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Applications of the SEDCON and FORAM Indices on patch reefs in Biscayne National Park, FL, USA

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Abstract. Coral cover remains highest on patch reefs at the northern end of the Florida reef tract. Two indices, the FORAM Index and the SEDCON Index, were developed to indicate the suitability of a reef environment for continued reef accretion. Patch reefs were sampled in Biscayne National Park, FL, to assess sediment characteristics and foraminiferal assemblages, as well as to examine trends between the two indices. Sediments associated with a majority (59%) of reefs were coarse sands; muddy sediments were restricted to a few inner patch reefs that were isolated from the flow of Caesar's Creek. Unidentifiable grains dominated the sediment constituents, along with calcareous algae and molluscan debris. Shells from 82 genera of Foraminifera were identified in the sediments. *Quinqueloculina* was the most consistently common genus. Percent mud was the most influential measured variable on the distribution of both sediment constituents and foraminiferal assemblages. Patterns of FORAM and SEDCON Index values and their similarity to temperature, salinity, and percent mud distributions show that Caesar's Creek is affecting the benthic community by providing flow that limits the accumulation of mud and potentially other anthropogenic stressors. Overall this study suggests that the reefs in this area are marginal for continued reef growth.

Key words: Foraminifera, SEDCON, FORAM, reefs, sediments.

Introduction

The Florida Fish and Wildlife Research Institute's Coral Reef Evaluation and Monitoring Program (CREMP) has monitored the decline of coral in Florida for over ten years. Their study has shown that coral cover remains highest on patch reefs at the northern end of the reef tract (16% coral cover) (Beaver et al. 2005). The reasons for this trend are not well understood, but may be related to the protection from extreme variations in water quality parameters provided by the near constant presence of islands at the north end of the Florida Keys.

Patch reefs were sampled in Biscayne National Park, FL (Fig. 1), to assess environmental patterns and test two environmental indices. Reefs in this area are protected from direct influence of Biscayne Bay by the presence of Elliot Key and Old Rhode's Key. However, Caesar's Creek, between the two Keys, has a known net outflow of water from the Bay directly onto the reefs.

Two indices have been developed based on Foraminifera and sediment constituents. The FORAM Index and the SEDCON Index were developed to relate the response of the calcifying benthic community to the status and suitability of the environment for future reef growth (Hallock et al. 2003, Daniels 2005). In both indices, shifts in assemblage contribution from mixotrophic organisms (symbiont-bearing foraminifers and coral) to heterotrophic organisms (smaller foraminifers and molluscan fragments) are hypothesized to reflect environmental changes associated with reduced potential for coral reefs to dominate and recover from stress events. The low-cost, easily applied nature of these indices provides a potential new tool for resource managers, especially in regions where technically trained personnel are more affordable than chemical analyses.

Figure 1. Sampling location within Biscayne National Park, FL

Material and Methods

Sediment samples and environmental data were collected from 32 reefs in Biscayne National Park, including 30 patch reefs and two bank-barrier reefs (Pacific Reef and Lugano Reef).

Sediments were wet sieved and the sand fraction was dried. A one gram subsample was removed for the FORAM index analysis. Grain-size analysis was performed on the remaining sample fraction. The 0.5-1mm and 1-2mm size fractions were recombined and a one gram subsample was taken for analysis for the SEDCON index.

For the FORAM Index, up to 150 foraminifers were picked from the 1g subsample. Each specimen was then identified to genus. For the SEDCON Index, 300 grains were randomly chosen from the subsample using a point-count method. Each grain was then identified to the extent possible.

The gathered assemblage data were then used to calculate FORAM and SEDCON Index values according to Tables 1a and 1b. An FI value >4 indicates water quality suitable for dominance by calcifying organisms with algal symbionts. A value from 2-4 indicates conditions where calcifying symbioses can persist but not dominate and may not be able to recover from a stress event. At <2, water quality is probably not suitable for reef growth (Hallock et al. 2003). SI values reflect sediment contributions: SI values >4 reflect sediment production dominated by calcifying symbioses (i.e., coral and foraminifers). From 2-4, dominance is by autotrophic and heterotrophic processes (calcareous algae and non-symbiotic animals); SI <2 reflects dominance by unidentifiable grains presumably reflecting bioerosion.

The SIMPROF and SIMPER tests in PRIMER statistical software (Clarke and Warwick 2001) were used to identify similarities between samples based on assemblage composition for both the foraminiferal assemblages and the sediment constituent assemblages. Surfer surface mapping system and ArcMap were then used to plot the similarity data as well as to create contour lines for temperature, salinity, percent mud, FORAM Index and SEDCON Index values.

Results

Spatial patterns were determined by calculating Moran's I value of spatial autocorrelation (Anselin et al. 2006). A significant value indicates non-randomness. All three environmental variables had significant spatial autocorrelation ($p<0.05$) (Mud - 0.42, Temperature - 0.31 and Salinity - 0.27 respectively). Temperature and salinity negatively correlated with each other (bivariate Moran's I: -0.33). Percent mud also had significant correlations with temperature and salinity (Pearson's ρ = -0.42, 0.53 respectively). The three environmental parameters also spatially correlated with the FI and SI values with significant Pearson's correlations ($p<0.05$) (Figs. 2, 3, and 4).

Table 1. Calculations for a) the FORAM Index and b) the SEDCON Index.

a)

$FI = (10*P_s)+(P_o)+(2*P_h)$	
Where,	$P_s = N_s/T$ $P_o = N_o/T$ $P_h = N_h/T$
And,	T = total number of specimens counted
	N_s= number of symbiont-bearing Foraminifera
	N_o=number of stress-tolerant Foraminifera
	N_h= number of other small, heterotrophic Foraminifera

b)

$SI = (10*P_c)+(8*P_f)+(2*P_{ah})+(0.1*P_u)$	
Where,	$P_c = N_c/T$ $P_f = N_f/T$ $P_{ah} = N_{ah}/T$ $P_u = N_u/T$
And,	T = total number of grains counted (300)
	N_c= number of coral grains
	N_f=number of symbiont-bearing Foraminifera
	N_{ah}=number of coralline algae, calcareous algae, and heterotrophic skeletal grains
	N_u= number of unidentifiable grains

Foraminiferal Analysis

Statistical tests in PRIMER showed sites clustered into five major groups (A, B, C, D, E) based on the foraminiferal assemblage (Fig. 5). Table 2 shows the averages for the environmental data within each cluster as well as the percent contribution by certain foraminiferal groups.

FORAM Index values were calculated in accordance to the formula presented in Table 1a for only those sites where more than 50 specimens were present in a one gram sample. The highest FI values (Fig. 5), correspond to SIMPER groups A and E, with Pacific Reef having the highest average FI value (7.0, SD=1.9). Lowest FI values correspond to SIMPER group C. The lowest FI value was at Bug Reef with an FI of 2.1 (SD=0.12).

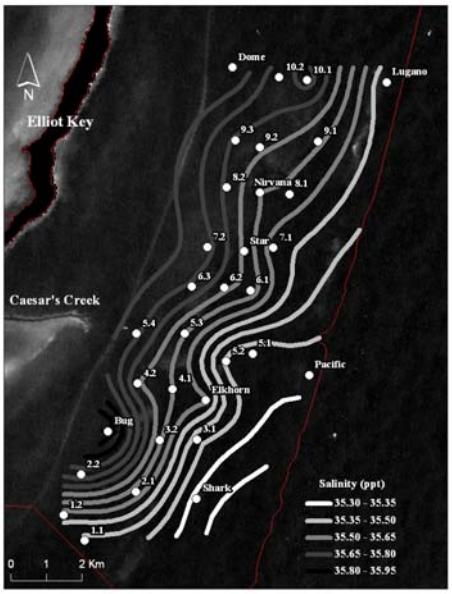

Figure 2. Contour lines of salinity values in the sampling area in Biscayne National Park. The less than 1ppt change over the sampling area indicates that this is not a major factor in shaping the indices patterns.

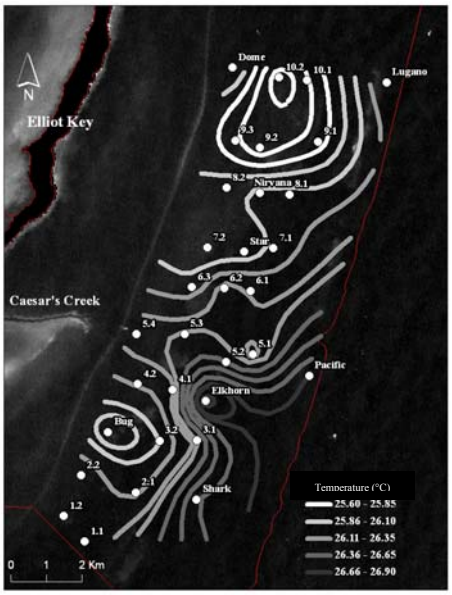

Figure 3. Contour lines of temperature values throughout the sampling area in Biscayne National Park. The less than 2°C change over the sampling area indicates that this is not a major factor in shaping the indices patterns.

Sediment Constituent Analysis

Only two clusters were identified in the sediment constituent data. Both groups were dominated by calcareous algae, mollusks, and unidentifiable grains. Unidentifiable grains dominated Group B which were located in higher energy areas. Table 3 summarizes the environmental data for each sediment constituent defined cluster.

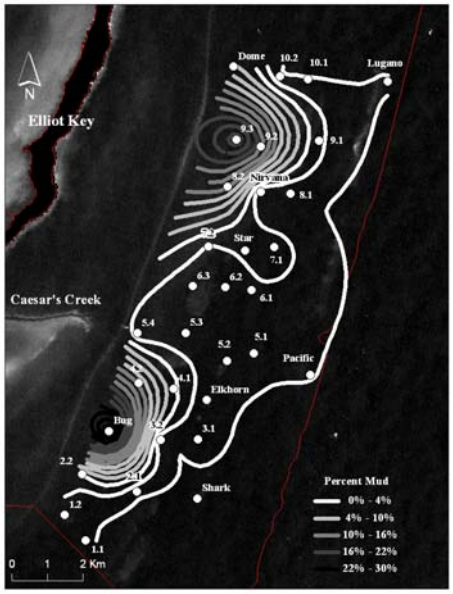

Figure 4. Contour lines of percent mud values throughout the sampling area in Biscayne National Park. The absence of mud offshore of Caesar's Creek and abundance of mud offshore of the Key islands may be influencing, or may indicate another influence that is shaping the patterns seen in the indices.

Unidentifiable grains had a strong negative Pearson's correlation (-0.72) with percent mud, while at the muddiest sites there were more identifiable calcareous algae, which positively correlated to the SI values (0.67)

SEDCON Index values were calculated based on the equation derived in Daniels (2005) and shown in Table 1b. The range of mean values among the reefs was from 0.64 (SD=0.03) at Shark Reef to 2.48 (SD=0.42) at Reef 9.3. The lower SI values are found in the vicinity of Caesar's Creek, while the reefs furthest from direct sources of water flow have higher SI values (Fig. 6).

Discussion

Waters emerging from Biscayne Bay through Caesar's Creek into the study area clearly influence temperature, salinity, sediment texture, and the foraminiferal and sediment -constituent assemblages as reflected in the FORAM and SEDCON Indices.

The SEDCON Index was faster and easier to apply, while the FORAM Index produced more inter-reef detail. However, there was an unanticipated negative Pearson's correlation between the FORAM Index and the SEDCON Index (-0.53). Spatially, the patterns between the two indices co-varied significantly with a Moran's I value of -0.399 (p=0.01).

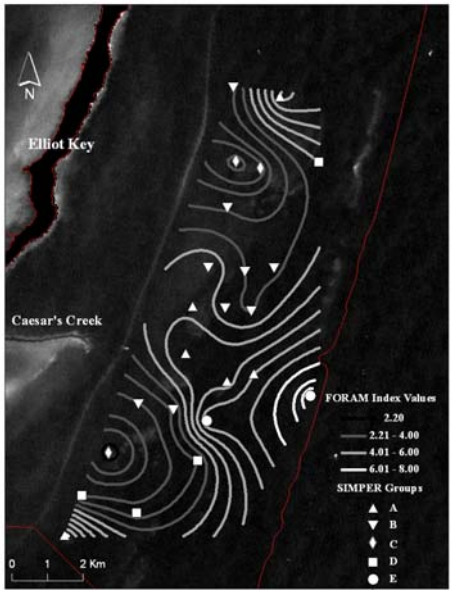

Figure 5. Reefs that clustered together based on similarity of foraminiferal assemblage are indicated with the same symbol. Five cluster groups were identified. Contour lines represent FORAM Index values throughout the sampled area of Biscayne National Park.

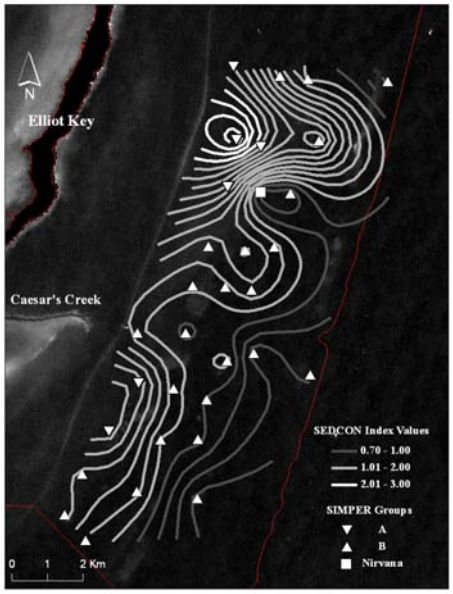

Figure 6. Reefs that clustered together based on similarity of sediment constituent assemblage are indicated with the same symbol. Two cluster groups were identified. Contour lines represent SEDCON Index values throughout the sampled area of Biscayne National Park.

The negative correlation between the two indices appears to reflect the difference between the potential for carbonate production by symbiont-bearing corals and foraminifers, as indicated by the FORAM Index, versus the reality of the decline of coral cover over the past several decades (e.g., Dupont et al. in press), which is reflected in the SEDCON Index. Water quality in the reef area of Biscayne National Park appears to be suitable for calcifying symbioses; the average FI value across all reefs was 4.12. However, the average SI value of 1.26 indicates that potential is not being realized and that erosional processes, and secondarily autotrophic and heterotrophic production, are dominant sources of carbonate sediments associated with BNP patch reefs.

The divergence between the two indices likely indicates that climatic (e.g., hurricanes), regional (e.g., coral diseases) and global (e.g., photo-oxidative stresses) influences are more important than local water quality in the decline of Biscayne patch reefs. Populations of the shorter-lived foraminifers can rebound from mortality events in a few years (Hallock et al. 2006), while long-lived corals have not been able to rebound from successive impacts and mortality events over the past several decades (e.g., Dupont et al. in press).

This study expands upon the original premise of the SEDCON Index, when used in conjunction with the FORAM Index. They were originally both thought to indicate whether water quality supports calcifying symbioses. But this study indicates that the FORAM Index does so, while the SEDCON Index indicates that factors other than water quality can control sediment composition, reflecting more of the history of processes affecting macrobenthos.

Table 2. Summary table of the environmental data averaged for each of the five clusters based on similarity of foraminiferal assemblages, and the % contribution of certain foraminiferal groups to each cluster.

Group	FI	Density (shells/g)	# of Genera	pH	Temperature	DO	Salinity	% Mud	Phi	% Symbiont-bearing	% Stress-tolerant	% Other taxa
A	4.85	126	21.7	8.31	26.09	6.32	35.57	0.55	1.11	34.76	5.24	51.2
B	3.60	957	31.7	8.32	26.08	6.25	35.66	5.76	1.33	22.71	9.12	59
C	2.22	5518	29.8	8.22	25.83	6.42	35.82	26.4	2.75	5.16	21.7	63.5
D	3.13	1015	33.0	8.26	26.11	6.46	35.60	1.95	0.75	15.9	11.7	63.37
E	6.36	123	25.3	8.29	26.81	6.79	35.44	0.30	0.67	54.8	0	36.23

Table 3. Summary table of the environmental data averaged for the two clusters based on sediment constituent assemblages.

Group	SI	pH	Temperature	DO	Salinity	% Mud	Phi
A	1.89	8.26	25.95	6.29	35.75	17.3	2.00
B	1.13	8.29	26.20	6.38	35.58	1.10	0.88
Nirvana	0.85	8.25	26.09	6.43	35.60	0.06	1.00

Conclusions

1. The patterns of salinity, temperature, and percent mud reflect waters emerging from Biscayne Bay through Caesar's Creek into the study area.
2. The influence of the water emerging from the bay is reflected in the FORAM and SEDCON Indices.
3. The SEDCON Index was faster and easier to apply, while the FORAM Index produced more inter-reef detail.
4. The negative correlation between the two indices may reflect the difference between the potential for carbonate production by symbiont-bearing corals and foraminifers, as indicated by the FORAM Index, versus the reality of the decline of coral cover over the past several decades, which is reflected in the SEDCON Index.
5. Water quality in the reef area of Biscayne National Park appears to be suitable for calcifying symbioses; the average FI value across all reefs was 4.12.
6. The average SI value of 1.26 indicates that erosional processes, and secondarily autotrophic and heterotrophic production, are dominant sources of carbonate sediments associated with BNP patch reefs.
7. The divergence between the two indices may indicate that regional (e.g., coral diseases) and global (e.g., photo-oxidative stresses) influences are more important than local water quality in the decline of Biscayne patch reefs.

Acknowledgement

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