

CLASSIFICATION OF SEAGRASS HABITAT STRUCTURE AS A RESPONSE TO WAVE EXPOSURE AT ETOILE CAY, SEYCHELLES

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ABSTRACT

Physical processes are thought to be a critical control on shallow water communities in the tropics. Past studies of seagrass community patterns have tended to be qualitative and failed to empirically link observed structures with the processes that govern them. Remote sensing technology, in the form of imagery acquired using a Compact Airborne Spectrographic Imager (CASI), has been used to construct a habitat map of seagrass communities at Etoile Cay, Amirantes, Seychelles. A simple definition of seagrass habitat structure, incorporating measures of complexity and heterogeneity, has been investigated along a wave exposure gradient via moving window analysis over the classified habitat map. Both complexity and heterogeneity values are greatest at high to moderate levels of wave impact, supporting the intermediate disturbance hypothesis.

Keywords: Seagrass habitat, seagrass wave exposure, seagrass hyperspectral imaging.

INTRODUCTION

Seagrasses, rooted and submerged angiosperms of several species, are one of the most productive components of shallow marine environments. They provide a range of important ecological goods and services, including provision of nursery areas that underpin fisheries, oxygenation of coastal waters and protection against coastal erosion. Within environmental limits determined by water depth, hydrodynamics and substrate type and stability (1), organisation ranges from closed canopy meadows, to sparse seagrass within extensive sand sheets.

Research on seagrass patterns has primarily been descriptive in the Indo-Pacific biogeographic province (2). In the western Indian Ocean, modern reef communities veneer an inherited topography developed during the Pleistocene (3). These surfaces are typically colonised by seagrasses; two species, *Thalassia hemprighii* and *Thalassodendron ciliatum*, are common throughout the Seychelles (4) where they are found at typical densities of 540-627 and 1123-1761 shoots per m² respectively (5). The aim of this study was to empirically investigate the structure of the seagrass landscape at Etoile (05°53'S, 53°01'E), a vegetated sand cay with surrounding reef platform in the middle of the Amirantes Ridge (Figure 1).

McCoy and Bell propose a graphical model (6) of general ecological habitat structure along three axes, comprising heterogeneity, complexity and scale. Heterogeneity is the variation attributable to the relative abundance of different structural components. Complexity encompasses variation attributable to the absolute abundance of individual structural components. The scale axis encompasses variation attributable to the measurement area used. Such a model is useful for comparing habitat structure at different locations.

A critical factor in shallow water marine environments in the Tropics and sub-Tropics is water movement. While it controls food supply and oxygenation, as well as removing metabolic waste products (7), it also presents a mechanical stress, as communities must adapt to current flows and withstand the force of breaking waves. In the case of coral reefs, Rosen viewed the presence of a particular reef community as a response to three mutually perpendicular components of water movement; these are water depth, distance across the reef flat and aspect relative to the direction of dominant wave attack (8). Deep reefs are generally less affected by water movement than shal-

low reefs; energy levels typically decrease across reef flats with distance from the reef margin; and windward reefs experience more energetic conditions than leeward reefs.

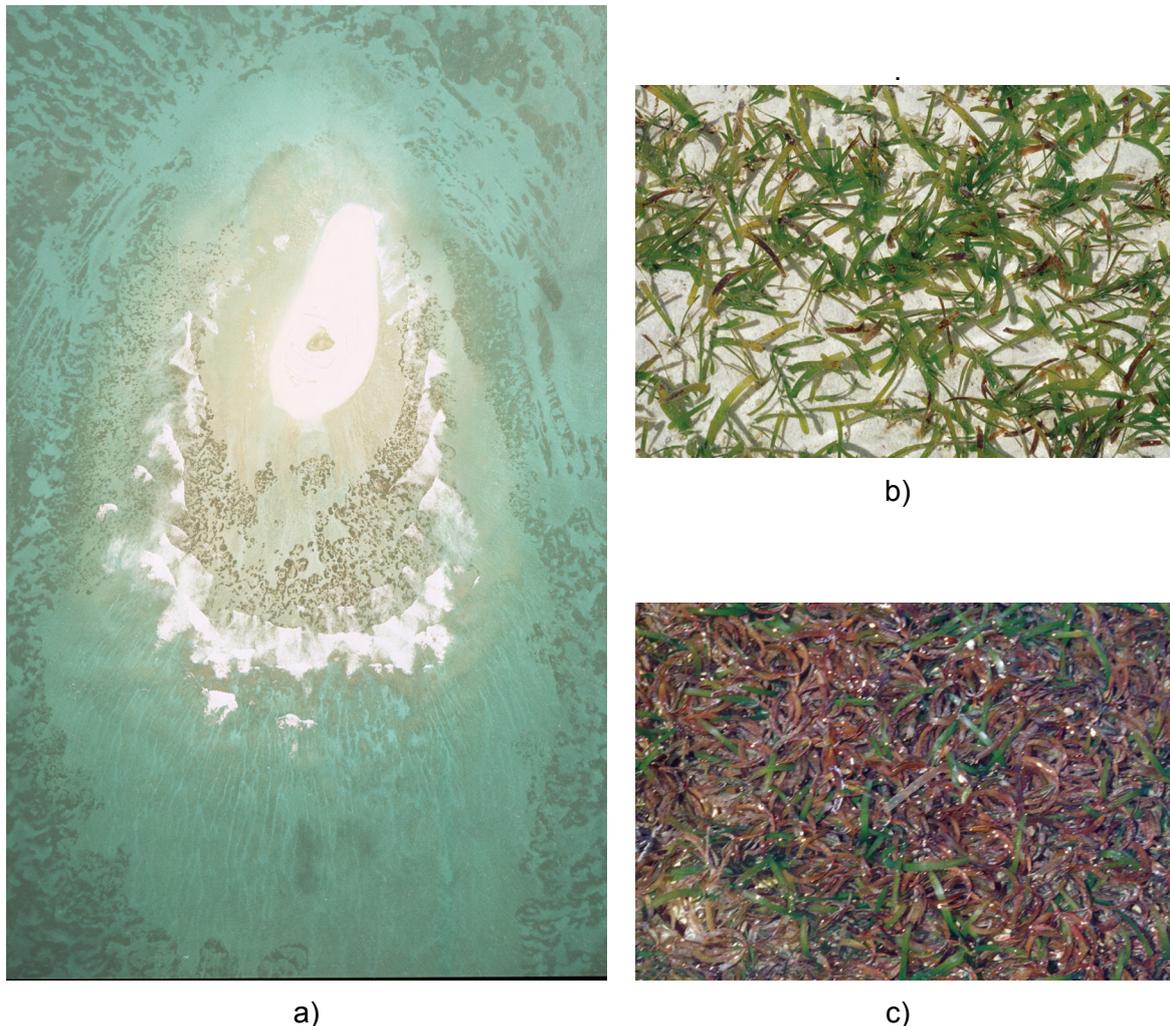


Figure 1: a) Etoile Cay, Amirantes The two main seagrass species in the Amirantes: b) *Thalassia hemprichii* and c) *Thalassodendron ciliatum*.

In this paper a habitat map, derived from remotely-sensed CASI data, is used to quantify the structure of seagrass communities at Etoile. Considerable physical disturbance arises from water movement here, particularly from the currents and surface waves associated with the north-east and south-eastern monsoons (9). Remote sensing provides synoptic coverage of the landscape and, by drawing on polygons compiling the vector data structure of the habitat map, the analysis unit moves from individual pixels to the patch scale adopted by landscape ecologists. The relationship between habitat structure and incident waves is explored by linking McCoy and Bell's habitat structure model to a wave exposure model based on Rosen's axes. Statistical properties of seagrass patch ensembles falling inside discrete analysis windows are explored across a range of exposures, using complexity and heterogeneity to characterise habitat structure.

METHODOLOGY

Fieldwork and remote sensing data were collected during a collaborative expedition between The Khaled bin Sultan Living Oceans Foundation, the Government of the Seychelles and Cambridge University in January 2004. Remote sensing aerial surveys were carried out using a high-resolution multispectral Compact Airborne Spectrographic Imager (CASI) mounted on an aircraft. Data were acquired at a spatial resolution of 1 m² across 17 spectral bands, yielding synoptic coverage of the area of interest.

Relative strip geocorrections adjusted the position and orientation of one strip to its neighbour, by identifying common ground control points on adjacent strips. Differences were corrected using a first order polynomial model to align the origin and scale. Once aligned, flight strips were mosaiced using a band-wise linear colour balancing model (10) to minimise across-track variance with histogram matching (11) to adjust for radiance offsets. Absolute corrections were performed to ensure that mosaiced imagery was geocorrected to an absolute reference with respect to the geoid. This was done by using a handheld GPS to record the *in situ* location of 5×5 m² sub-marine targets that were visible on the imagery and changing the underlying map model to align these.

The method outlined by Lyzenga (12) was used for band-wise correction of the effects of absorption and scattering in the water column, assuming that the vertical radiative transfer through a water column can be approximated to a logarithmic decrease in radiation with increasing depth. Two bands of data from a single benthic substrate (e.g. sand) were exported from range of depths, log transformed and regressed against each other; subtracting the product of the gradient and transformed longer wavelength data (*x*-axis) from the shorter wavelength data (*y*-axis), yielding a depth-invariant index (*y*-intercept) for that particular band pair.

Ninety-eight training areas derived reflectance measures over a number of spectral subclasses to build up statistical populations of habitat classes apparent within the imagery in feature space. Populations were constrained to avoid spurious pixel allocation as a result of class overlap. A maximum likelihood classification (13) was performed on depth invariant bands, which assigned each pixel of the image to the most likely habitat class on the basis of statistical probabilities. Habitat map accuracy was assessed *in situ* by exporting 283 polygon centroid coordinates to a handheld GPS and using this to guide the analyst to the corresponding location in the field, where the habitat type was recorded and compared against the map. Overall accuracy of the habitat map was defined as the total number of correct patches divided by the total number of patches in the validation assessment (14). A raster to vector conversion was performed on the final output habitat map to enable investigation of seagrass patterns.

To delineate the wave exposure zones, three separate polygon layers were created in ArcGIS to represent each axis of the Rosen model (8). These were overlaid onto the habitat polygon map and spatial queries were used to sequentially select and export polygons falling into each wave exposure class.

To model the effects of wave exposure on habitat structure, data from ten analysis windows of 10 m² were exported from each of the wave exposure zones. Habitat heterogeneity was defined as the number of different habitat classes represented in a window and habitat complexity as the number of patches recorded in a window. Because the resolution of the image used to make the habitat map was constant, along with the size of the analysis windows, scale was standardised across the windows and therefore omitted from the definition of habitat structure.

Analysis of Variance (ANOVA) tests were used to determine whether habitat heterogeneity and complexity were dependent on wave exposure. To test the hypothesis that habitat structure is influenced by wave impact, data from analysis windows inside five different zones of wave exposure were compared.

RESULTS

A good quality image classification was achieved, providing a clear representation of the heterogeneity apparent in the raw image and yielding an overall habitat map that required minimal contextual editing (Figure 2). Six habitat types are present at Etoile: beach sand, reef-flat sand, fore-reef slope sand, low density seagrass, medium density seagrass and high density seagrass. Overall accuracy of the habitat map was found to be 77%, as 218 patches from 283 included in the validation procedure were found to be assigned the correct habitat class.

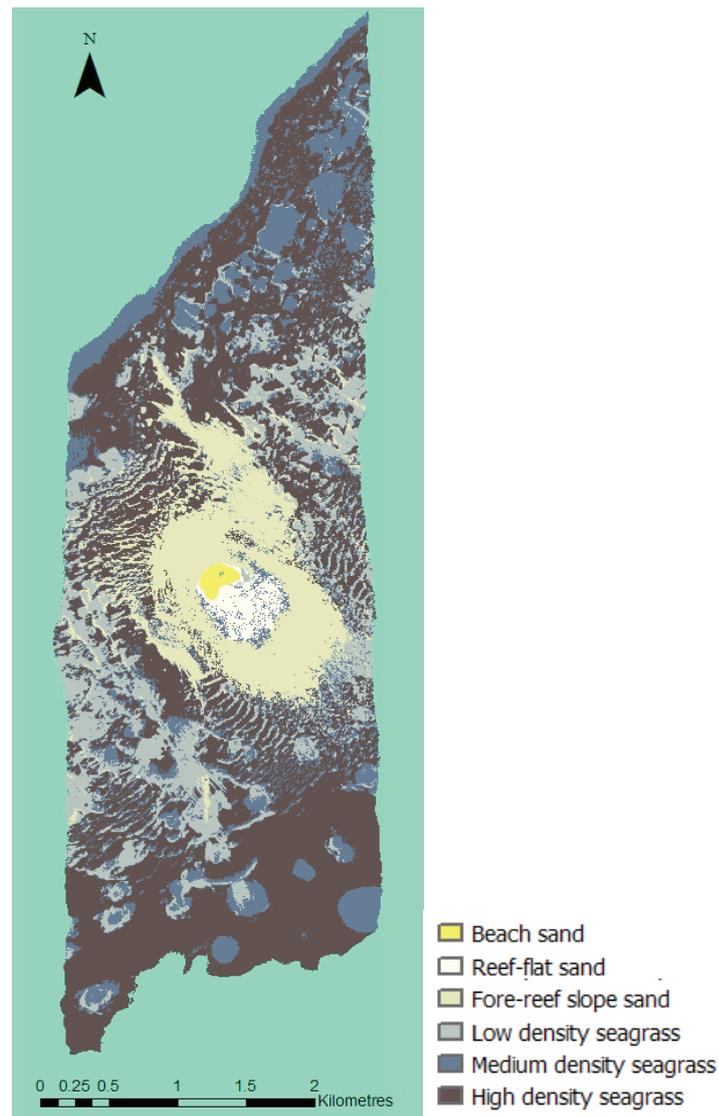


Figure 2: Habitat types and distribution at Etoile.

Five location-specific wave exposure classes were clearly identified using Rosen's model (8). Zone 1 was primarily located on the reef flat. Zones 2 – 4 were found progressively seaward from this zone, following the contours of the cay and the shallow water (20-25 m) shelf upon which it sits. More extensive seagrass beds were classified as zone 5 due to their characteristic water depths and distance from the point of wave impact.

Figures 3 and 4 illustrate how levels of habitat complexity and heterogeneity varied for the different wave impact classes. The class of highest impact (wave class 1) was characterised by relatively low complexity and heterogeneity. Class 2 had comparable heterogeneity to class 1, but with increased complexity. Class 3 also had high complexity, accompanied by increased heterogeneity. Class 4 was characterised by similar levels of heterogeneity to class 3 but low complexity. Finally, class 5 was described by intermediate levels of heterogeneity (with mean levels similar to classes 1 and 2) but a narrow range of low complexity.

F-statistics for heterogeneity and complexity were found to be 24.38 ($p < .0001$) and 56.76 ($p < .0001$) respectively. In both cases this was significantly greater than the expected variation in group averages, suggesting that the null hypothesis should be rejected and that seagrass habitat structure is dependant on wave exposure (and hence location) at Etoile.

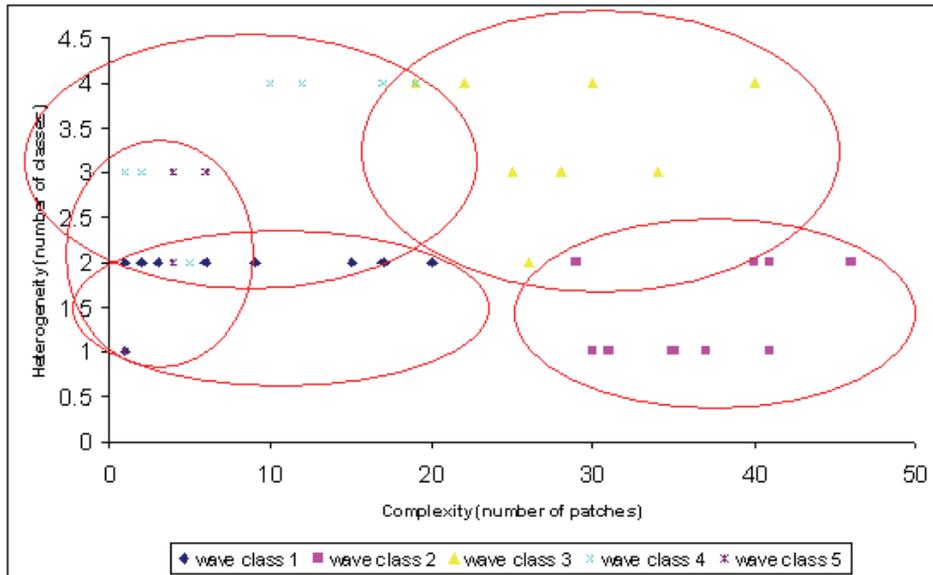


Figure 3: Complexity and heterogeneity of seagrass habitat inside analysis windows for the wave exposure classes (1 = highest exposure, 5 = lowest exposure). Red lines delineate wave exposure classes.

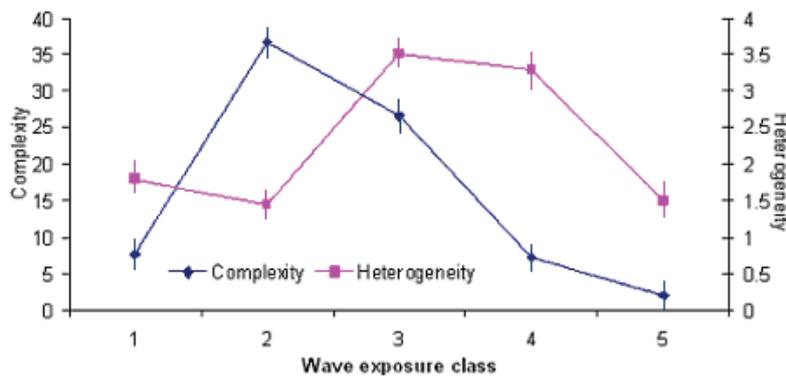


Figure 4: Seagrass habitat heterogeneity and complexity for wave exposure class (1: highest exposure, 5: lowest exposure).

DISCUSSION

Seagrass habitat at Etoile appears to be structured according to exposure to incident waves. Figures 2 and 3 indicate the nature of this structural variation, described by habitat heterogeneity and complexity.

Along the heterogeneity axis, it is clear that areas of moderate wave impact (class 3 and 4) supported the maximum number of classes, whereas sheltered (class 5) and exposed areas (classes 1 and 2) tend to be dominated by one particular class. Disturbance operates in two ways to increase environmental heterogeneity; by providing the opportunity for local differentiation through random colonization and by constantly interrupting natural successional sequences (15). The intermediate disturbance hypothesis proposes that moderate wave impact favours heterogeneity by limiting successional interruptions, whilst simultaneously preventing competitive dominance. With low disturbance, competitive exclusion by the dominant species arises, whereas with high disturbance, only species tolerant of the stress can persist (16). At the landscape scale, the balance between competitive exclusion and destruction of the competitive dominant of coral reef assemblages in response to storms has been found to maximise diversity (17). Trends observed here appear to support this hypothesis.

The complexity axis, or number of patches per unit area, showed a marked increase in value for areas of high to moderate (classes 2 and 3) wave impact, with lower complexity for both the highly exposed (class 1) and more sheltered (classes 4 and 5) areas. Low complexity in highly exposed areas results from the dominance of sand on the reef-flat.

Higher complexity in submerged areas exposed to waves may result from natural physical processes, such as substrate erosion and the formation of seagrass 'blowouts' (18), which tend to produce boundaries. These provide stability to adjacent systems as vibration and energy associated with incident waves becomes dampened (19). Complexity may therefore indicate structural adaptation for tolerating wave stress within seagrass beds. Physical disturbance has been shown to increase and maintain spatial complexity of seagrass beds, which respond to environmental settings by altering growth architecture. Hydrodynamically-induced changes in plant morphology increase resistance to being dislodged via modification of rhizome branching frequency or direction, and affect seagrass bed geometry (20).

Lower complexity in sheltered areas and at greater water depths may reflect a lower disturbance regime, where an initial random distribution becomes aggregated, giving minimal pattern in stable communities (21). A coverage value of 59.28% has been noted for general landscape elements, above which they join in percolating clusters (22); seagrasses appear to follow this rule. At Beaufort, North Carolina, a threshold of 50% cover was found at current speeds of $\sim 25 \text{ cm s}^{-1}$. Above this threshold landscape elements aggregated whilst below it they existed as discrete patches (23). This threshold is thought to coincide with the "initiation of motion" current speed for local sand sediments, representing a level of seagrass loss which, when exceeded, results in an abrupt collapse of bed integrity. At coverages close to the threshold, seagrass tends to exist as elongated patches, broken up by narrow corridors that are particularly susceptible to disturbance and which contribute to the rapid decline of coverage under wave attack (20).

CONCLUSIONS

The limitations placed upon this study by use of remote sensing data should be noted. Complexity of habitat structure in the vertical dimension is critically important from an ecological perspective, yet this cannot be measured accurately with an optical remote sensor. There is also limited opportunity to distinguish between the nature of the factors determining habitat structure. Multiple stressors often have significant effects on recruitment and regenerative processes of assemblage (24), yet the classification scheme here relates structure to one functional factor only. Nevertheless, it is clear that a wave-based disturbance regime is a primary factor determining both seagrass habitat diversity and complexity at Etoile. Low disturbance rates allow long term persistence of dominant *Thalassodendron ciliatum* communities, with low habitat complexity, whereas high rates of disturbance favour sand sheet deposits on tidally-exposed reef-flats, and more complex seagrass community structures below low tide level.

Finally, this paper demonstrates how the use of remote sensing data permits the structure of seagrass patterns to be empirically linked to functional factors at the landscape scale, a substantial improvement on descriptive research to date on seagrass patterning in shallow marine environments in the western Indian Ocean.

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