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Intra-annual Changes in Seagrass Standing Crop, Green Island, Northern Queensland

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Abstract

A visual estimation technique was used to estimate the standing crop of a mixed-species seagrass meadow at Green Island, northern Queensland. This technique measured monthly changes in the standing crop of seagrass within 10 fixed quadrats along three fixed transects from May 1987 to April 1988. The mean standing crop fluctuated by a factor of two from 60 g dry weight (DW) m^{-2} (August 1987) to 133 g DW m^{-2} (December 1987). The climatic factors that correlated with mean monthly standing crop were investigated. Owing to the high degree of association between these factors, principal-components analysis was used to create new orthogonal variables to be included in an 'all-subsets regression'. The best regression model explained only 12% of the variation in seagrass standing crop. This model and the magnitude and direction of the loadings of the vectors associated with the first principal component suggested that seagrass standing crop was positively correlated with any day length and temperature and negatively correlated with number of strong-wind days. These variables were indirect measures of light availability and temperature, suggesting that fluctuations in seagrass standing stock at Green Island were influenced by changes in temperature and light availability.

Introduction

Seasonal changes in seagrass standing crop have been linked to changes in day length, light, temperature, salinity (Zieman 1975; Sand-Jensen 1975, 1989; Aioi 1980; Bulthuis 1987; Walker and McComb 1988; Kerr and Strother 1990) and, more recently, nutrients (Powell *et al.* 1989). The difficulty in separating these parameters in the field is usually acknowledged because they tend to vary in concert (e.g. light and temperature) and have combined effects in modifying photosynthetic rates and growth. In the eastern Australian tropics, seasonal rainfall has been suggested as a factor strongly influencing seagrass growth (Bridges *et al.* 1982; Coles *et al.* 1987; Lanyon *et al.* 1989). However, the factors influencing the timing of seasonal growth appear to be poorly understood, and there have been no experimental studies. Lanyon *et al.* (1989) sampled intertidal seagrass meadows in the Townsville region (northern Queensland) at three-monthly intervals and observed that there was an increase in seagrass biomass coincident with the summer rains, presumably as a result of nutrient runoff.

Our study was sited at Green Island reef on the inner edge of the Great Barrier Reef. Because Green Island is 27 km off the coast, we expected any seasonal changes in seagrass standing crop to be less influenced by terrestrial runoff than were changes in the inshore meadows studied by Coles *et al.* (1987) and Lanyon *et al.* (1989). However, around 120 000 tourists visit Green Island each year (Anon. 1990), and there has been concern over their effect on the nutrient loads within the seagrass meadow (Baxter 1990).

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This study investigates the fluctuations in the standing crop of seagrasses (predominantly *Halodule uninervis* and *Cymodocea serrulata*) on the reef top at Green Island over the course of a year and the environmental parameters correlated with these fluctuations.

Materials and Methods

Study Site

Green Island (16°46′S,145°58′E) is a vegetated sandy cay almost surrounded by an extensive multi-specific seagrass meadow interspersed with coral bommies (coral heads). The meadow is subtidal and densest on the sheltered north-western side of the island, where *Halodule uninervis* (Forsk.) Aschers. (wide-leafed variety) is the dominant species. *Cymodocea serrulata* (R. Br.) Aschers. & Magnus and *C. rotundata* Ehrenb. et Hempr. ex Aschers. are also present but at lesser densities. *Halophila minor* (Zoll.) den Hartog is sparsely scattered throughout the entire meadow. On the north-eastern and southern sides of the island, where the seagrasses are intertidal and less dense, *Thalassia hemprichii* (Ehrenb.) Aschers. and *C. rotundata* are the main species present.

Sampling

Sampling was restricted to the subtidal, dense north-western meadow between May 1987 and April 1988. Permanent transects (50 m long) were established at each of the three sampling sites (Fig. 1) and

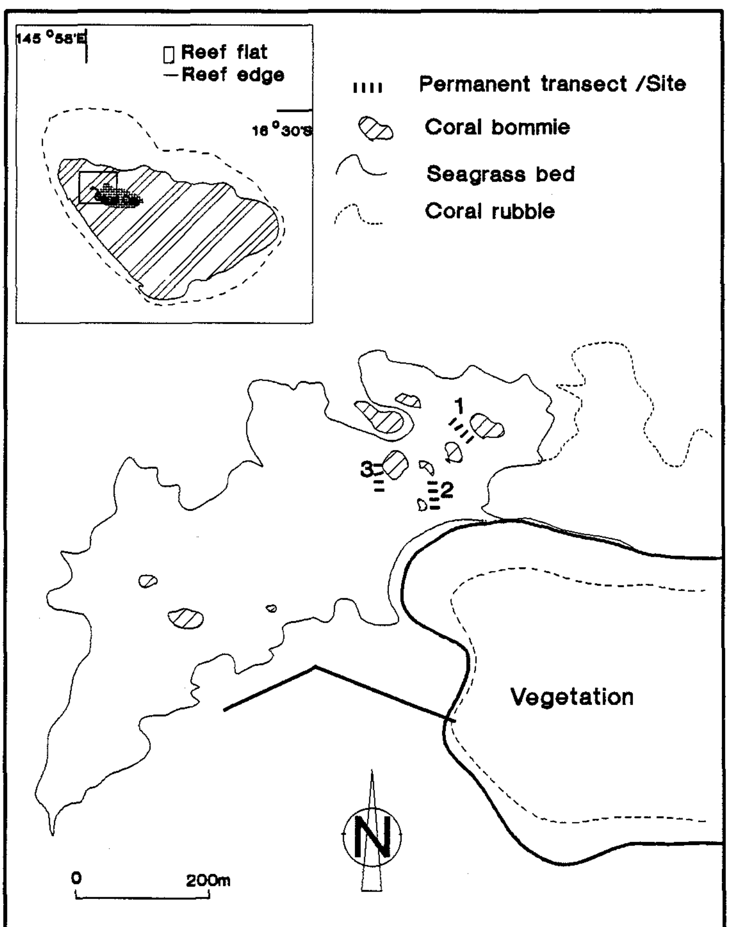

Fig. 1. Locality map, showing sampling sites.

sampled systematically to ensure that the observers were travelling over and ranking exactly the same area in every sampling period. A tape measure 50 m in length was laid out between the permanent markers. Observers took it in turn to rank visually the standing crop (above-ground biomass) of seagrass within $0{\cdot}25\text{-m}^2$ quadrats placed every 5 m along this tape, as detailed in Mellors (1991). At the end of each sampling period, 10 quadrats away from the permanent transects were harvested to calibrate the ranked scale for that period.

The final biomass estimates and their variances were adjusted (as outlined in Andrew and Mapstone 1987) to provide a measure in grams of dry weight per square metre in order to make our results comparable with those of other studies. No distinction was made among species of seagrass because the meadow was evenly mixed and this study was an assessment of seagrass habitat rather than individual species.

Statistical Analysis

A two-factor analysis of variance, with quadrat as a repeated measure, was used to examine the effects of month and site on seagrass standing crop. Parametric correlations were performed between the monthly seagrass standing crop per quadrat averaged over the entire meadow and the corresponding values for *(1)* seven climatic variables obtained from the Bureau of Meteorology for weather stations nearest to Green Island—minimum and maximum air temperatures, total monthly rainfall, number of cloud days (days with more than five-eighths of cloud cover at 0900 or 1500 hours), number of wind days per month (winds above 44 km h^{-1} at 0900 or 1500 hours), mean hours of sunshine per month, and mean day length—and *(2)* water-quality index. This index was devised on the assumption that the sewage outfall is proportional to the number of people visiting Green Island. The index was therefore obtained by multiplying the number of visitors to Green Island by the length of their stay.

The correlations were also calculated with these variables lagged by one month. None of the outcomes of such analysis was significant, so further discussion and analysis deals only with the unlagged variables. Those variables that correlated significantly with seagrass standing crop were used in an 'all-subsets regression'. Because the climatic variables chosen for the regression were also highly correlated, a principal-components analysis (based on the correlation matrix) was used to generate new environmental variables that were orthogonal. These new variables were then used as the independent variables in the regressions. The dependent variable used in the regression consisted of the residuals obtained from a one-way analysis of variance with (permanent) quadrat as the (orthogonal) treatment variable. The residuals were used in order to reduce the noise caused by spatial variation within the seagrass meadow.

Results

Standing Crop

Seagrass standing crop declined from May to August 1987, increased from September to December 1987, declined again from January to March 1988, and increased slightly in April 1988 (Fig. 2*b*). Mean standing-crop estimates for the entire meadow ranged from 60 g dry weight (DW) m^{-2} (August 1987) to a high of 133 g DW m^{-2} (December 1987), an increase of more than twofold (Fig. 2*b*).

Both month and site had highly significant effects on the standing crop of seagrasses at Green Island ($F=9{\cdot}59$, 11×297 d.f., $P<0{\cdot}0001$, Fig. 2*b* and $F=26{\cdot}79$, 2×27 d.f., $P<0{\cdot}0001$, Fig. 2*c*, respectively); the interaction between month and site was also significant ($F=1{\cdot}59$, 22×297 d.f., $P=0{\cdot}0462$, Fig. 2*a*). The trend in changing biomass was similar for all three sites except that Site 3 deviated from the general pattern by increasing in biomass in June and November 1987 instead of decreasing as at the other two sites. Overall, the months of August 1987, March 1988 and June 1987 had low standing-crop estimates, whereas December, October and November 1987 were months of high standing crop (Fig. 2*b*). Spatially, Site 1 had the highest standing crop of seagrass, Site 2 had the lowest, and Site 3 was intermediate (Fig. 2*c*).

Data on the presence/absence of seagrass for each quadrat for each month were tabulated to determine whether an increase in standing crop was a result of seagrass spreading into unvegetated areas. Site 1 and 3 consistently had seagrass present in all quadrats throughout the year. Site 2, however, had months in which bare quadrats were present, consistent with

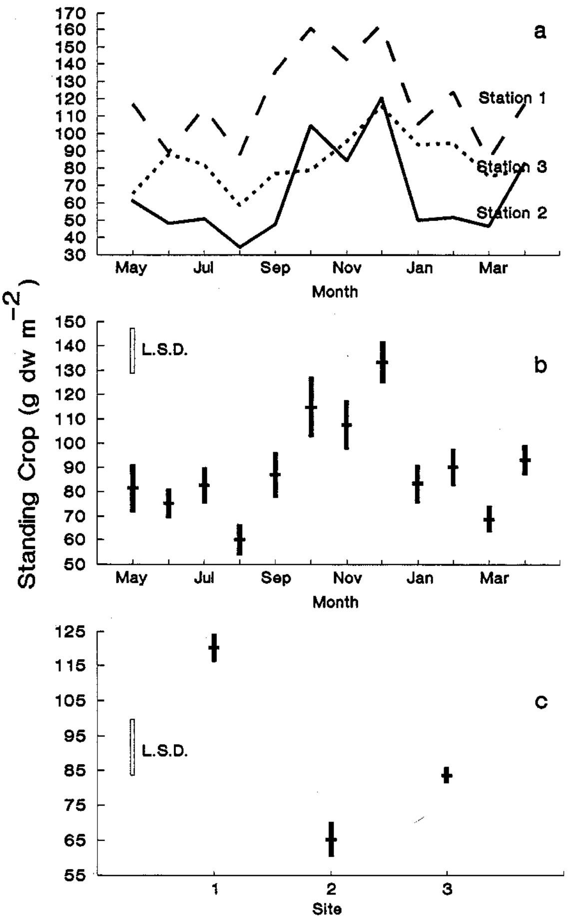

Fig. 2. Values of seagrass standing crop for (*a*) the month-by-site interaction, (*b*) differences between months averaged over sites, and (*c*) differences between sites averaged over months. Mean, standard error and least significant difference (L.S.D.) are shown. The means for each main effect have been averaged over the other main effect because the main effects are much more significant ($P<0\cdot0001$) than is the interaction ($P=0\cdot462$).

the blowouts (areas bare of seagrass) found at this stie. The positions of these blowouts moved somewhat during the year. This movement may have been caused by seagrass recolonizing at one edge of a blowout and being smothered at the other edge as the sand within the blowout was redistributed. Overall, there was little change in the presence/absence of seagrass throughout the year. This implies that the increase in seagrass standing crop is likely to have been due to an increase in leaf height, number of shoots per plant, and number of leaves per plant rather than the encroachment of seagrass into unvegetated areas.

Correlation of Vegetation with Environmental Factors

Physical factors that correlated significantly with seagrass standing crop averaged over the entire meadow were day length ($r=0\cdot6088$), maximum temperature ($r=0\cdot498$) and wind ($r=-0\cdot7437$) (Table 1). The first two principal components explained 97·4% of the variance in the climatic variables (Table 2). The other principal component explained a negligible proportion of the variance and was not considered further. All three of the abiotic factors contributed about equally to principal component 1, but the number of strong-wind days contributed proportionately more to principal component 2 than did the other factors (Table 2). Inspection of the adjusted r^2 and Mallows' C_p (Weisberg 1985) of the all-subsets regression including the first two prinicpal components indicated that the most satisfactory model included only the first principal component. The model was significant (analysis of variance, $F=24\cdot79$, 357 d.f., $P<0\cdot0001$) but explained only 12% of the variation in seagrass standing crop. The coefficient for the independent variable ($-9\cdot1857$) indicated that principal component 1 was negatively correlated with seagrass standing crop. Examination of the magnitude and direction of the loadings of the vectors associated with this principal component (Tables 1 and 2) indicated that seagrass standing crop at Green Island was positively correlated with day length and temperature and negatively correlated with number of strong-wind days.

Table 1. Correlations between seagrass standing crop averaged over the entire seagrass meadow and environmental factors

Critical $r_{(10)}=0\cdot497$

Variable	Standing crop	No. of cloud days	Day length	Maximum temp.	Minimum temp.	No. of rain days	Sunshine duration	Water-quality index	No. of strong-wind days
Standing crop	1·0000								
No. of cloud days	−0·2892	1·0000							
Day length	0·6088	−0·2942	1·0000						
Maximum temperature	0·4983	−0·1100	0·9129	1·0000					
Minimum temperature	0·4319	0·0346	0·8368	0·9728	1·0000				
No. of rain days	−0·1428	0·7846	−0·0099	0·1704	0·3471	1·0000			
Sunshine duration	0·2655	−0·8953	0·1453	−0·0356	−0·1760	−0·8485	1·0000		
Water-quality index	−0·0197	−0·6336	−0·2214	−0·4496	−0·5857	−0·6982	0·6996	1·0000	
No. of strong-wind days	−0·7437	0·2188	−0·6839	−0·5914	−0·5412	0·1571	−0·2797	0·0229	1·0000

Table 2. Results of the principal-components analysis of the climatic variables: the coefficients of the eigenvectors of the first three principal components

Factor/vector	Principal component 1	2	3
Day length	−0·6124	−0·2616	0·7460
Maximum temperature	−0·5920	−0·4736	−0·6521
No. of strong-wind days	0·5239	−0·8410	0·1351
Cumulative percentage of variance	82·3	97·4	100·0

Discussion

Seasonal Variation in Seagrass Biotic Parameters

In temperate Australian waters, seasonal biomass studies have been carried out on several seagrass species (Kirkman *et al.* 1982; Bulthuis and Woelkerling 1983; Larkum *et al.* 1989; Kerr and Strother 1990). The standing-crop values reported in these studies all followed a unimodal seasonal variation, with peak values in summer or early autumn followed by a decline in winter. Unimodal seasonal variation is also the most common pattern for studies of temperate seagrass in the Northern Hemisphere (Sand-Jensen 1975; Aioi 1980; Hillman *et al.* 1989).

For subtropical/tropical Australian waters, most studies on seasonality have been on 'temperate' species (*Posidonia australis* and *Amphibolus antarctica*) approaching the northern limits of their distribution (Walker and McComb 1988) or on 'tropical' species (*Cymodocea serrulata* and *Zostera capricorni*) approaching their southern limits (Boon 1986). Except for *P. australis*, which showed no obvious seasonal trends, the biomass values of the other species varied throughout the year, though nonsignificantly (Walker and McComb 1988; Boon 1986). Similarly, Brouns (1985, 1987) found that seasonal variation in the above-ground biomass of five tropical species of seagrasses (*Thalassia hemprichii*, *C. serrulata*, *C. rotundata*, *Halodule uninervis* and *Syringodium isoetifolium*) in Papua New Guinean waters was also nonsignificant. This evidence led Hillman *et al.* (1989) to conclude that seasonal changes in the standing crop of subtropical/tropical seagrasses were less pronounced than those of temperate seagrasses and rarely exceeded a twofold variation. These authors related this lack of variation to the smaller seasonal changes in environmental factors (especially light and water temperature) than are experienced in temperate latitudes (Hillman *et al.* 1989). These studies were based on data collected from randomly harvested quadrats, so any temporal change in seagrass standing crop could have been masked by spatial patchiness. The Northern Hemisphere studies of Zieman (1975) and Wahbeh (1988) record significant seasonal fluctuations for the tropical seagrass species *T. testudinum* (twofold) and *H. uninervis* (sixfold) respectively. Both of these studies report maximum values of standing crop in the warmer months.

We found that the seasonal change in seagrass biomass was slightly greater than twofold (Fig. 2*b*). The seasonal pattern of this biotic parameter appeared to be bimodal, with peaks occurring in October and December 1987 and again in April 1988. We cannot confirm whether this perceived pattern is truly bimodal because of the cessation of sampling after 12 months. This seasonal trend could also be interpreted as being unimodal, with a concurrent increase in these parameters in the following season. This is not an unreasonable assumption because past research has shown that climatic differences can cause considerable year-to-year variation in both the seasonal pattern and the maximum standing stock at any one site (Orth and Moore 1986; Walker and McComb 1988; Hillman *et al.* 1989). The slow declines in seagrass standing crop, in comparison with the quick increases (Fig. 2*b*), could be due to the stored starch reserves that seagrasses contain in their extensive rhizome system (Zieman 1975).

The downturn in standing crop in November is anomalous and could be an artefact of our use of an inexperienced second observer for that month. This observer apparently used percentage cover rather than standing crop *per se* when ranking his dry-weight yields, thereby affecting his calibration curve and subsequent standing-crop estimates (see Mellors 1991).

Effect of Environmental Parameters on Biotic Parameters of Seagrass

The abiotic factors that correlated with seagrass standing crop were day length, maximum temperature and number of strong-wind days, with number of strong-wind days having the strongest (negative) correlation coefficient (Table 1). These correlations were supported by the measures of standing crop, which showed declines at the time of year when temperatures were near minimum, day lengths were short, and numbers of strong-wind days were high.

Light

Our results suggest that availability of light is important for the regulation of seagrass growth at Green Island. Light is a key factor that sets the limits of plant distribution and abundance (Hillman *et al.* 1989). Many studies have reported that high light saturation is required for seagrass photosynthesis (McRoy 1970; Bittaker and Iverson 1976; Williams and McRoy 1982; Zimmerman *et al.* 1991). This suggests that some seagrasses are frequently light-limited in their natural habitat.

In the Great Barrier Reef lagoon, high light attenuation is caused by the resuspension of fine sediments. Sedimentation rates quoted for elsewhere in the world are frequently an order of magnitude lower than those quoted for the Great Barrier Reef (Hopley *et al.* 1990). These large rates have been attributed to the sea-level history of this region compared with that of the northern Pacific and the Caribbean. Off the Australian mainland coast, the sea level has been stable or close to its present position for approximately 6500 years. During this time, fluvial sediments from the mainland have been able to accumulate into a large nearshore sediment wedge consisting largely of fine sediments (from Hopley *et al.* 1990). It is this wedge of fine sediment that is easily resuspended by even moderate wave activity, causing high turbidity and light attenuation. Previous workers have recognized the importance of turbidity in limiting the amount of light available for seagrass growth (Coles *et al.* 1987; Zimmerman *et al.* 1991).

Temperature

In this study, temperature also correlated with seagrass standing crop (Table 1). One of the ways in which temperature affects seagrass growth is by altering the characteristics of the photosynthesis–irradiance (PI) curve (Bulthuis 1987); this is because the growth of seagrasses in high (saturating) light environments increases with temperature. This could account for the high values of standing crop in October and December (Fig. 2*b*). During this time, the number of strong-wind days (days with decreased light availability) was low and temperatures were high. However, high temperatures can be harmful to photosynthesis and plant survival, particularly when they occur in combination with high irradiances (Bulthuis 1987). At higher temperatures, more light is needed to maintain a positive carbon balance; i.e. seagrass growth may be more affected by reduced irradiance in summer than in winter (Dennison 1987). This could explain the lower values of seagrass standing crop during January and February (Fig. 2*b*), when temperatures were at their highest and the number of strong-wind days increased slightly after being negligible during October, November and December. The high number of cloud days in February may also have contributed to decreases in seagrass standing crop during this month.

Other Factors

Salinity

Rainfall did not correlate significantly with seagrass biotic parameters, suggesting that salinity does not have a major effect on Green Island seagrasses. This is probably due to the Green Island seagrass meadow experiencing very little terrestrial runoff from the island *per se.*

Nutrients

Owing to the sewage outfall across the reef flat at Green Island, it has been assumed that phosphorus is not limiting and that the seagrasses at Green Island have displayed unlimited growth over the last decade. The water-quality index showed no association with the biotic parameters (Table 1). We suggest two reasons for this: *(1)* the number of hours that people remained on Green Island was an uncalibrated index of water quality (nutrient quantity) that did not take into account nutrient fluctuations due to sediment resuspension (Walker 1981), and *(2)* nutrient concentrations within the sediment at Green Island (a factor not measured in this study) may have a greater effect on seagrass growth than do nutrient concentrations in the water column.

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