When bigger isn't better: the relationship between oyster reef "clump" volume and biodiversity in the Henderson and Blackwater estuaries, southwestern Florida

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INTRODUCTION

Rookery Bay National Estuarine Research Reserve (RBNERR), located in southwestern Florida, is composed of more than 100,000 acres of submerged, coastal, and near-coastal land (Savarese, 1999). An estuary, defined as an ecosystem lying at the interface between an ocean and a river, is characterized by a unique and variable combination of biotic and abiotic components. One important component of an estuary ecosystem is oyster reefs; oyster reefs in the RBNERR are communities of organisms dominated by the eastern oyster *(Crassostrea virginica)* that are located in subtidal and intertidal zones of moderate salinities. Oyster reefs in the RBNERR may be divided into a hard oyster-valve substrate and freestanding "clump" structures. "Clumps" are composed of living and non-living oysters as well as a diverse assemblage of macroinvertebrate organisms that includes mussels and other bivalves, gastropods, barnacles, crabs and other arthropods, worms, sponges, and bryozoans (Bahr, 1981). Organisms also exist on the substrate, but the "clump" structures support much of the oyster reef diversity.

Some facets of estuarine oyster reefs in southwestern Florida have been explored previously by RBNERR employees and Florida Gulf Coast University (FGCU) faculty and students. Works in progress by Brewster and Savarese concentrate on oyster growth and productivity on estuarine oyster reefs (Brewster, this volume; Savarese, pers. commun.); other previous work has focussed on oyster reef crab diversity (Savarese, pers. commun.). No quantitative oyster reef "clump" biodiversity research in the RBNERR has been conducted to date.

The Theory of Island Biogeography states that large islands support more diverse communities than small islands (MacArthur and Wilson, 1967). Though this theory is based on studies of oceanic islands, MacArthur and Wilson suggested that biogeographic "islands" occur throughout nature. MacArthur and Wilson (1967) also indicated that there are many other factors that control biodiversity on an "island" such as colonization and extinction of species; environmental conditions; and the size, shape, and proximity of surrounding "islands." However, they conclude that island size most heavily controls biodiversity.

The Theory of Island Biogeography has a pervasive presence in the study of ecology as it has been used to study the diversity of organisms in many environments. In this research project, I inferred that oyster reef "clumps" are biogeographic islands because each "clump" is freestanding. I tackled the following question in an effort to quantify oyster reef biodiversity in southwestern Florida: is "clump" biodiversity related to "clump" size on an oyster reef? By extrapolating the Theory of Island Biogeography, I predicted that oyster reef "clump" biodiversity is related to "clump" size; that is, large "clumps" are more diverse than small "clumps."

METHODS

Field work. I conducted field work on oyster reefs in the Henderson and Blackwater estuaries located in the RBNERR (Fig. 1). The Henderson and Blackwater estuaries are about 0 cm to 3 m in depth, tidally influenced by a 50-cm mean average tide, and variable in salinity through both tidal and seasonal phases (Savarese, pers. commun.). Estuary oyster reefs generally occur along mangrove forest fringes or occasionally as solitary bars in channels. The reefs vary in size, but are approximately 3 to 25 meters in length and exhibit up to about 2 meters of relief. The upper 30-50 cm of the oyster reefs is typically exposed at low tide, but exposure amounts vary with reef morphology and tidal fluxes. The morphological characteristics of an oyster reef are primarily controlled by tidal currents, channel currents, oyster reef organism behavior, waves, human-induced currents and waves, storms, and/or mangrove forest growth (Bahr, 1981).

Both the Henderson and Blackwater estuaries are divided into five homologues (Fig. 1) (Savarese, pers. commun.). Each homologue contains multiple oyster reefs, which include any estuary fringe and bar oyster reefs. I collected "clumps" from Meghan's Reef at Henderson's Homologue 2 and the Hall Bay Reef from Homologue 4 as well as an oyster reef at Blackwater's Homologue 5. I divided each of these oyster reefs into three-dimensional quadrates, and collected "clumps" randomly in the quadrates for a total of 6-8 "clumps" from each reef.

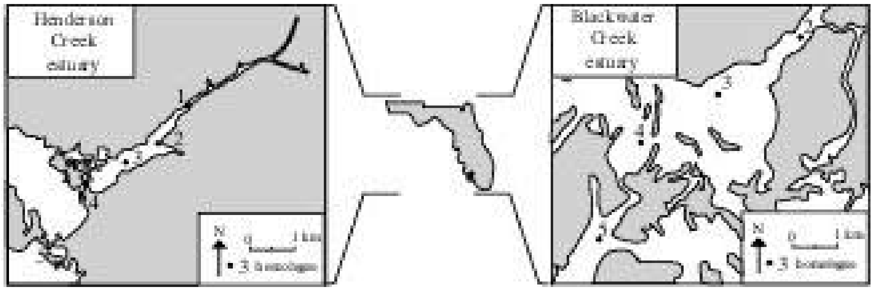

Figure 1. Maps of field sites in the Henderson and Blackwater estuaries. Numbers represent homologue sites.

Laboratory work. I measured "clump" size using two techniques: 1) volume by water displacement, and 2) volume by average diameter calculation using a "clump's" three principal axes, assuming a regular ellipsoidal shape. I observed "clump" characteristics such as shape, presence/absence of dominant organism(s), and preferential growth areas on the "clump." I then disarticulated the "clumps" by collecting visible vagrant organisms, removing sessile organisms attached to oyster valves, and separating oysters with a hammer and chisel. During this process, I classified, counted, and measured each individual's size. This process allowed me to obtain data for the species richness, species abundance, and individual size of all the species present on a "clump." Species richness is defined as the number of species present; species abundance is the number of individuals of each species present; individual size is the maximum length of an individual organism.

Analysis. I determined 2 values: species richness and species evenness. Whereas species richness presents the number of species found on each "clump," species evenness factors in the relative abundance of species on a "clump" as well. These values allowed me to compare "clump" volume measurements with 2 different measures of biodiversity.

RESULTS

"Clump" descriptions. I collected 22 "clumps," 6 from Meghan's Reef (Homologue 2, Henderson), 8 from Hall Bay Reef (Homologue 4, Henderson), and 8 from Blackwater Reef (Homologue 5, Blackwater), which housed a total of 50 species and 6604 individuals (Table 1).

clump	# species	volume type 1 (cm^3)	volume type 2 (cm^3)	clump	# species	volume type 1 (cm^3)	volume type 2 (cm^3)	clump	# species	volume type 1 (cm^3)	volume type 2 (cm^3)
MR1	7	2370	4620	HB1	14	1130	8180	BW1	4	399	831
MR2	11	770	524	HB2	14	800	3500	BW2	12	473	2010
MR3	10	655	762	HB3	7	385	1060	BW3	24	920	3880
MR4	13	965	1830	HB4	8	467	3780	BW4	21	1230	6510
MR5	12	900	1020	HB5	8	533	1060	BW5	14	525	1030
MR6	14	1900	3140	HB6	21	2500	3880	BW6	11	540	1200
				HB7	19	1290	5200	BW7	10	1470	4190
				HB8	21	953	3780	BW8	19	1200	2730

Table 1. Number of species and "clump" volume measurements on each of 22 "clumps." MR, HB, and BW respectively stand for Meghan's Reef, Hall Bay Reef, and Blackwater Reef. Volume type 1 is calculated by water displacement and volume type 2 is calculated assuming regular ellipsoid.

The most commonly occurring species were oysters, striped barnacles, slipper shell #1, and mussels. Table 2 shows the occurrence of these species on each of the 22 "clumps."

clump	MR1	MR2	MR3	MR4	MR5	MR6	HB1	HB2	HB3	HB4	HB5	HB6	HB7	HB8	BW1	BW2	BW3	BW4	BW5	BW6	BW7	BW8
oyster	3	1	1	1	2	3	1	1	2	1	3	1	3	2	2	1	2	2	3	1	2	2
striped barnacle	2	5	2	3	1	1	3	4	1	0	5	4	4	4	1	3	10	4	2	2	1	1

slipper shell #1	0	0	0	0	0	0	4	2	4	2	0	3	1	1	3	2	1	1	1	3	3	3
mussel	1	2	6	4	3	2	2	3	0	4	2	2	2	3	0	0	16	0	0	0	0	14

Table 2. Species-abundance rank for the 4 most commonly occurring species on all oyster reef "clumps" sampled. Abbreviations as in Table 1. "0" indicates that the species is not represented on that "clump"; therefore, no rank is available.

"Clump" volume versus species richness. Figures 2 and 3 summarize the results of this analysis:

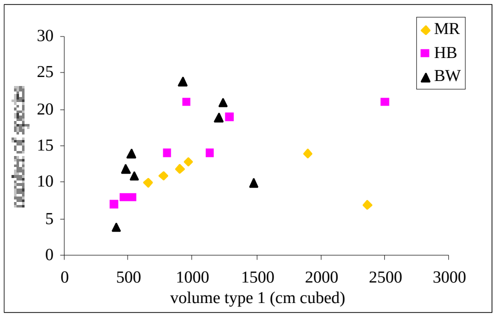

Figure 2. Relationship between volume type 1 (water displacement) and number of species. Abbreviations as in Table 1.

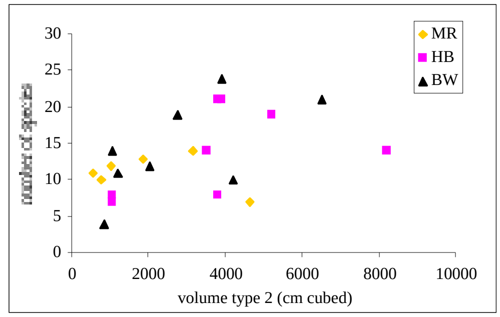

Figure 3. Relationship between volume type 2 (assuming regular ellipsoid) and number of species. Abbreviations as in Table 1.

"Clump" volume versus species evenness. Figures 4 and 5 summarize the results of this analysis:

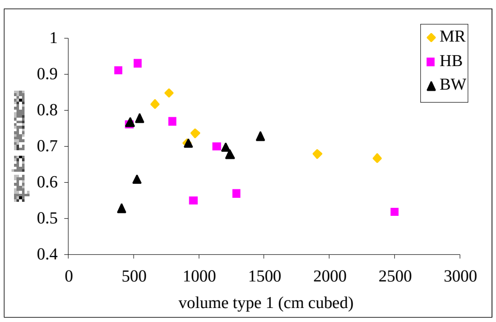

Figure 4. Relationship between volume type 1 and species evenness. Abbreviations as in Table 1.

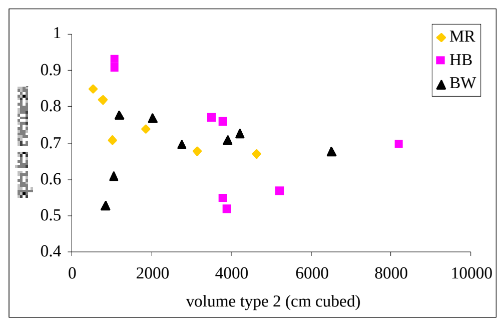

Figure 5. Relationship between volume type 2 and species evenness. Abbreviations as in Table 1.

DISCUSSION

Figures 2 and 3 indicate that species richness is weakly correlated with "clump" volume (r=0.341 and 0.468, respectively) and Figures 4 and 5 show that species evenness is weakly correlated with "clump" volume (r= -0.459 and -0.368, respectively). Therefore, I suggest that other controlling factors may affect the biodiversity of oyster reef "clumps."

"Clump" density. Figures 2-5 identify significant differences in type 1 and 2 volume calculations. Type 2 values measure the volume of the "clump" as a solid, regular ellipsoid while type 1 values measure only the volume of each "clump's" solid portions. Differences in volume values between types 1 and 2 may be attributed to variable "clump" density. I observed that the Blackwater Reef "clumps" were typically less dense as they contained more exposed internal surface area and less cryptic space.

Variation in "clump" density may result in the differential presence and/or absence of organisms that live in certain microhabitats on a "clump." For example, the mussel, *Guekensia demissa*, is preferentially found in cryptic areas where it remains submerged during the tidal cycle to avoid predation (Bahr, 1981). Wells (1961) suggested that predators, such as gastropods, sponges, and crabs, are more abundant and diverse in high-salinity environments. As a result, oysters and consequently other attached macroinvertebrates situated in high-salinity environments with many predators prefer to live in the intertidal zone to avoid this predation. Because the mussels do not prefer a high-salinity, intertidal environment, they may rarely occur on the Blackwater Reef, as suggested by Table 2.

Salinity. Salinity is the primary controller of oyster-reef occurrence and size in estuaries; oysters prefer moderate salinities, though they may exist in a wide salinity range. The other macroinvertebrate fauna living on oyster reefs in estuaries are primarily marine organisms that tolerate a wide range of salinities. Interestingly, Wells (1961) concluded that macroinvertebrate species richness and abundance generally decreases upstream in estuaries because the only organisms present are those with low-salinity tolerances; further, there is generally no compensation of freshwater species upstream in estuaries (Wells, 1961). This concept is demonstrated in the Henderson estuary; Hall Bay Reef, located in a higher-salinity environment, possessed a total of 298 individuals from the 4 most commonly occurring species while Meghan's Reef, located in a lower-salinity environment, housed a total of 148 individuals from the 4 most commonly occurring species. Salinity also fluctuates seasonally, such as the 20 ppt annual fluctuation that occurs in the Blackwater and Henderson estuaries (Wilkening, this volume); this variation also produces seasonal fluctuation in macroinvertebrate fauna on oyster reefs (Gunter, 1956).

Macroinvertebrate reproduction. Macroinvertebrate reproduction, occurring annually in the summer, is triggered by warm water temperatures. Planktonic oyster and other macroinvertebrate larvae colonize in areas with certain specific sunlight, salinity, temperature, and current velocity properties to begin their sedentary adult life (Bahr, 1981). Though colonization patterns are unique in each ecosystem, typically the periods of high colonization occur either both early and late or at the midpoint of the summer (Andrews, 1951). Because I collected data during early summer, early stages of macroinvertebrate reproduction may have affected the biodiversity of the "clumps."

One example of preferential colonization and its potential affect on biodiversity is the slipper shell #1, *Crepidula plana*, whose larvae grow and metamorphose into sedentary, benthic, adult life stages faster in higher-salinity areas (Zimmerman and Pechenik, 1991). Table 2 indicates that the slipper shell #1 is almost entirely missing from Meghan's Reef, which is located upstream in a lower-salinity environment.

Predation. Predation by crabs, boring sponges, drilling gastropods, and other organisms affect population dynamics and may decrease biodiversity. Gunter (1955) indicated that the natural mortality rates for oysters in estuaries were about 2-18% whereas mortality rates for oysters in estuaries when predators were present was about 8-90%. With greater predator presence in the high-salinity environments of the Henderson and Blackwater estuaries, macroinvertebrate biodiversity may also reflect this preferential predation.

Other controlling factors. Many other potential conditions may also affect "clump" biodiversity. Oysters strategically orient on a "clump" so that their planes of commissure are parallel to the direction of current flow and so that a small amount of surface area is exposed to sunlight. Macroinvertebrate fauna prefer environments with low sedimentation rates, low wave energies, and strong current flow. Many of the macroinvertebrate fauna present on an oyster reef live in certain vertical zones. Finally, greater daily and seasonal temperature fluctuation occurs upstream than downstream; thus, the organisms living upstream must be tolerant of such temperature change.

CONCLUSION

MacArthur and Wilson (1967) identified numerous factors that control biodiversity on a geographic island and concluded that island area was the dominating factor. For oyster reef biodiversity in the Henderson and Blackwater estuaries, many other factors may have greater control on diversity. Because my results only qualify the potential presence of these other controlling factors, they provide more questions than answers. However, the most important conclusion is that when it comes to the biodiversity of oyster reef "clumps" in southwestern Florida, bigger may not be better.

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