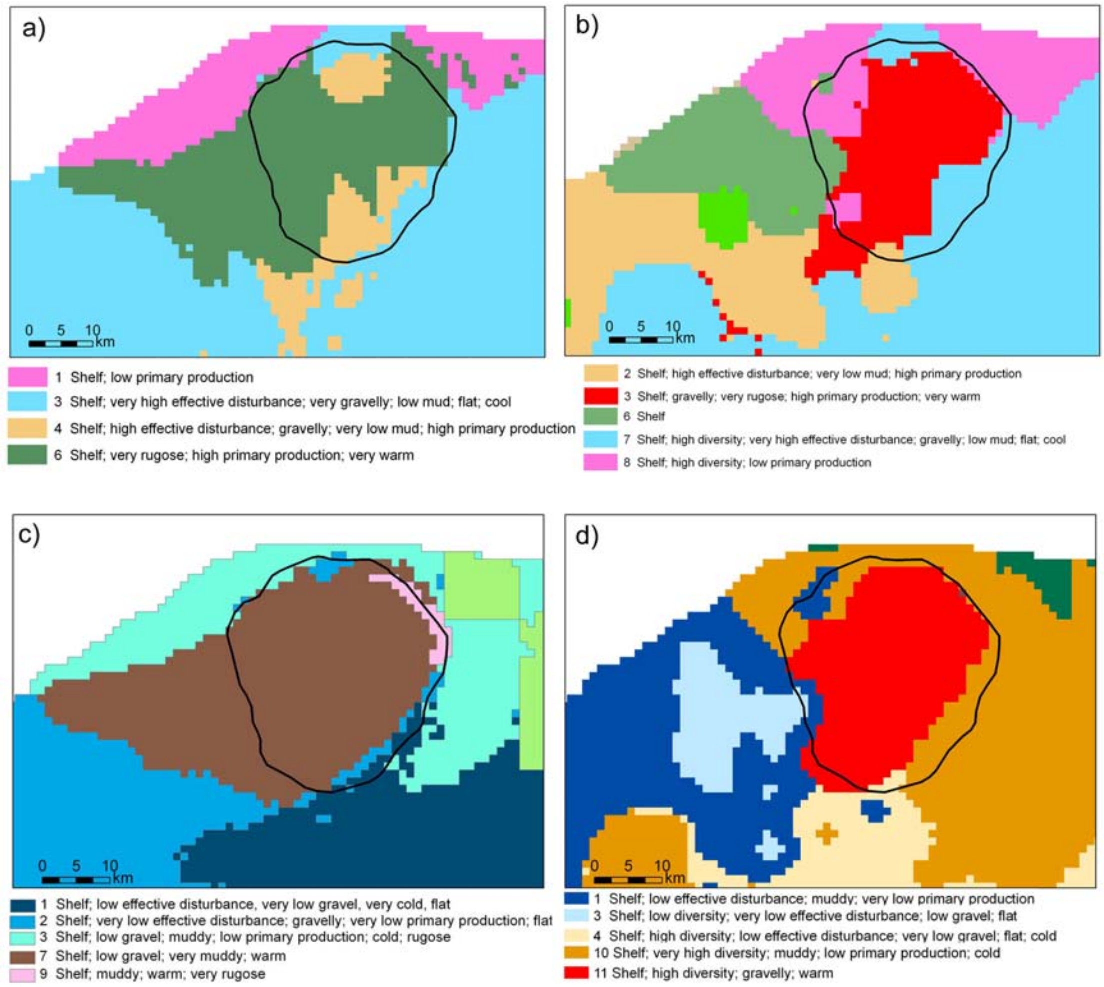


Figure 4.20. Comparison of seascapes in the Glomar Shoals region from an analysis of: (A) regional data excluding biological data, (B) regional data including a biological layer based on the Shannon index, (C) local data excluding biological data, and (D) local data including a biological layer based on the Shannon index. Black line denotes Glomar Shoals.

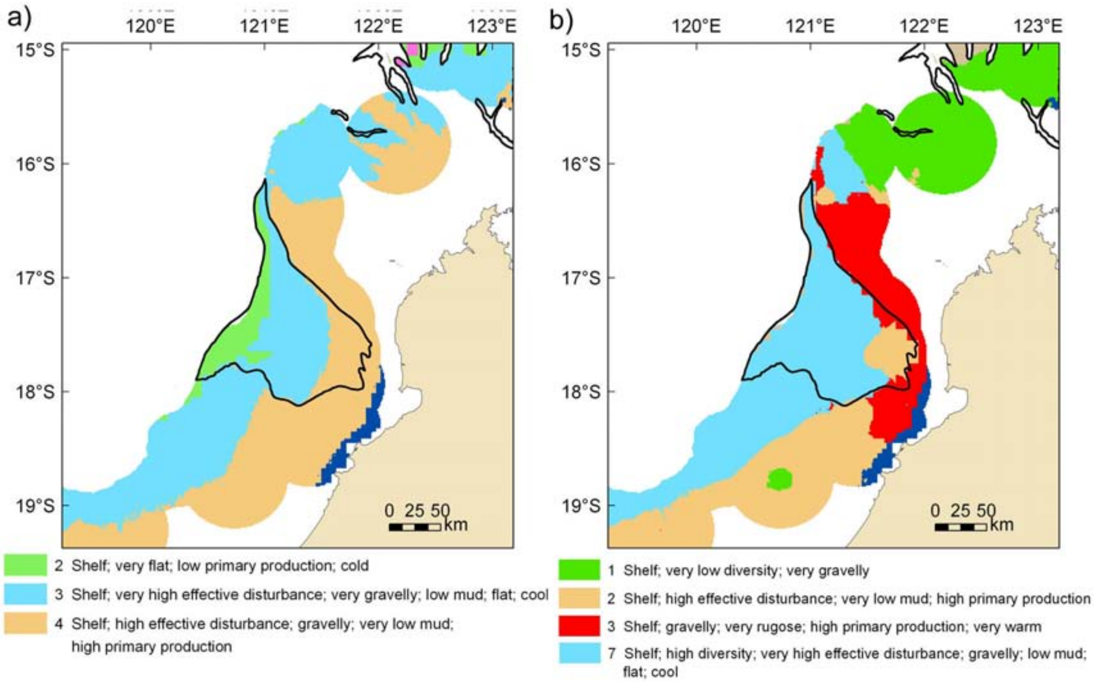


Figure 4.21. Comparison of seascapes in the Rowley Depression region from an analysis of: (A) regional data excluding biological data, and (B) regional data including a biological layer based on the Shannon index. Black line denotes the boundary of the Rowley Depression.

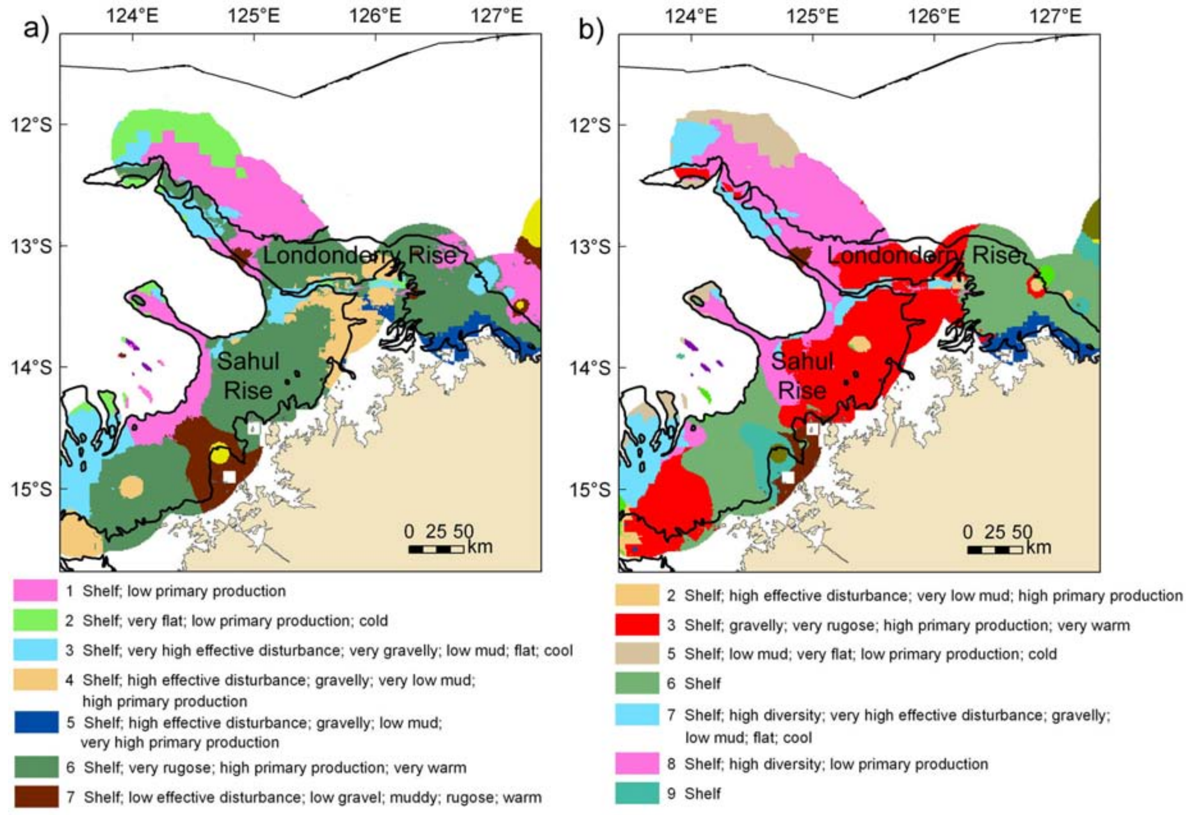


Figure 4.22. Comparison of seascapes in the West Londonderry and Sahul Rises from an analysis of: (A) regional data excluding biological data, and (B) regional data including a biological layer based on the Shannon index. Black lines denote the boundaries of the West Londonderry and Sahul Rises.

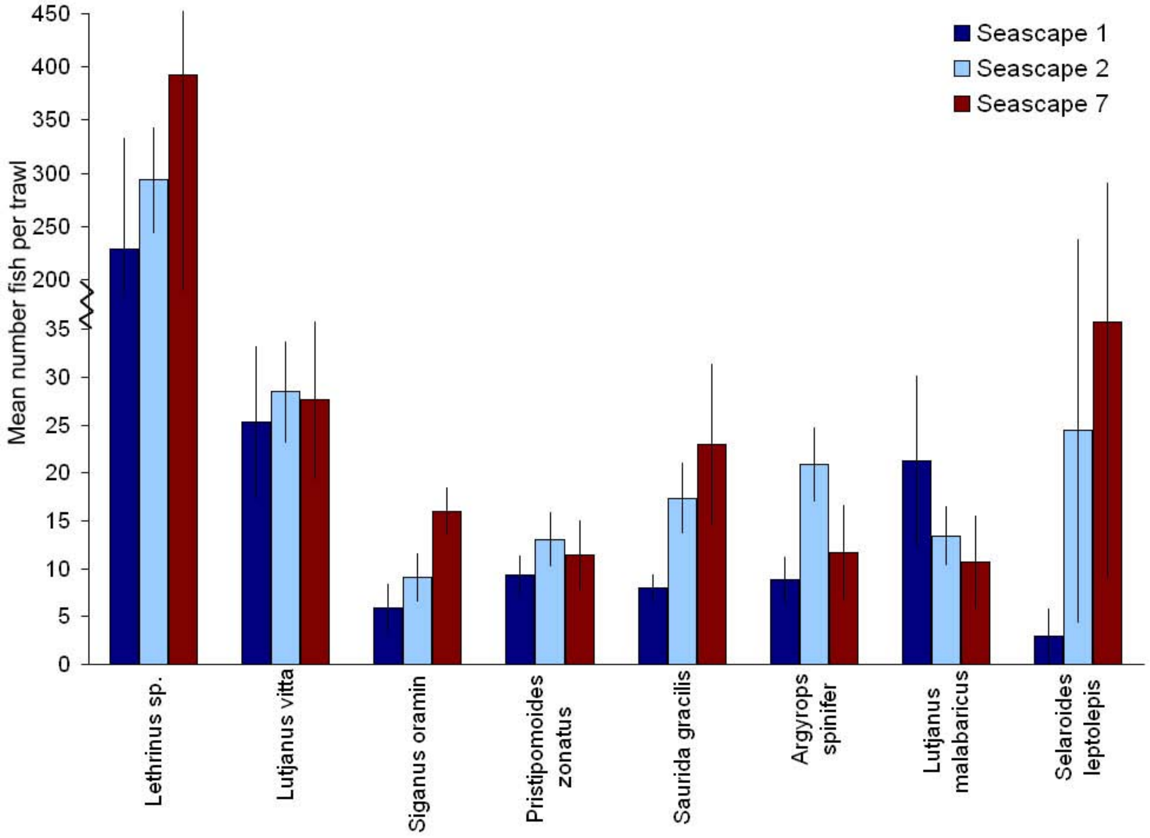


Figure 4.23. Abundance of key demersal fish species across seascapes. Seascapes were derived at the local scale without the integration of biology and here include only those where >10 stations occurred (seascape 1: n=19; seascape 2: n=60; seascape 7: n=21), although all were used in the analyses. Error bars are standard errors of mean.

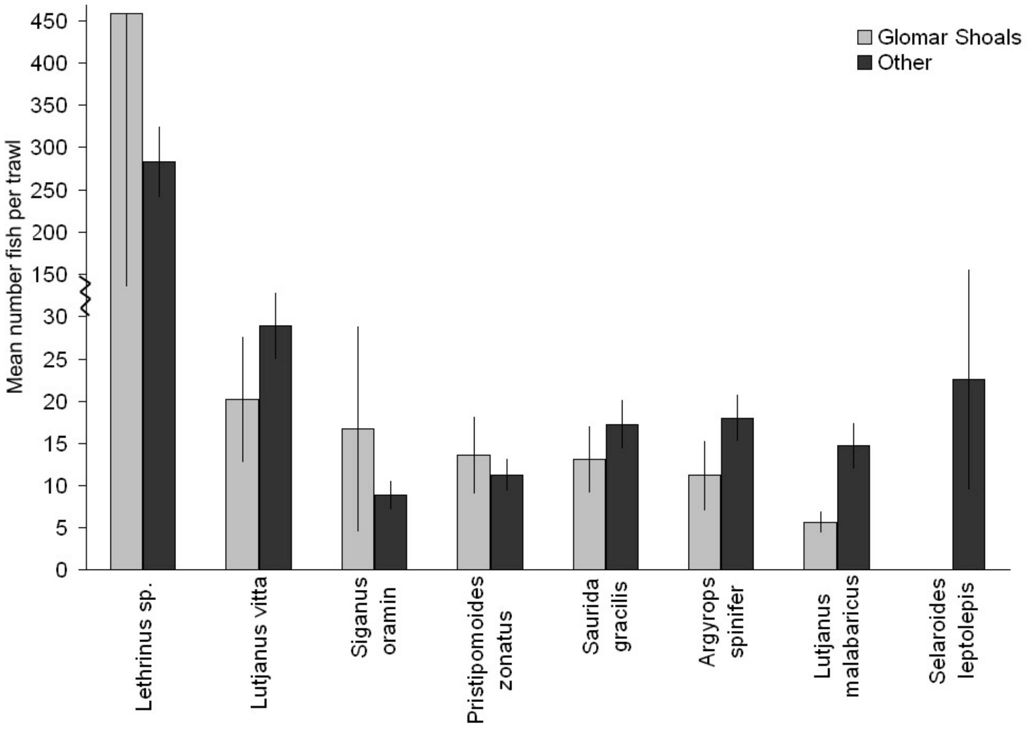


Figure 4.24. Abundance of key demersal fish species from Glomar Shoals and surrounding regions (Glomar Shoals: n = 12; other: n = 101). Error bars are standard errors of mean.

statistically analysed because the data were zeros for one factor). The comparatively low numbers of stations from Glomar Shoals (n=12) and the high variance in abundance of most species, as confirmed by the large error bars in Figure 4.24, contributed to the inability to detect significant relationships between individual species and geomorphology.

4.3.5. Physical Drivers

4.3.5.1. Univariate analysis

Biodiversity as measured by the Shannon index was not significantly correlated with any single environmental factor. Multiple regressions revealed that no combination of environmental factors was significantly associated with biodiversity. One of the strongest correlations resulted from a combination of slope, mud, gravel, and seabed temperature, but these combined factors still contributed only 4% to the overall variation in biodiversity (R^2=0.0400, p=0.3492).

4.3.5.2. Multivariate analysis

Similarly, biodiversity as measured by multivariate fish assemblages did not show any discernable patterns based on among individual environmental variables (Fig. 4.25). Individual environmental factors exhibited much weaker correlations with fish assemblages than combinations of environmental factors. The strongest individual correlation was for depth (Spearman rank correlation (ϱ) 0.151) and percent mud (ϱ=0.130) while the weakest correlations were for percent gravel (ϱ=0.026) and slope (ϱ=0.038).

In contrast to individual factors, demersal fish assemblages were significantly related to a combination of environmental factors. Depth, primary production, percent mud, effective disturbance, and slope had the strongest correlation, accounting for 22.6% of the differences observed in demersal fish assemblages (ϱ=0.226, p=0.01). However, the removal of slope from these factors decreased the strength of the correlation only slightly (ϱ=0.223),

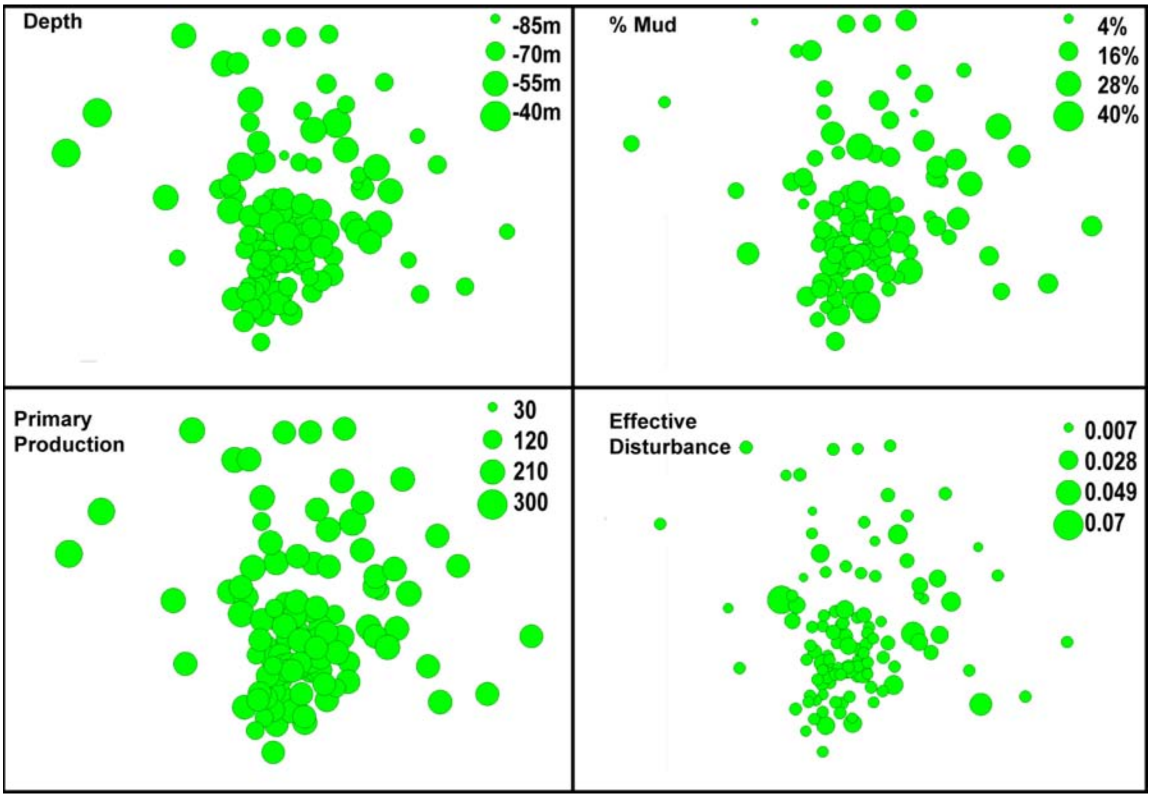


Figure 4.25. n-MDS ordinations with each bubble representing a station. The distance between the centers of bubbles illustrates the similarities of the associated fish assemblages; the greater distance between the bubbles, the more disparate the fish assemblages. The size of each bubble represents an untransformed environmental measurement (depth, percent mud, primary production, effective disturbance). These environmental variables were chosen because when combined, they produce the best correlation to the fish data. Stress = 0.22.

suggesting that the combination of depth, percent mud, primary production, and effective disturbance are the physical factors most related to demersal fish assemblages.

4.4. SUMMARY

The work on Glomar Shoals represents the first time biological data has been incorporated into the derivation of seascapes for Australia. Comparisons of seascape maps indicate that the integration of biological data into derivations at the local and regional scales may produce seascapes that more accurately reflect the shelf geomorphology, but only for features where the biological assemblages are very distinct compared to the surrounding region. At the local scale, an additional biology layer resulted in seascapes that more accurately represented the boundaries of Glomar Shoals a relatively prominent shallow-water, hard-seabed bank surrounded by relatively low-gradient shelf characterised by soft sediment. These physical factors are sufficiently distinct to result is a different biological assemblage in demersal fish for the two regions. Importantly, integration of biological data into local seascape derivations produced focal variety analyses that were more representative of the biodiversity in the region than those focal variety analyses based on seascape derivations without biological data. At the regional scale, relationships between seascapes and associated geomorphology were more complex. The addition of biological data produced seascapes that better matched the boundaries of Glomar Shoals but were only slightly better matched to the boundaries of other geomorphic features (Rowley Depression) or had no correspondence at all (West Londonderry & Sahul Rises).

The diversity of demersal fish varied across the Glomar Shoals region, with significantly higher biodiversity recorded on the Glomar Shoals than the surrounding shelf. Interpolated diversity values suggest that the highest diversity is located on the eastern part of the shoals. However, no significant differences in demersal fish biodiversity were detected across any of the seascapes. Only 5% of the species were classed as biological drivers, although analysed separately, most of these species showed no significant differences among seascapes or between Glomar Shoals and its surrounding shelf.

No single environmental driver significantly affected demersal fish biodiversity in the Glomar Shoals region. However, a combination of depth, percent mud, primary production, and effective disturbance had a significant correlation with demersal fish assemblages, suggesting these factors together partly drive biodiversity in this region. The narrow range of environmental parameters examined at the local scale may simply not represent a range at which we could detect relationships between biological and physical data. For example, maximum depth in the region was only 100 m, representing a fairly narrow depth range which may not have significantly affected the distribution of most of the demersal fish species. The weak effects of most environmental factors on biodiversity may reflect a true lack of relationship although the relationships are likely to be complex and require more sophisticated modeling approaches to be discerned. In addition, the inherent mobility of demersal fish may have resulted in less segregation between geomorphic features than reflected by environmental factors.

Data quality plays a significant role in the analysis and less than ideal data will only serve to mask significant relationships between abiotic and biotic factors. The only robust and reliable data that could be sourced for the present analysis are biological data collected from a 1967 Russian fish survey. There is bias towards commercially-important species, estimates of abundances, and unverified species identifications, as assessed by CSIRO (Koslow *et al.*, 1999). While these data are robust for the species used in the analysis others comprising the assemblages that were not captured/recorded and other environmental factors such as competition and predation were not considered. It is also likely that any analysis of abiotic relationships to biotic data (i.e., surrogacy) is confounded by the modifications to the trophic structure of marine biota through the impacts of commercial and recreational fishing that would even been apparent in 1967 (the degree to which the trophic structure has been modified is still poorly quantified for many marine species). Environmental factors used in the present analysis may be being assessed against a demersal fish assemblage still reaching equilibrium within a severely modified trophic structure.

5. Discussion

5.1. THE SEASCAPES CONCEPT

The national seascapes model incorporates environmental parameters available at a national scale (such as seabed mud content, sea surface temperate, and bathymetry) to predict areas of seabed with similar habitat types. Analysis of the focal variety within the seascape model measures the amount of habitat heterogeneity within these seascapes. The seascapes approach has clear rules for both incorporating variables (e.g. national extent) and interpolating variables at the national scale, which enable standardised comparisons to be made between regions. Importantly, the methods and data types used in the seascapes model are transparent to all stakeholders, which offers some level of certainty to help inform decision making.

If seascapes are to be used to inform managers and stakeholders about national, regional, and local issues in marine habitat and biodiversity management, then an essential and critical requirement is that the models be independently tested and validated against robust biological data to determine how well they capture real biodiversity patterns. In this report we have presented a sequence of biological validation approaches at three spatial scales: national, regional, and local to examine the utility of the current seascapes model. While a national scale approach is the most applicable to testing a national model, nationally compiled datasets are rare and fraught with holes and inconsistencies. At the time of writing this report, the only option available to us was to use OBIS records for around Australia. While the OBIS dataset contained over a million records and provided valuable insights into the national capabilities of the seascapes model in discriminating biological assemblages, OBIS records are presence only data that reflect a range of un-stated sampling types, sampling intensities, species targets, and biases around the nation, such as records dominated by museum collections—which often over-represent rare species and under-estimate common species. Therefore, although the OBIS data was valuable, there is a definite need for the compilation of a national biological datasets, which remove, or at least better account for, these biases. The CERF Marine Biodiversity Hub, which is funded by the Commonwealth Environment Research Facilities program (CERF) and Geoscience Australia is a partner of, has compiled a national biological dataset using quantitative regional datasets. Again, different sampling methods and target species between surveys has meant that this processes is not a simple feat, and requires assessments of uncertainties associated between and within survey types. While the CERF biodiversity hub has made important in-roads into this problem, compilation of national biological data requires considerably more attention and will be an essential requirement to validating future national biodiversity and seascape models.

5.2. SEASCAPE MODEL – BIOLOGIAL MEANINGFULNESS

The correlation of the seascape with biological data identified several important findings. At the national scale, seascapes explained several forms of biological pattern in three representative taxa (scleractinian corals, bivalves, and wrasse). The strongest patterns were contrasts between tropical and temperate provinces, and on-shelf versus off-shelf zones. Beyond this, the seascape derivation also contributed to explanatory ability in some limited conditions—generally in heterogeneous environments of the northern on-shelf provinces, and for some taxa between reefal and soft-bottom habitats (e.g., specific bivalves & wrasse genera). Such patterns reflect those published in bio-geographic literature (e.g. Veron, 1993).

At the regional scale, the three on-shelf seascapes examined in the GAB survey (i.e. seascapes 1, 4, and 6) adequately predict the observed assemblage patterns. Although based on a limited number of samples (i.e. 40 stations) seascapes correlated with a biologically meaningful depth gradient within a relatively homogenous soft sediment ecosystem. The three seascape classes differentiated three sequential depth zones: seascape 1 in the shallowest zone (comprising ~90% of the seabed in the GAB), seascape 6 in the deepest zone (comprising ~4% of the seabed in the GAB), and seascape 4 in an intermediate zone (comprising <2% of the seabed in GAB) representing what appears to be a transitional depth-zone assemblage (i.e. sharing species from both the shallower and deeper zones). However, unlike the GAB region that consists almost entirely of unconsolidated shelf sediments across the shelf and slope (Ward *et al.*, 2006), the GBR is probably one of Australia's most heterogeneous shelf systems comprising a diverse mixture of hard and soft substrata within a complex inter-reefal shelf ecosystem (Hutchings *et al.*, 2009). These more complex and heterogeneous habitats of the GBR were not well predicted by the current seascapes model. Seascapes on the GBR (i.e., Seascapes 2, 3, 7, 8, 9, 10, 11, 12, and 13; seascapes 1, 4, 5 and 6 were either absent or not well represented in the GBR region) did described a range of different benthic assemblages including bioturbated soft-sediments, seagrass-dominated systems, to areas of gravel with suspension-feeding invertebrates, but in general these seascapes were not strong predictors of habitat or biological pattern (11-50% success). This was due mostly to a combination of high within-seascape variability (e.g. a single seascape containing multiple assemblage types) and similarities between-seascapes where by multiple seascapes describe the same assemblage type (e.g. five seascapes described bioturbated-sediments).

While the findings of the analysis in the GBR identify interesting spatial and environmental differences and showed that the national seascape derivation provided some explanatory power, overall they had limited to low predictive capability. The results from the national and regional biological survey assessments, suggest that the utility of seascapes appear to vary between regions, possibly due to different levels of seabed (substrate) complexity and water depths.

5.3. SEASCAPE CLASSIFICATIONS – CHECKING PREDICTIONS

The misalignment between the current seascapes and the observed habitats and assemblages derived from the regional biological surveys resulted in the reduced predictive strength of the present model. An evaluation of whether this misalignment reflected between-class correlations in the physical variables used to define these seascapes or some other factor(s) was undertaken with reference to the GBR data to explore the nature of these patterns.

To examine if the relationships between the physical variables deriving the seascapes explained the observed biological patterns, a Principal Components Analysis (PCA) was run on the covariance matrix of the physical data (with each variable scaled to 0-100%) for both the national on-shelf and national off-shelf datasets. The correlation between variables and the principal components (factor loadings) were then plotted relative to the seascape centroids (mean ± 1 standard deviation for each seascape class) for both the on-shelf and off-shelf seascapes to examine how strongly correlated the physical variables were between the different seascape classes (Figs. 5.1 & 5.2).

The on-shelf ordinations of the physical variables strongly reflect patterns seen in the GBR habitat and biological ordinations (Fig. 5.1). The strongest pattern shows that seascapes 7, 9, 11, 12, and 13 are spatially intermingled and support a similar assemblage characterised by bioturbated soft-sediments. In contrast, seascapes 2, 3, 8, and 10 represent overlapping

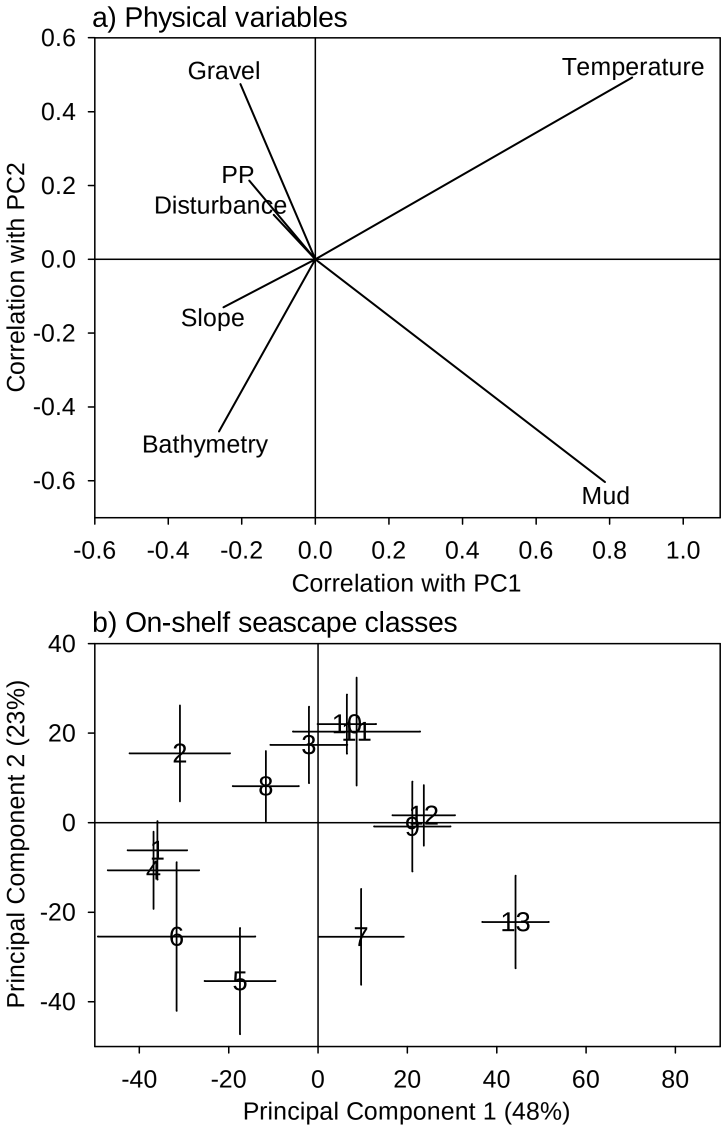


Figure 5.1. Principal Components Analysis (PCA) on the covariance matrix of the physical seascape variables for on-shelf Australia: a) Correlation of physical seascape variables with principal component (PC) axes, b) Seascape mean centroids ± standard deviation for the 13 on-shelf seascape classes. PP = primary production, disturbance = effective disturbance, temperature = sea surface temperature.

assemblage types, with seascape 8 characterised by seagrass, while seascapes 2 and 3 represented hard-substrate areas and associated sessile invertebrates. These patterns were strongly reflected by the on-shelf physical variables (Fig. 5.1a). For example, seascapes 2 and

3 are characterised by gravel content and effective disturbance. Both seascapes have similar seabed gravel contents but seascape 2 has slightly higher effective disturbance values than seascape 3. The GBR biological analysis identified that these two seascapes were spatially intermingled, and jointly described a similar seabed habitat—one of high bed stress with exposed hard-grounds—and a similar biological assemblage characterised by sessile invertebrate communities, including octacorals and sponges. Similarly, seascapes 7, 9, 12, and 13 are all characterised by seabed mud content. Consequently, although the present seascapes model did not strongly predict GBR benthic habitats and assemblages, the subsequent analysis of the physical variables identifies strong parallels between the relationships between seascapes and the types of marine assemblages present. Future improvements of the seascapes model should implicitly incorporate the relationships between physical variables when selecting seascape classes. By using improved rules for selecting classes some seascapes might be combined (e.g., seascapes 2 and 3) while others

might be split (e.g., seascape 10). Inclusion of an improved class criterion that incorporates these relationships for both the on-shelf and off-shelf models will likely improve the predictive power of the seascape models.

Ordinations for the on-shelf physical variables strongly reflect patterns seen in the data from the GAB. The three seascapes (seascapes 1, 4, and 6) in the GAB adequately predict the observed benthic invertebrate assemblages—structured by seabed mud content and water depth (Fig. 5.1b). The ordination of the physical variables identified that these three seascapes lay along a depth gradient, and therefore adequately characterised both the habitat type (homogeneous mud) and water depth gradient across the shelf. Biological patterns are known to vary strongly with water depth gradients (e.g., Kingsford & Battershill, 1998). Depth differences captured in the seascapes were therefore enough to predict differences in the invertebrate assemblages for this relatively mud-dominated region of the shelf.

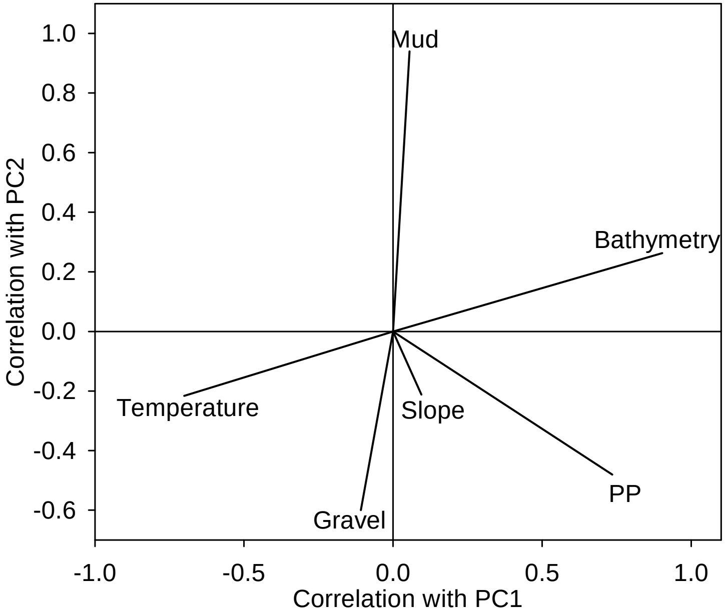
The relative importance of seabed mud content and water depth for predicting benthic biota as revealed in the present analysis is also borne out by other studies. For example, mud content and median grain size were the abiotic factors with the strongest correlations to macrobenthos of the North Sea, but depth was not found to be significant (Degraer *et al.*, 2008). Mud content and water depth were significantly correlated to species richness of macrobenthos in Moreton Bay but only in combination with distance to the ocean (Stevens & Conolly, 2004). Similarly, mud content and water depth showed moderate correlation to epibenthic assemblages in the Gulf of Carpentaria but only in combination with longitude (Post *et al.*, 2006; Post, 2008). Seabed mud content seems to have a particularly strong correlation with infauna (Post, 2008), likely due to the closer association with sediments of infauna than epifauna.

The off-shelf ordinations of the physical variables identified significant overlap only in seascapes 1 and 8 (Fig. 5.2). Seascapes 4 and 5 overlap slightly, with both characterised by primary production. Unfortunately, few robust off-shelf biological datasets exist to evaluate whether these seascapes describe/predict similar or different assemblages. This highlights the need to collect and compile datasets for off-shelf areas around Australia.

The national seascapes do not include variables that measure or predict hard-grounds. Consequently, in regions characterised by soft-sediments, the seascapes model are likely to differentiate biological assemblages along water depth, slope, and primary productivity gradients. However, where biota varies strongly by substrate type the current seascape model does not reliably distinguish the habitats and assemblages. Consequently, the national seascape derivations are useful at a regional and local scale for soft-sediment ecosystems, but more complex systems, such as the GBR, are not predicted well using the current model. Analysis of the physical data identified several overlaps in seascape types that mirror the biological patterns found in this report. This suggests that the classes currently used to discriminate predicted seascape classes can be improved. Nonetheless, including variables that measure or predict the distribution of hard-grounds will be an essential requirement for the prediction of complex ecosystems at any spatial scale.

5.4. INTEGRATION OF BIOLOGY INTO SEASCAPES

Integration of biology into the derivation of seascapes was successful at a local scale, producing seascape models that more closely matched the underlying geomorphology and finer-scale variability. Integration of both biological and physical data provides a holistic approach, in which both biological and physical factors are of intrinsic interest. Habitat mapping using both physical and biological variables has been used to inform management of the GBR Marine Park in which biological data was comparatively dense and robust


a) Physical variables

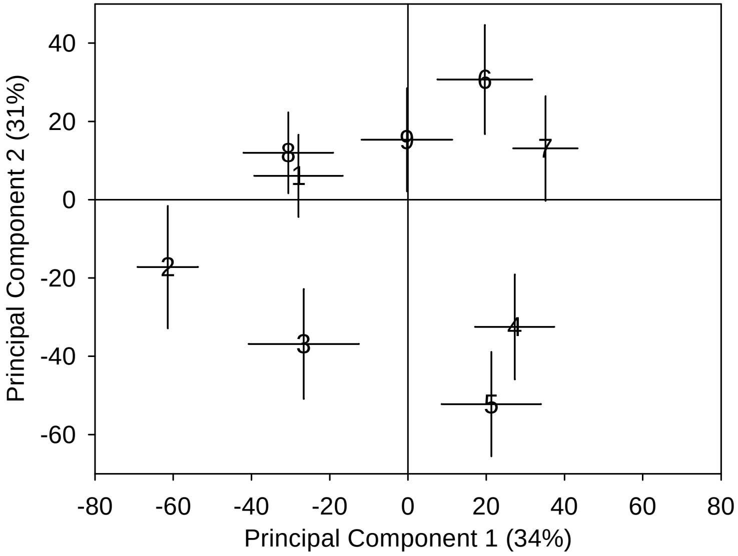

b) Off-shelf seascape classes

Figure 5.2. Principal Components Analysis (PCA) on the covariance matrix of the physical seascape variables for off-shelf Australia: a) Correlation of physical seascape variables with principal component (PC) axes, b) Seascape mean centroids ± standard deviation for the 9 off-shelf seascape classes. PP = primary productivity, temperature = sea surface temperature.

(Pitcher *et al.*, 2007). The seascape models derived in this study, in which a univariate biological layer was incorporated with multiple physical data layers, may provide a more appropriate, if coarser, method to broadly delineate habitat types at a local scale, even when biological data are available but still limited by data density or quality.

5.5. TAXONOMIC RESOLUTION AND DATA LIMITATIONS

As taxonomic resolution is reduced, the ability to differentiate biological assemblages among seascapes decreases. These results are supported by previous research in which coarse taxonomic resolution hinders the quantification of biodiversity (reviewed by Bertrand *et al.*, 2006; Pitcher *et al.*, 2007) and decreases distinction between habitats (Anderson *et al.*, 2005; Post *et al.*, 2006). Functional groups could be considered the lowest resolution in the current study, with only two groups at mobility (sessile, mobile) and five groups at trophic level (predator, grazer, suspension-feeder, deposit-feeder, and scavenger). With this perspective, it is not surprising that functional groups were not differentiated among seascapes.

Nonetheless, lower taxonomic resolutions and functional groups may still be of value in detection of differences in biological assemblages across seascapes, particularly since the identification to species-level is so difficult, time-consuming and costly (Ponder *et al.*, 2002). Several studies have shown that identification at the genus-, family-, and even order-level is sufficient to detect community response to environmental gradients (Doerries & Van Dover, 2003; Post *et al.*, 2006; Wlodarska-Kowalczuk & Kedra, 2007), depending on the group chosen (e.g., polychaetes in Wlodarska-Kowalczuk & Kedra, 2007) and the age of a community (Magierowski & Johnson, 2006). Similarly, functional groups have been shown to be effective in detecting differential relationships between biotic and abiotic factors (Collins *et al.*, 2005, Sanders *et al.*, 2007). In the current study, analysis of functional groups showed a very slight but non-significant tendency for invertebrate assemblages from a seascape to group together. However, the extremely unbalanced number of animals in the functional groups coupled with the unbalanced number of stations in each seascape probably contributed to the poor detection of any true relationships. Functional groups may also have been linked to substratum, a factor that is not considered in seascape derivations. Hard substrata are often associated with sessile suspension feeders, while soft substrata are more likely dominated by mobile deposit-feeders (Beaman *et al.*, 2005; Post *et al.*, 2006; Post, 2008). The utility of low taxonomic resolution and functional groups to detect differences across seascapes on a balanced dataset should ideally be tested across regions of differing habitat heterogeneity.

Evaluating seascapes at broader spatial scales requires robust and consistent biological data over the extent of the area of interest. OBIS is one of the few biogeographic datasets that attempts to amalgamate biogeographic information from around the world. However, while OBIS is an extremely large dataset, with records extending across Australia out to the EEZ, there are major constraints associated with using these data. Most significant to the examination of distribution patterns of taxa is that OBIS comprises presence-only data with no sample effort information. Geographic bias will also be present for certain taxa because: 1) different taxonomists work in different areas and tend to sample their local area, and 2) certain regions and taxa have received differing amounts of attention because of research priorities that reflect economic and national interests rather than unbiased attempts to quantify biodiversity. Finally, little data quality control has been undertaken on the OBIS data. Consequently, many records are missing important taxonomic information such as class, order, family. Many species are entered with misspelt names, or have uncertain identification (i.e., entered with a question mark). Therefore while the OBIS data provide a range of utilities, caution must be used in their analysis and evaluation.

Biological and physical data often show significant variation in their spatial extent, with appropriate physical data readily available on a national scale (e.g. depth, temperature, grain size) and robust biological data available only at much smaller local or regional scales (e.g., GBR, GAB). This will likely hinder the integration of biological data into seascapes on a large spatial scale.

5.6. FOCAL VARIETY

One relatively simple method for quantifying variations in the spatial distribution of seabed habitats is to apply a focal variety analysis to the national seascapes dataset. The focal variety analysis in ArcGIS simply counts up the number of different classes within a specified radius (in this case 50 km). Locations where seascapes and a range of geomorphic features intersect imply high potential habitat variability (Day & Roff, 2000; Harris *et al.*, 2007; 2008). Areas of high habitat heterogeneity are regions targeted for the establishment of marine protected areas, where the goal is to protect as much of the habitat diversity in the smallest area (DEH, 2005). Knowing where the greatest seabed habitat heterogeneity exists at a national (continental) scale can be a useful guide in the development of system of marine protected areas.

Focal variety indices were thus calculated separately on the seascapes (which comprise continuous data) and geomorphic features (which comprise categorical spatial data; Heap & Harris, 2008) and the results combined. Areas of highest habitat heterogeneity are denoted by highest focal variety indices (i.e., where many different seascapes occur). While we have undertaken a new focal variety analysis on the national seascapes here, full details of the calculation of the focal variety index are presented in Whiteway *et al*. (2007).

In Australia, for the on-shelf region, greatest focal variety and thus seabed heterogeneity generally occurs on the outer shelf, as well as next to islands and coral reefs (Fig. 5.3). Generally, the shelf of northern Australia displays higher focal variety indices than those on the southern shelf regions. The inner-shelf, particularly in the Great Australian Bight, Gulf of Carpentaria and North West Shelf, displays low (<5) focal variety indices. This indicates that these places are characterised by relatively uniform seabed habitat types that cover relatively large areas. Highest (>12) focal variety indices occur at the southern end of the Great Barrier Reef-Capricorn Channel region, and on the Arafura and Ashmore Shelves. These regions coincide with regions of the outer shelf that are relatively rugose (steep) and contain relatively complex geomorphology (i.e., a large number of different geomorphic features).

For the off-shelf region, greatest focal variety occurs on the mid- to outer-slope regions, particularly associated with rugose regions of the slope dissected by submarine canyons and the margins of submerged marginal plateaus (Fig. 5.4). Highest (12–13) focal variety indices occur adjacent to Lord Howe Island, on the Kenn Plateau, near the head of the Townsville and Queensland Troughs and northwest margin of the Queensland Plateau, Offshore of the Sahul Banks, the southern margins of the Exmouth and Naturaliste Plateaus and Eyre Terrace, and the Diamantina Zone. Abyssal plain/deep ocean floor regions are characterised by relatively low (<3) focal variety indices implying that the seabed habitats in these environments are comparatively uniform and cover relatively large areas.

Because seascapes and geomorphology are treated separately, the national focal variety analysis indicates that it is capturing real differences in seabed habitat heterogeneity at a broad (national) scale, and the magnitude and distribution of the indices are not solely based on underlying data density. This also implies that areas of diverse geomorphology are also areas of relatively diverse seabed habitat types, supporting the assumption that the spatial heterogeneity of the geomorphic features can be used as a first-order approximation of seabed habitat variability (i.e., the concept of physical surrogacy). This concept has particular application in the deep ocean where biological data are relatively scarce.

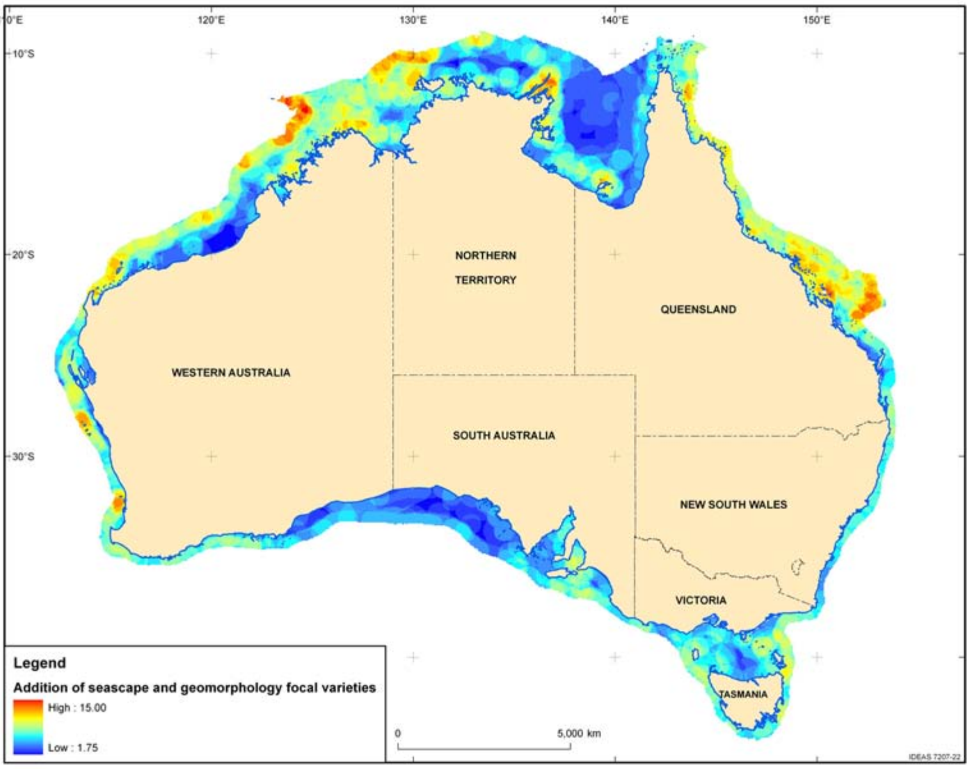


Figure 5.3. Focal variety indices for the on-shelf region of the Australian margin. The focal variety shows where the seabed is most heterogeneous. For the on-shelf region, greatest seabed heterogeneity (>12) occurs on the rugose and steep outer shelf regions, particularly at the southern end of the Great Barrier Reef-Capricorn Channel, and Arafura and Ashmore Shelves.

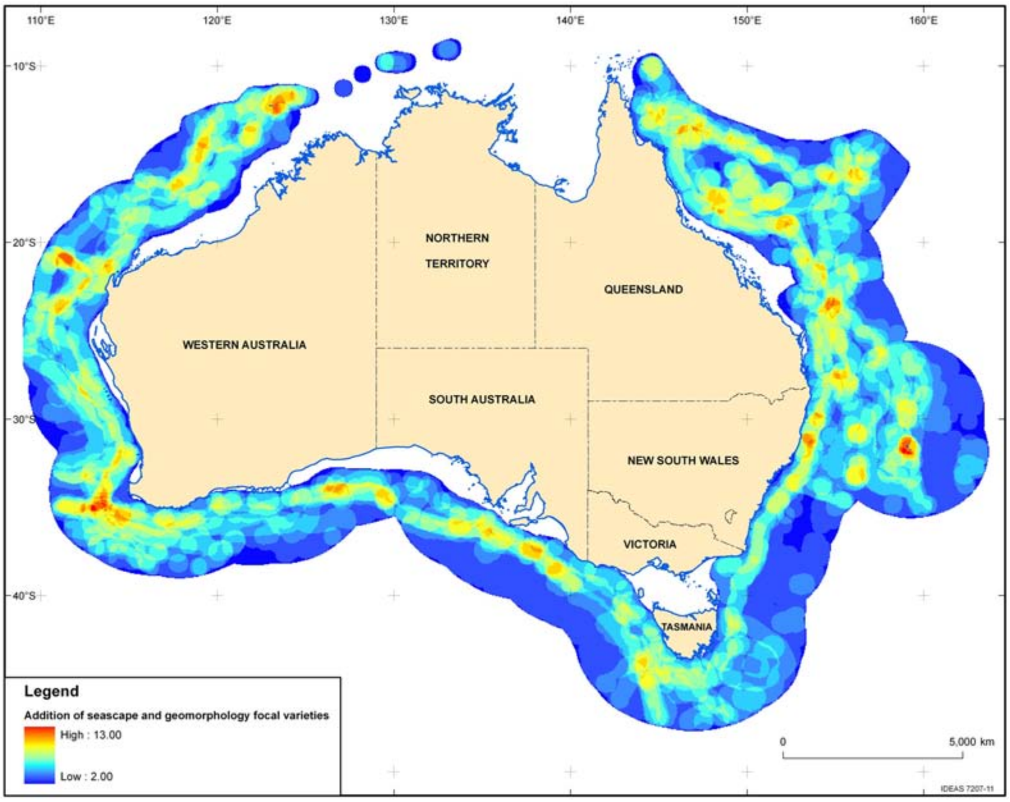


Figure 5.4. Focal variety indices for the off-shelf region of the Australian margin and adjacent deep seabed. The focal variety shows where the seabed is most heterogeneous. For the off-shelf region, greatest seabed heterogeneity (>10) occurs on the mid- to lower-slope in regions characterised by rugose environments and areas incised by numerous submarine canyons.

6. Future Directions

The national seascapes were derived as a broad-scale spatial representation of seabed habitats to meet the immediate needs of Australia's marine bioregional planning program. Derivation of the seascapes is a necessarily iterative process and the methods employed here were intended to be refined to improve the associations with biodiversity patterns at various scales. Based on previous literature and the results herein, several recommendations for future seascape derivations are presented. These recommendations can be divided into two areas, namely improvements to data layers and classification modelling.

6.1. IMPROVEMENTS TO DATA LAYERS

Future refined seascape derivations should include updated layers of the underlying biophysical data. Effective disturbance has been updated to reflect more robust modelling and estimation of seabed disturbance as it relates to biota. Primary productivity represents the annual average of satellite-derived fluxes of chlorophyll-*a* and should be modified to account for differences in onshore and offshore processes. Deep sea benthic animals particularly may be responding to seasonal changes in primary productivity rather than the annual average, with higher diversity occurring in areas with less difference between seasons (Corliss *et al.*, 2009). Replacing this layer with other data, such as seasonal variation of primary productivity, organic content of sediment or particulate organic carbon, may improve the explanatory power.

Additional abiotic layers relevant to seabed characterisation may be incorporated into future seascape derivations. A layer differentiating hard and soft substrates seems particularly useful (cf., Beaman *et al.*, 2005). Other abiotic factors, including: distance across shelf, oxygen availability, nutrients, and light attenuation, also explained portions of the biological variability for fish and invertebrate assemblages in the GBR lagoon (Pitcher *et al.*, 2007). While factors will apply only to on-shelf seascapes (e.g. light attenuation) addition of other factors may improve future seascape derivations.

Most abiotic variables that significantly contributed to benthic invertebrate assemblages in the GAB were depth-related, thus confounding the effects of single variables and potentially diminished the effects of non depth-related variables such as percent gravel. Weighting of the data layers to account for these interactions could be useful in improving relationships with biotic variables. Also, application of alternative interpolation methods that are tailored to the characteristics of the different data layers will improve their accuracy (Li & Heap, 2008; Post, 2008).

6.2. IMPROVEMENTS TO CLASSIFICATION MODELLING

In the current seascape-classification model, all the biophysical variables are treated as continuous variables. Biological responses to bio-physical variables are often complex and non-linear. For example, numbers of hermatypic corals do not steadily increase with temperature, but rather reflect a threshold response whereby corals occur in regions where the winter temperatures is warmer than ~20° C (Veron, 1993). Incorporation of non-linear factors such as thresholds would reflect the biophysical boundaries that marine assemblages respond to and enhance the predictive ability of seascapes.

The current cluster analysis of continuous biophysical information is fitted into a discrete number of seascape classes (13 in the case of the on-shelf, 9 in the off-shelf). Discrete seascape classes, if not aligned properly with biological data, may reduce predictive ability.

For the GBR, physical variables are known to be strong predictors of benthic assemblage structure, and importantly the seascapes on the GBR did describe different assemblages. However, the predictive strength of these relationships was low because of internal variability within seascapes and similarity between seascapes. Correlations with biology also identified that some seascapes might be better combined. For example, seascape 2 and 3 could be combined as both described similar suspension-feeding assemblages. Similarly, combining seascapes 7, 11, 12, and 13 together would describe a single but expansive bioturbated habitat with few other fauna and flora. By combining seascapes with similar assemblages, predictive ability will greatly improve. In addition, seascapes that described multiple habitats within a single seascape (e.g. seascape 10) require additional splitting so that again one seascape describes a distinct assemblage.

A process-oriented model, rather than a factor-oriented model, may facilitate an improved understanding of the different relationships between abiotic and biotic factors among regions (Post *et al.*, 2006). An abiotic factor may not necessarily be driving biological patterns but may instead be linked to processes driving the patterns. For example, mud content is affected by sediment mobility and input, including seabed exposure and disturbance (Post *et al.*, 2006) which in turn affect nutrient availability, light attenuation, and larval recruitment (Newell *et al.*, 1998). In areas with high variability in sediment mobility, mud may be significantly correlated to biological assemblages as it is a proxy for sediment mobility. In areas with more uniform sediment mobility, both percent mud and biological assemblages may be more homogenous and show weaker correlations.

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9. Appendices

APPENDIX A: IMAGE FILES

This appendix contains images of the final data layers used to derive the present national seascapes model. The images are in Joint Photographics Experts Group (jpg) format and contained on the accompanying CD.

APPENDIX B: GAB SEABED VIDEO DESCRIPTIONS

Qualitative descriptions of video from Geoscience Australia GABSEEPS (GA-231) and SS01/07 surveys are presented below. For each video transect animal abundance and transitions in relief, substrate, and overall bioturbation patterns were recorded at 10-20 minute intervals. Time is based on a time stamp imprinted on the video.

GABSEEPS GCV-01 (14:16:24 – 15:00:45)
The seabed was flat and muddy, with a few patches of consolidated sediment or mud-covered rock at 14:21:25 and 14:33:45 (~20 s) and mud-rock at 14:35:30 (~15 s). Various tracks and mounds were visible, including some star-shaped impressions, likely due to brittlestars. The most predominant fauna were echinoderms, with brittlestars, holothurians, and sea urchins prevalent. A relatively large species of sea urchin was also seen regularly. Scattered prawns and fish were also seen, as well as one glass sponge.

GABSEEPS GCV-02 (18:27:47 – 20:29:30; ~4 mins of lost footage)
The seabed was flat and muddy, although rocks were observed at 18:48:21, 18:50:26, 19:26:10, and 19:27:48 (~30 s). High-relief rock faces were observed at 19:39:10 and 19:52:17 (~90 s), although their extent is unknown because most of the footage was black. Various tracks, mounds and burrows were observed, including some acorn worm switchback trails; adults were not observed. The most predominant fauna were echinoderms, with brittlestars, crinoids, holothurians, and sea urchins prevalent. Brittlestars were more common in the first few minutes, while crinoids were more common in the latter half. The same large sea urchins seen in *GCV-01* were even more common at this station, particularly for two minutes from 18:46:30. The largest animals were pointy-nosed rays, observed three times buried partially in the sediment and swimming at 19:17:50. Scattered starfish, fish, prawns, anemones and glass sponges were also seen.

GABSEEPS GCV-03 (20:31:10 – 22:24:30; ~29 mins of lost footage)
The seabed was flat and muddy. Sediment was dotted with distinctive halo-like mounds with a burrow in the centre. Very few trails were seen. The most dominant fauna were fish and prawns, with crinoids, holothurians, and a whip also seen. Several unknown spheres floated beneath the camera; these may have been swimming sea cucumbers.

GABSEEPS GCV-04 (19:32:45 – 21:24:30; ~4 mins of lost footage)
The seabed was muddy. Craters and larger impressions of low relief were observed across the entire transect. Trails, burrows and halo-like mounds were also observed. Odd spherical structures that looked like lumpy sponges dotted the seabed, sometimes in high densities (~30 per min of footage). The dominant fauna were fish, prawns and sea piglets, the latter which appeared in the second half of the video (20:40:00 to end). Other fauna included starfish, glass sponges, and swimming sea cucumbers.

GABSEEPS GCV-07 (06:10:28 – 08:13:42; ~3.5 mins of lost footage)
The seabed was flat and muddy. Various tracks and burrows were visible. Swimming sea cucumbers were the most prevalent animal, with herds of them seen swimming and resting on the seabed throughout the entire transect but they were particularly abundant in the first 10 minutes. Brittlestars, urchins, starfish, fish, prawns, and crabs were also seen. An unknown gelatinous, tentacled animal was also seen resting on the seabed on several occasions, including one time when it swam away from the camera, moving like a jellyfish (08:04:02).

GABSEEPS GCV-08 (13:11:55 – 14:53:11; ~8 mins of lost footage)
The seabed was flat and muddy. Scattered burrows and mounds were visible but in low densities. Towards the end of the transect a few scattered small craters were observed. Swimming holothurians were by far the most abundant animal, particularly toward the latter half of the transect where over 500 animals were seen between 14:36:30 and 14:41:30. Unknown gelatinous animals were seen resting on the seabed on many occasions (moving at 14:24:15). Fish were also prevalent, with a species of relatively large 'eel-like' fish seen on multiple occasions. Other uncommon fauna included starfish, a prawn, an unknown stalked sessile invertebrate, and swimming white worms.

GABSEEPS GCV-09 (15:07:50 – 16:50:40; 0 mins of usable footage)
Video was out of focus and identifications were compromised. The substrate type was muddy with low-relief. Scattered fish were seen, and the occasional dark shape like a swimming sea cucumber was noted. Abundant zooplankton occurred in the water column.

GABSEEPS GCV-10 (09:34:00 – 10:55:00+; 0 mins of usable footage)
Video was out of focus, although scattered fish and small groups of swimming sea cucumbers were seen. The seabed comprised mud with flat or low relief, and occasional rocky patches appear to have been crossed towards the end of the video.

GABSEEPS GCV-11 (23:02:48 – 24:19:05)
The seabed was flat and muddy at the start of the transect and interspersed by a few rock faces. Rocky patches were common later in the transect, interspersed with the flat muddy seabed. Few signs of bioturbation were seen, with only a few trails and burrows present. The most abundant animals were galatheids (squat lobsters), large prawns or scampi, and gelatinous animals that looked like swimming dumbbells. Other scattered fauna included fish, holothurians, a crinoid, glass sponges, and a white worm.

GABSEEPS GCV-12 (19:48:00 – 21:10:00)
The seabed was rocky with high-relief, comprising steep rock walls, mud-covered in places interspersed by muddy flat plains. Gorgonians and soft corals dominated the visible fauna, with >100 individuals observed in the first 5 minutes. Crinoids and ophiuroids were also commonly seen in their branches. Gorgonian rubble was common around the live gorgonian gardens. Other sessile fauna such as sponges, ascidians, and bryozoans likely live in this community but were unable to be identified due to the quality of video. Fish, swimming sea cucumbers and non-gorgonian associated ophiuroids were common. Other less abundant fauna included non-gorgonian associated crinoids, anemones, urchins, prawns, sea whips, glass sponges, and 'lumpy sponges'. Unfortunately, after 20 minutes of video, the focus lever appears to have been knocked and the video remaining footage was out of focus.

GCV-13 (21:04:55 – 21:54:55)
The seabed was muddy and flat, with very few tracks or burrows. No group was relatively dominant. Fish, urchins, brittlestars, prawns, holothurians, and 'lumpy sponges' were seen. Several starfish were also observed along with their distinct star impressions. On several occasions a stalked animal with flower-like top was noted, likely a glass sponge stalk with a single crinoid at the top.

SS01/07 (11:14:00 – 11:38:00)
The seabed was muddy, with larger mounds and shallow depressions throughout the transect. The mounds may have been formed by calianassid shrimp but none were seen. Other less abundant fauna were demersal fish (including cusk eels), an anemone, and unknown sessile organisms, one of which had a distinctive bi-lobed trunk. In several places, a pinkish long-legged animal drifted through the water column, possibly a crustacean phyllosoma.

APPENDIX C: ARCGIS DATASETS

The appendix contains gridded data and shapefiles for the on-shelf and off-shelf seascapes and focal variety analyses. All files and data are contained on the accompanying CD.

Contents of the Data CD

SEASCAPES FOR THE AUSTRALIAN MARGIN AND ADJACENT SEABED

This data CD contains the above-titled report as: **Record2011_06.pdf**

View this .pdf document using Adobe Acrobat Reader (click Adobe.txt for information on readers)

Double click on **Record2011_06.pdf** to launch the document.

Directories on this DVD

Appendix A: Image Files

Images of the final data layers used to derive the seascapes are contained on the data CD in jpg format.

Appendix C: ArcGIS Datasets

Gridded data and shapefiles for the on-shelf and off-shelf seascapes and focal variety analyses are contained on the data CD.