

PHYSIS

Journal of Marine Science

CIEE RESEARCH STATION BONAIRE
TROPICAL MARINE ECOLOGY &
CONSERVATION PROGRAM
VOL. III SPRING 2008

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Physis (φύσις), is the Greek word for nature, used to describe the natural growth of living organisms. *Physis* is capable of generating great change within an individual while maintaining the integrity of its species. It is *physis* which transforms the tiny fish egg into the transparent, drifting larvae, to the juvenile hiding in the roots of the mangrove, to the quick, silver tarpon glinting in the darkness.

Our time in Bonaire has been focused on the place where all life began: the oceans. Over the past fifteen weeks, we have studied marine ecology, developed skills that have enabled us to conduct our own independent research and learned of the many conservation issues plaguing the marine environment. We have sorted through beach trash and looked upon raw sewage, contemplating the possibilities of a sustainable future. We have been given the opportunity to use science as a gateway for reaching a greater understanding of the world that we live in. The following pages are the culmination of that research.

Through our experiences within the classroom and in the field, we have developed a stronger understanding of the connections between all of Earth's systems. As sure as the desert dust of Africa blows over the ocean, the rivers of the Great Plains will reach the sea. Thoreau thought of *physis* as the movement from darkness into light; as we fall in step with the rhythm of the earth we begin to walk our own path towards a brighter future.

Cheers,
Jenna Mawhinney
Christine San Antonio
CIEE Class of Spring, 2008

Photo Credit:
Front Cover: Lola Nygaard
Back Inside Cover: Rita Peachey
Back Cover: Claire Dell

Foreword



The Council on International Educational Exchange (CIEE) is an American non – profit organization with nearly 100 study abroad programs in 35 countries around the world. Since 1947 CIEE has been guided by its mission... *to help people gain understanding, acquire knowledge and develop skills for living in a globally interdependent and culturally diverse world.* As a membership organization, composed of mainly U.S. institutions of higher education, CIEE responds quickly to the changing academic needs and desires of its member institutions.

The Tropical Marine Ecology and Conservation program in Bonaire is one of the newest programs offered by CIEE and is an example of our ability to foresee the need for science – based programs abroad. Our goal is to provide a world class learning experience in Marine Ecology and Conservation. Our program is designed to prepare students for graduate programs in Marine Science, Environmental Science, or for state and federal jobs in Natural Resource Management. Student participants enroll in five courses: Coral Reef Ecology, Scientific Methods using SCUBA, Cultural and Environmental History of Bonaire, Marine Conservation Biology and Independent Study. In addition to a full program of study, this program provides dive training that prepares students for certification with American Academy of Underwater Scientist, a leader in the scientific dive industry at their home universities.

The proceedings of this journal are the results of each student’s Independent Research project. The research was conducted within the Bonaire National Marine Park with permission from the park and the Department of Environment and Nature, Bonaire, Netherlands Antilles. Students presented their findings in a public forum on 9 April 2008 at CIEE Research Center, Bonaire.

The Independent Research Advisors for the projects published in this journal were: Rita B.J. Peachy, Ph. D, Caren Eckrich, M.S. and Daniela Maldini, Ph. D, and Claire Dell.

Independent Research Advisors

Dr. Rita Peachey is the Resident Director of the CIEE Tropical Marine Ecology & Conservation program in Bonaire and the lead Instructor for the Cultural & Environmental History and Independent Research courses.

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Advisees: Jean Pearson and Alex Carrera



Dr. Daniela Maldini is the Marine Conservation Biology Post-doc and is the Instructor for the Tropical Marine Conservation Biology course.

Advisees: Sarah Marr, Jillian Coddington and Jenna Mawhinney



Claire Dell is the Tropical Marine Ecology Intern and is the Teaching Assistant for the Fundamentals of Scientific Diving and Coral Reef Ecology courses. She is quite brilliant.

Advisees: Luisa Velasquez and Brian Reckenbeil



Student Profiles

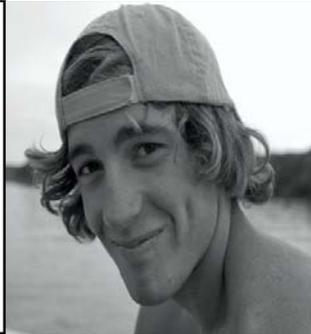
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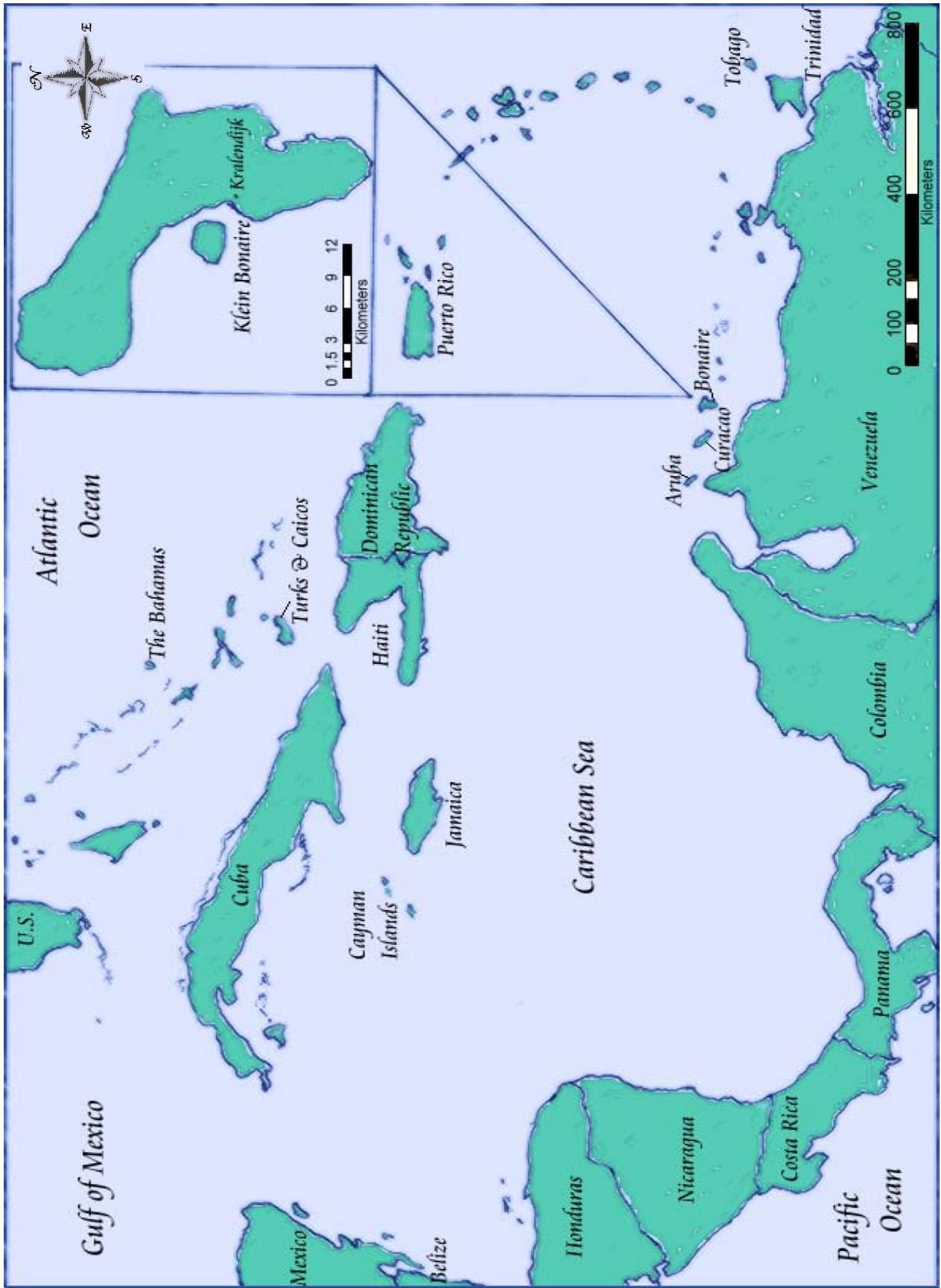
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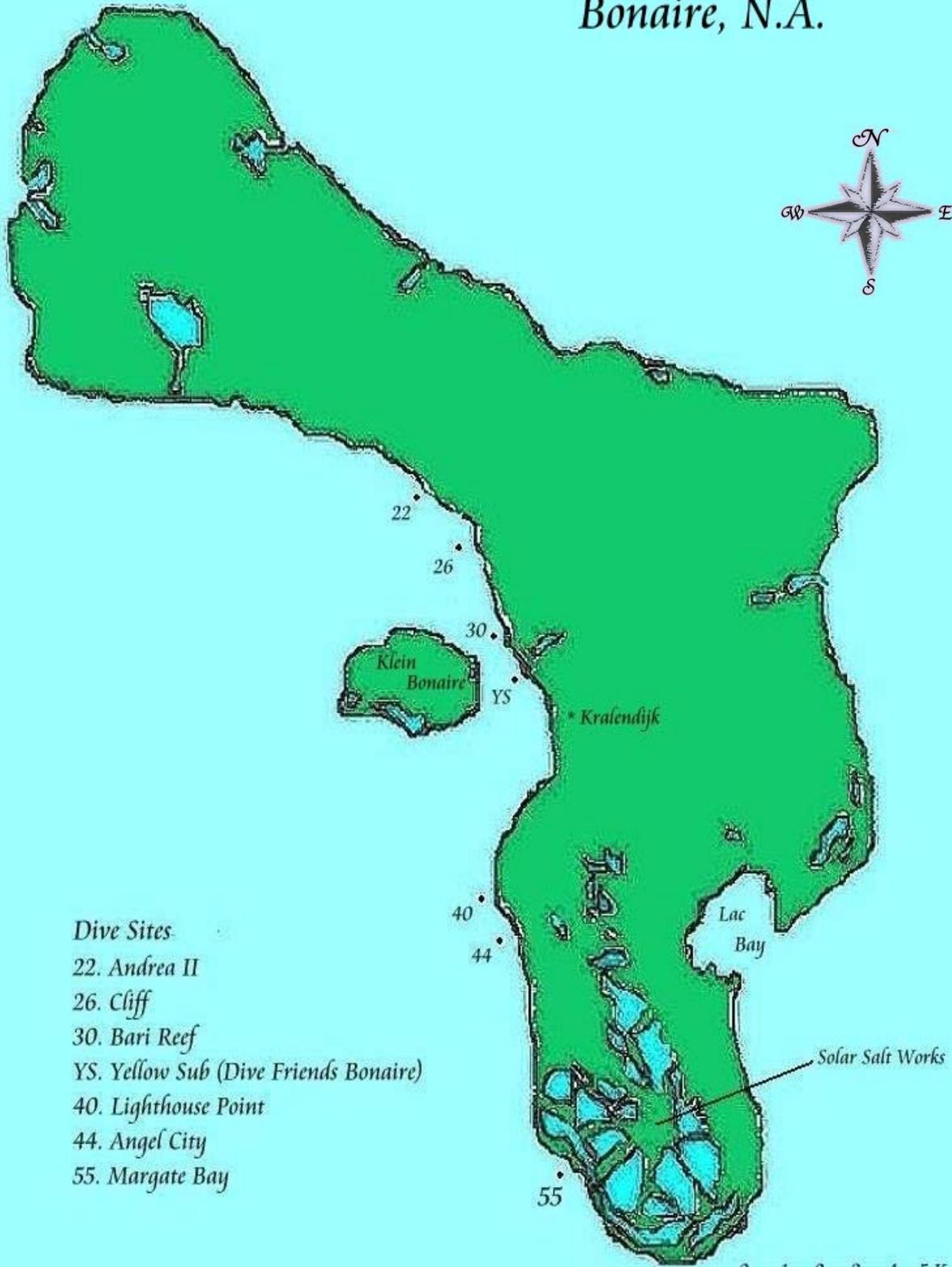
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Bonaire, N.A.



Dive Sites

- 22. Andrea II
- 26. Cliff
- 30. Bari Reef
- YS. Yellow Sub (Dive Friends Bonaire)
- 40. Lighthouse Point
- 44. Angel City
- 55. Margate Bay

Flamingo (*Phoenicopus ruber ruber*) Distribution and Feeding Behavior in Relation to Salinity Levels on Bonaire, Netherland Antilles

Jenna Mawhinney

Abstract

Bonaire is home to the largest natural flamingo reserve in the western hemisphere, housing one of the four remaining crucial breeding grounds in the world and the primary breeding ground of the Americas. Flamingos filter feed on gastropods, crustaceans and chironomids in salt water lakes and ponds. This study examined flamingo distribution and feeding behavior in relation to changing salinity levels in condenser ponds used for salt production on Bonaire, Netherland Antilles. Flamingo density was found to be highest (44.4-172.7birds/km²) in ponds with the highest salinity (184-205g/l) among the ponds tested, followed by ponds with the lowest salinity (55 g/l). Ponds with an intermediate salinity (84-154 g/l) hosted significantly fewer birds (0-1.6 birds/km²). The type of feeding behavior used by flamingos was found to be related to water depth and salinity range and could possibly be explained by differences in prey found at different salinities and depths; however, this specific question was only addressed in a qualitative manner in this study. Grubbing was most prevalent in high salinity ponds while skimming occurred with higher frequency in low salinity ponds. Because grubbing is generally used to feed on pond bottoms results suggest that prey items in high salinity ponds may be densest at the bottom and probably consist of chironomids such as brine fly pupae. Conversely, skimming is used in shallower water and its prevalence in low salinity ponds indicates that prey is concentrated in the water column and best caught by filter feeding mechanisms.

Introduction

The Caribbean flamingo (*Phoenicopus ruber ruber*) population on Bonaire and in Venezuela is estimated at 20,000 individuals, with many birds moving between the two locations in the mornings and evenings to nest and feed (Ross and Scott 1997; Espinoza *et al.* 2000). Flamingos feed in large flocks in areas with high food concentrations and low numbers of predators. Their main prey items are gastropods, crustaceans and chironomids generally found in lagoons and salt water lakes and ponds (Arengo and Baldassarre 1995).

Flamingos exhibit a variety of feeding behaviors depending on the type of prey available (Rooth 1965; Table 1). Using skimming, a type of filter feeding behavior, flamingos are capable of filtering up to 20,000 gallons of water per day to catch small and planktonic organisms in the water column (Bildstein *et al.* 1993). Flamingo beaks are also adapted to pick up larger organisms and “throw” them into the mouth, as well as to scrape and filter top soil and mud (Zweers *et al.* 1995). Brine shrimp and flies are an important prey item, tending to concentrate in higher salinity ponds, called salinas (Casler and Esté 2000).

Flamingos are particularly vulnerable to human disturbance because the highly saline environments that they prefer are ideal for salt extraction. In 1965, a solar salt plant was built on the island of Bonaire and its construction effectively reduced flamingo habitat by 50% (Arengo and Baldassarre 1998). In 1971, the Dutch Kingdom signed the RAMSAR Contract, which aims to protect wetlands of great international

importance (STINAPA 2007). Five wetlands reserves were registered for Bonaire, including Pekelmeer, which is located near the salt plant and houses a 55 ha (120 acre) natural flamingo reserve; the largest in the western hemisphere (STINAPA 2007). This reserve is particularly important because it is one of the four major flamingo breeding sites which remain in the world today (De Boer 1976).

Arengo and Baldassarre’s (1998) study of flamingo use of commercial salt impoundments found that low and high salinity ponds (4-87 ppt and 127-218 ppt respectively), but not intermediate ponds (68-150 ppt), contained suitable food resources for flamingos. Their study found that high salinity ponds contained feeding material primarily located in the water column and were dominated by brine shrimp while low salinity ponds did not contain brine and housed most potential food in the substrate layer. High salinity ponds also showed low fluctuations in the number of food items over the course of the study and therefore may be a more consistent source of food (Arengo and Baldassarre 1998).

This study tested Arengo and Baldassarre’s findings in a series of salt concentrators with rigidly maintained salinity brackets located in the southern portion of the island of Bonaire. It also looked at several types of feeding behaviors and their relationship with salinity and water depth. The following hypotheses were tested:

H₀₁: There is no difference in flamingo density among different salinity brackets;

H₀₂: There is no difference in frequency of occurrence of different types of feeding behavior at different water depths;

H₀₃: There is no difference in frequency of occurrence of different types of feeding behavior at different salinity levels.

Methods

In March 2008, six flamingo counts were conducted in six salt concentrators of different salinity levels at Cargill Solar Salt Plant on Bonaire, Netherland Antilles (Figure 1). The same six ponds within three salinity brackets: 40-69 (low), 70-160 (medium) and 161-250 (high) g NaCl/liter respectively, were censused

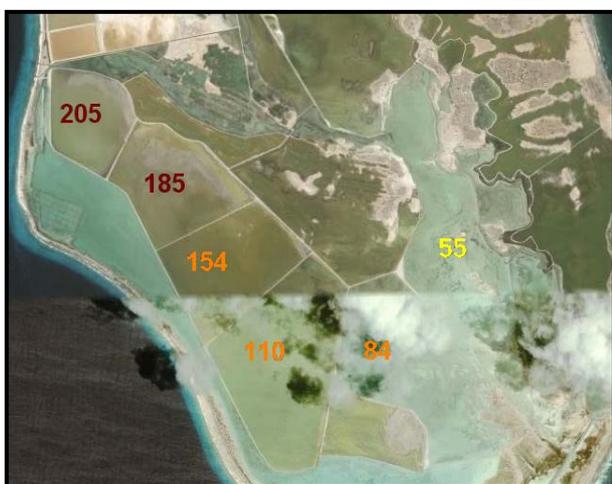


Figure 1. Map of the study area in Cargill Salt, Bonaire, showing the salinity of each pond studied in g/liter (Google Earth, 2008).

Using binoculars, each pond was scanned; the number of feeding flamingos, the type of feeding behavior (Rooth 1965) and water depth relative to flamingo leg length (Mascitti 1998) was recorded (Tables 1 and 2). Salinity measurements of each of

the ponds were provided by Cargill personnel. Salinity is artificially maintained at a constant level in the ponds so fluctuations for the study period were insignificant and were not taken into account.

The significance of differences in flamingo density among salinity brackets was tested using Kruskal-Wallis corrected for ties, followed by post hoc paired comparisons (Langley 1979).

Results

Flamingo Density in Relation to Salinity

Flamingo densities were found to be significantly different among the six ponds tested (Fig. 2; $H=30.573$, $P<0.0001$). Densities were greatest (44.5 to 172.7 birds/km²) in the highest salinity ponds (184 g/l- 285 g/l), very low (<1 bird/km²) and not significantly different in the three intermediate ponds (84-154 g/l) and second greatest (22.9 birds/km²) in the low salinity pond (55 g/l). Because bird density was not significantly different and close to zero in the three intermediate salinity ponds, these ponds were not used in subsequent analyses. Significant differences in density were also found between the two ponds in the high salinity bracket ($K= 14.3$; $P<0.01$) with the highest salinity pond having almost four times the density (172.7 birds/km²) than the slightly lower salinity pond (44.5 birds/km²).

Feeding Behaviors

Not all types of expected feeding behaviors (Table 1) were recorded during the study period. For all ponds combined grubbing was the most frequently occurring behavior (39%), followed by skimming (24%), seizing (17%), stabbing (9%), searching (8%), and walking (2%). Stamping was never recorded during the study period. Because the frequency of occurrence of walking and stamping was close to zero, these behaviors were not analyzed further.

Flamingos spent twice as much time searching in the low salinity pond, suggesting an overall lower food concentration than the high salinity ponds (Fig 3).

Table 1. Observable feeding behaviors in *Phoenicopterus ruber ruber* (Rooth 1965)

Behavior	Definition
Skimming	Moving beak back and forth in the across the top layer of water
Grubbing	Up-ending in deep water to feed for several seconds on bottom
Seizing with beak	Dipping head in shallow water and “chewing” prey
Stamping	Standing in one place, lifting feet up and down to flush prey from sediment
Walking	Scooping shallow water with beak while walking
Stabbing	Thrusting beak into water
Searching	Walking slowly with head near water

Table 2. Approximate water depth relative to flamingo leg length

Water Depth	Water Level Relative to Flamingo Leg
≤2 cm	Metatarso-tarsal joint
≈15 cm	Halfway up tarsus
≈30 cm	Tarso-tibiotarsal joint
≈45 cm	Halfway up tibiotarsus
≈60 cm	On tibiotarsus

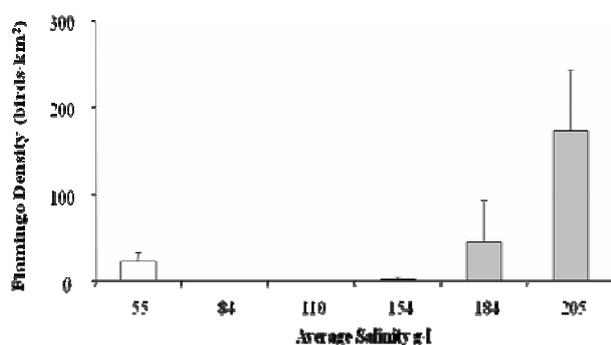


Figure 2. Flamingo density birds/km² in relation to pond salinity (grams NaCl/liter), including the standard deviation.

Skimming (40%) and stabbing (21%) were twice as prevalent in the low salinity pond, compared to the high salinity pond. Conversely, grubbing (44%) was almost four times and stabbing (21%) more than twice as prevalent in the high salinity ponds. Different feeding strategies in the two salinity levels suggest different types or location of prey.

Feeding Behavior in Relation to Water Depth

The highest water level used by feeding flamingos was approximately 60 cm, a level which reached all the way up to the belly of the bird. The occurrence of specific types of feeding behavior appeared to be associated with certain water depths and not others (Fig. 3). Skimming was never observed in water deeper than 30 cm and occurred with the greatest frequency in water deeper than 30 cm and occurred with the greatest frequency at 30 cm water depth (Fig. 2). Grubbing was observed at all water levels up to 60 cm, occurring with the greatest frequency at 30 cm and declining in frequency in either direction. Seizing was seen at water depths up to 30 cm but was most frequently observed at water depths around 15 cm. Stabbing was not observed in water deeper than 30 cm where it occurred with highest frequency.

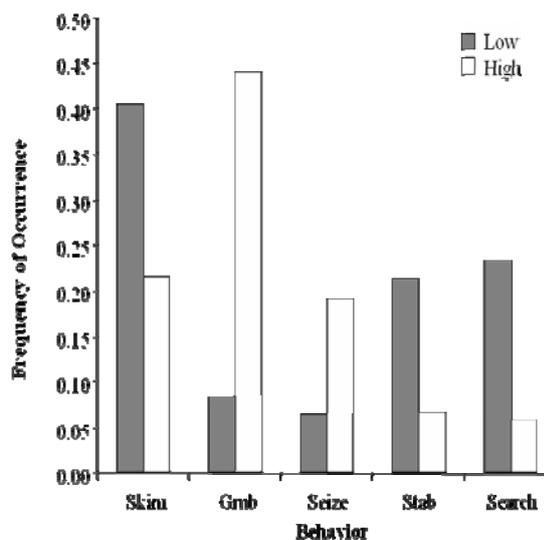


Figure 3. Frequency of observed feeding behaviors in ponds of high versus low salinity.

Discussion

Flamingo Density in Relation to Salinity

Results of flamingo density in correlation with salinity negate the null hypothesis and suggest greater feeding bird densities in high salinity ponds. This supports findings in Venezuela by Arengo and Baldassarre (1998). However, the current study detected significant differences in flamingo density between the two highest salinity ponds (184 g/l and 205 g/l), while corresponding salinities in Venezuelan ponds were reported in the same salinity bracket (Arengo and Baldassarre 1998). The current study suggests that a finer scale subdivision of salinity brackets may better describe flamingo habitat use.

As flamingos concentrate in areas with the highest food density (Sutherland 1983; Arengo and Baldassarre 1995; Arengo and Baldassarre 1999), the results of this study suggest that ponds with salinity at approximately 205 g/l may have ideal prey concentrations for flamingos. This is also supported by the finding that searching behavior was not occurring with high frequency in the high salinity ponds (Fig 3), suggesting that little searching was required due to the high abundance of prey.

The jump in bird density between the 184 g/l pond and 205 g/l pond further suggests that prey density may be optimal in the pond with the highest salinity (Fig. 2). Although not directly confirmed during this study, existing data about ponds with salinity higher than those measured show that these ponds generally host only a small number of feeding flamingos (Bret Schuttpelz, pers. comm.), supporting the

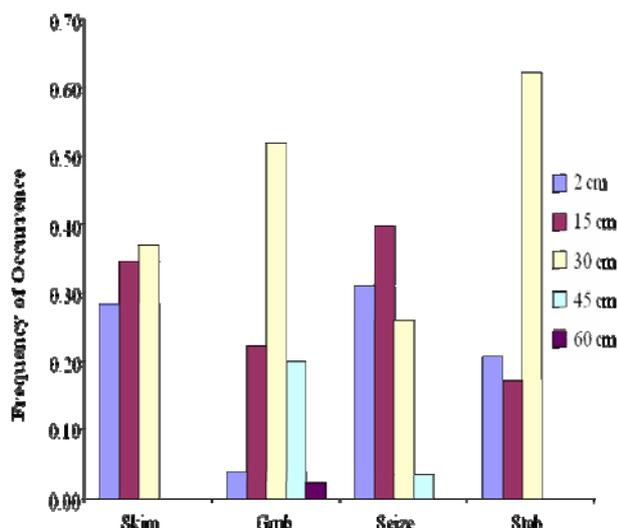


Figure 4. Frequency of observed feeding behaviors in relation to water depth.

idea that a salinity of approximately 205 g/l provides the ideal environment for flamingo prey items.

Feeding Behaviors in Relation to Salinity and Water Depth

Monitoring the occurrence of different types of flamingo feeding behaviors in relation to salinity and water depth may be useful to indirectly gauge what birds are feeding on and where in the water column birds are finding their food. When correlated with salinity, behavior can suggest whether there is a difference in the type of prey present among ponds. Results negate the null hypothesis that there is no difference in frequency of occurrence of feeding behavior in ponds of different salinity.

Grubbing behavior was seen with the highest frequency in high salinity ponds and occurred with significantly higher frequency in waters 30cm or deeper. When grubbing, flamingos submerge their head and neck and feed on the bottom of the pond, suggesting that in high salinity ponds flamingos are feeding primarily on prey located on the bottom such as crustaceans, nematodes and mollusks (Arengo and Baldassarre 1998).

Skimming was seen with the highest frequency in low salinity ponds and occurs with significantly higher frequency in water shallower than 30 cm. Skimming flamingos swing their neck left and right while holding the partially open beak in the water; this type of “filter feeding” is ideal to collect prey floating or swimming in the water column such as brine shrimp. It should be noted that these findings were in contradiction with the results of Arengo and

Baldassarre’s (1998) study where bottom feeding dominated in low salinity ponds and feeding in the water column was seen with greatest frequency in high salinity ponds.

In general, while each of the feeding behaviors did not dominate a different water depth, each behavior appeared to occur preferentially at specific depths (Fig. 4). It is difficult to determine whether water depth truly determines prey availability or simply determines the choice of feeding behaviors because of flamingos’ anatomical constraints. Further studies to directly sample prey abundance and distribution in the condensers are needed to better understand the results and give a more complete picture of flamingo habitat use.

Final Conclusions

The differences in feeding behaviors and water depths between the low and high salinity ponds suggest that flamingos are feeding on different prey types in these two salinity brackets. Further sampling to explore prey types could prove interesting for future studies.

Bildstein *et al* (2000) call for a new approach to the study of flamingos that moves away from the naturalist approach of making single site observations of flamingo behavior. These scientists would like to see a broader approach that explores the whys of the flamingo’s choice of habitat, patterns of movement and behavior in order to better explain why we need to protect vast areas of habitat (Bildstein *et al.* 2000). Examining the feeding behavior of flamingos could prove to be an important tool in monitoring the ways in which flamingos are utilizing their habitats, including what prey type they are feeding on. Combining long-term observations of salinity measurements, prey abundance and flamingo distribution may prove instrumental in understanding predator-prey dynamics.

Acknowledgements

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The Effects of Intruder Size on the Territoriality of the Threespot Damselfish (*Stegastes planifrons*)

Jillian Coddington

Abstract

The Threespot Damselfish, *Stegastes planifrons*, defends a variable territory size depending upon the level of threat posed by the species encroaching upon it. Aggression patterns in the Threespot Damselfish were studied in relation to intruder size, attack duration, maximum distance of attack and intruder species on a reef in Bonaire, Netherland Antilles. Thirteen species were found to intrude upon Threespot Damselfish territories with the Bicolor Damselfish (*Stegastes partitus*) being the most frequent visitor (37.8%) followed by the Brown Chromis (*Chromis multilineata*; 20.2%), Blue Tang (*Acanthurus coeruleus*; 15.1%) and the Stoplight Parrotfish (*Sparisoma viride*; 9.2%). Analysis showed a positive correlation between intruder size and attack duration as well as maximum distance traveled by the Threespot Damselfish in pursuit of the intruder during the attack. Data supported the hypothesis that the Threespot Damselfish alters its behavior based on intruder size. Data, however, did not support a species specific relationship between the Threespot Damselfish aggression patterns and the variables selected.

Introduction

The stability of a highly diverse community depends on complex interactions among multiple species making each species an essential link to ecosystem balance (Carr et al. 2002). A keystone species is a species whose presence is essential to the diversity of life in a given ecosystem (Sole and Montoya, 2001). A non-carnivorous keystone species, the Threespot Damselfish (*Stegastes planifrons*) is critical to the reef ecosystem as it affects the structure of the community (Williams 1980).

Known for its utilization of aggressive tactics in territorial defense of its algal lawn, the Threespot Damselfish will guard its territory to claim its right to the food supply present on its algal lawn, to protect its spawn and to maintain a safe living space on the reef (Thresher 1976). The Threespot Damselfish has an average adult size of 9 cm and defends its territory against other much larger herbivores such as parrotfish and surgeonfish (Deloach 2002; Humann and Deloach 2002). Damselfish territories are about a meter in diameter and are usually non-overlapping (Kaplan 1982; Bay et al. 2001).

Threespot Damselfish influence their community and create intermediate disturbance levels by regulating grazing intensity of algal mats as well as "farming" them (Connell 1978; Axline-Minotti 2003). Farming is defined as including all activities that promote the establishment and growth of algal crops such as weeding, preparing substratum, fertilizing and excluding herbivores (Ceccarelli 2001). By conditioning their habitat, damselfish have been shown to maintain and enhance multi-species coexistence in coral reefs (Hata and Nishihira 2002).

Studies have shown that when the Threespot Damselfish algal mats are caged, the algal diversity

declines (Hinds and Ballantine 1987). Damselfish territories appear to influence the standing crop, productivity, and community structure of coral reef algae while herbivory by other reef fishes promotes coral survival through reduction of competitive algae (Hatcher 1983). Herbivorous fish have been shown to consume 60-95% of the reef's primary productivity. The Threespot Damselfish has been shown to be especially efficient in absorbing primary production through grazing which equates to more transferable energy available to higher trophic levels (Cleveland 1999).

By measuring differences in the rate of oxygen consumption when an intruder is present and when an intruder is absent, Cleveland (1999) showed that the energetic costs of agonistic behavior are minimal for the damselfish, leaving energy available for growth and reproduction which translates into more secondary energy flow.

It is crucial to have energy readily available for growth because only the larger and more aggressive damselfish are capable of capturing and defending the most valuable territories (Meadows 1994). These territories are located in the center of conspecific territories where aggressive encounters with conspecific intruders are common (cost), but where damselfish enjoy a higher growth rate, and lower food stealing by heterospecific intruders (benefits) (Meadows 1994). Other costs to territoriality include increased risk of predation, increased risk of injury, decreased time for foraging, and decreased time for mating (Cleveland 1999). The fitness of an individual damselfish depends on its ability to weigh the costs and benefits of each of its actions given its individual ability to defend its territory.

Thresher (1976) stated that the size of territory

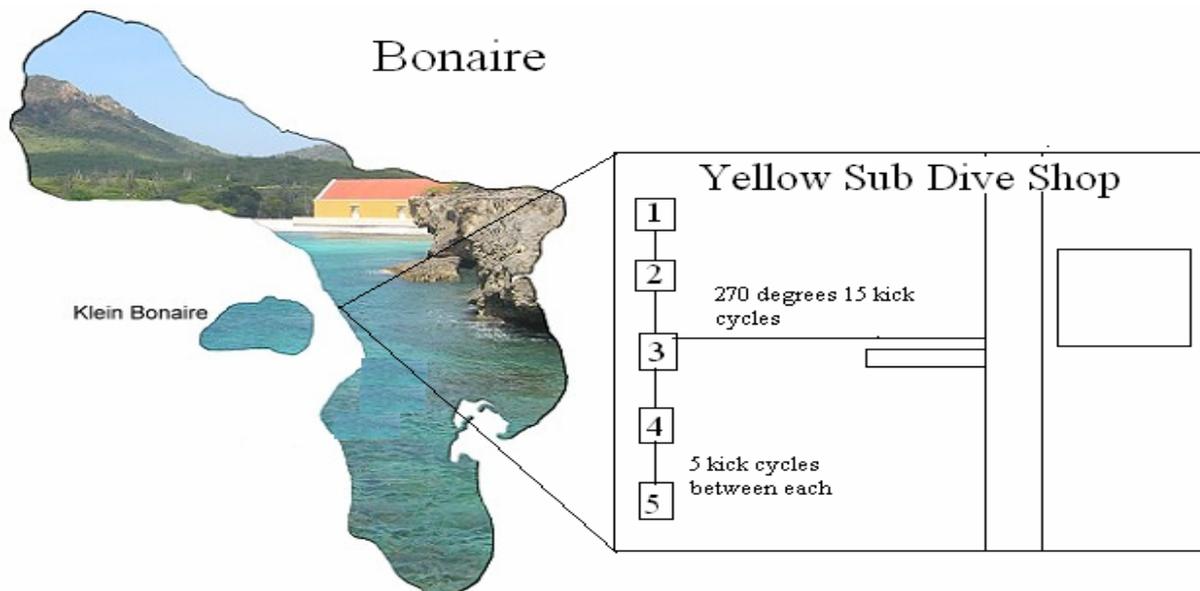


Figure 1: Location of observed individual Threespot Damselfish (*Stegastes Planifrons*) territories (1, 2, 3, 4, and 5).

defended by the Threespot Damselfish is correlated to the amount of threat the intruder poses to damselfish resources. Thresher (1976) implemented model-bottle experiments where species of common intruders were incased in a bottle and manually moved closer to the Threespot Damselfish until an attack commenced. Thresher noted the maximum distance that provoked an attack by the Threespot Damselfish and called it the “maximum distance of attack” (MDA).

The main goal of the proposed project is to examine Threespot Damselfish aggression patterns and their relationship with intruder size within a species. Specifically, the following null hypotheses will be tested:

H₀₁: For each species of intruder, aggression intensity displayed by the Threespot Damselfish (*S. planifrons*) is independent of size.

Based on Thresher’s (1976) results it is expected that H₀ will be supported and that the size of the individual, and not the species identity, will influence aggression patterns. Analysis of Threespot Damselfish behavior will help to elucidate reef dynamics with respect to interspecific competition. By understanding the nature of these relationships on the reef we will be better prepared to protect the equilibrium of the environment and therefore preserve the diversity on which it flourishes.

Methods

Study Area

Located in the Dutch Antilles, Caribbean Sea, the Island of Bonaire is surrounded by a fringing coral reef which still exhibits high species diversity making it an ideal site for research. The main study area for the proposed project was the reef on the leeward side of the island. Observations were made at a depth of 10 and 15 meters to each side of the Yellow Submarine Dive Shop pier (12°09’36.38’’N, 68°16’55.43’’W); (Fig. 1).

Procedure

Territorial behavior of the Threespot Damselfish was recorded using videography and direct underwater observations while scuba diving. Ten individuals were filmed using an underwater video camera placed at a distance of 1.5 meters from the territory and manually operated. Each of the ten fish observed was filmed for 30-min time periods. Digital video was reviewed using a personal computer and software allowing stop-frame imaging. The following data was collected from the video: size of the intruder measured in relation to the size of the damselfish (about 9 cm), species identity of the intruder, distance from the intruder to the damselfish when the attack commenced (MDA; measured in relation to the size of the damselfish) and the total length of time the damselfish pursued the same intruder (in secs.). MDA and attack duration were the variables used to characterize aggression intensity.



Figure 2: The author filming Three-spot Damselfish behavior in Bonaire.

Analysis

Data was tested to determine if there was a correlation between MDA and size of intruder within a species. The data was also tested to determine if there was a correlation between attack duration and size of intruder within a species. Data was analyzed using Statview© software. An ANOVA was used to test the relationship between MDA and size of intruder for each species of intruder as well as the relationship between duration of attack and size of intruder for each species of intruder. Alpha level for all statistical tests was 0.05.

Results

Intruder Species Diversity

Several species were observed intruding on Three-spot Damselfish territories during the study (Figure 2). Brown chromis (*Chromis multilineata*; 20.2%), Stoplight Parrotfish (*Sparisoma viride*; 9.2%), Bicolor Damselfish (*Stegastes partitus*; 37.8%) and Blue Tang (*Acanthurus coeruleus*; 15.1%) were observed with higher frequencies. Other species observed (17.6%) included Sharpnose Puffers (*Canthigaster rostrata*), Queen Parrotfish (*Scarus vetula*), Bluehead Wrasse (*Thalassoma bifasciatum*), French Angelfish (*Pomacanthus paru*), Smooth Trunkfish (*Lacophyrus triqueter*), Princess Parrotfish (*Scarus taeniopterus*), Banded Butterfly Fish (*Chaetodon striatus*), Redtail Parrotfish (*Sparisoma chrysopterus*), and Creole Wrasse (*Clepticus parrae*). These were observed in low numbers and therefore are not included in the detailed analyses.

Size vs. MDA and Attack Duration

Stoplight Parrotfish were observed being attacked a total of 11 times by the Three-spot Damselfish. MDA and size of individual intruder were significantly correlated ($R^2=0.492$; $P=0.0161$). Attack duration and individual intruder size were significantly correlated as well ($R^2=0.779$; $P=0.0003$) (Table 1, Figure 3 and 4).

Brown Chromis were observed being attacked 24 times. Neither duration of attack nor MDA were significantly correlated to size of intruder.

Bicolor Damselfish were observed being at-

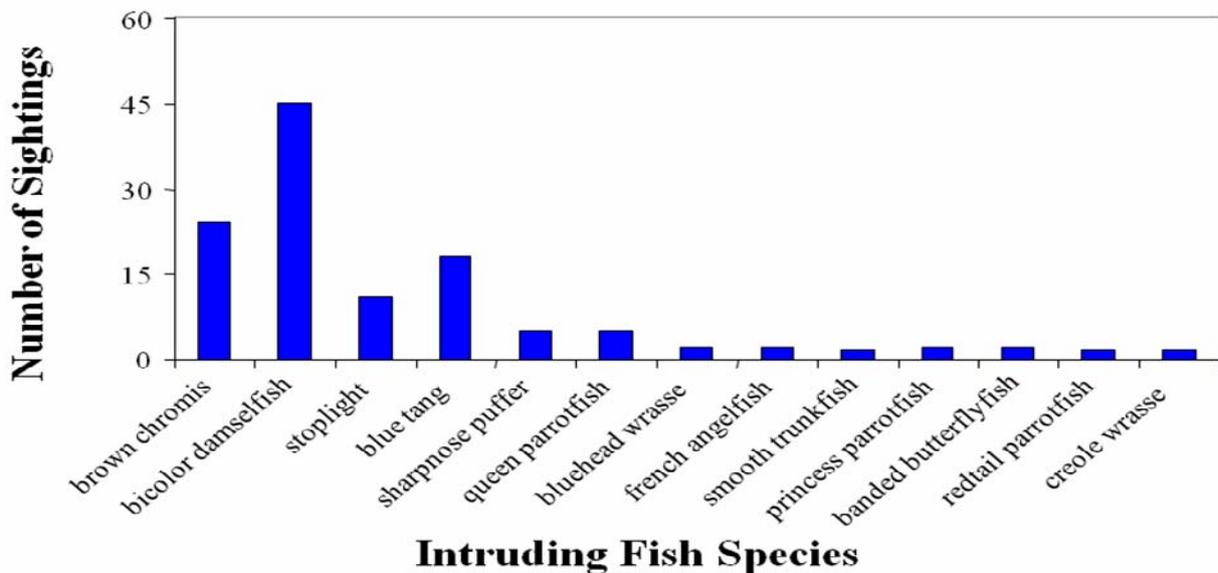


Figure 3. Frequency of occurrence for species observed intruding upon Three-spot Damselfish (*Stegastes planifrons*) territories at a study site on Bonaire, Netherland Antilles.

Table 1. Number of attacks by the four most common intruding species and the significance of correlation between of individual size and maximum distance of attack (MDA) as well as individual size and duration of attack.

Species	N of Attacks	MDA	Duration of Attack
Stoplight Parrotfish	11	R ² = 0.492 P=0.0161	R ² =0.779 P=0.0003
Brown Chromis	24	NS	NS
Bicolor Damsel fish	45	NS	NS
Blue Tang	18	NS	NS

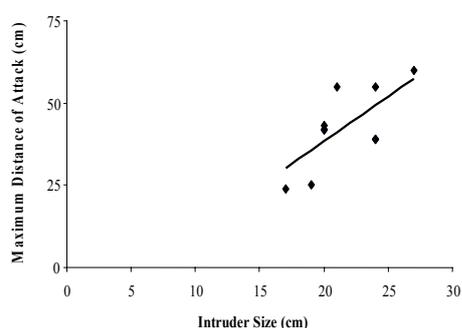


Figure 4. Relationship between Threespot Damsel fish (*Stegastes planifrons*) maximum distance of attack and size of intruding Stoplight Parrotfish (*Sparisoma viride*).

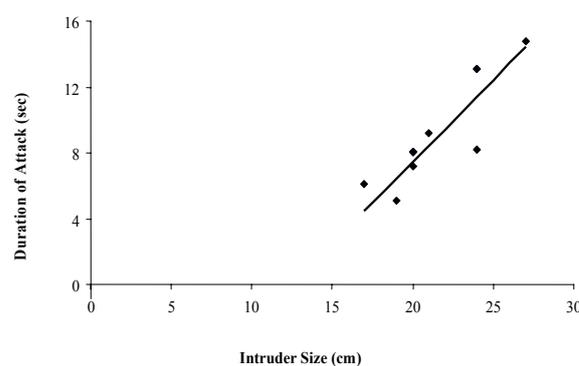


Figure 5. Relationship between Threespot Damsel fish (*Stegastes planifrons*) attack duration and size of intruding Stoplight Parrotfish (*Sparisoma viride*).

tacked 45 times. Neither duration of attack nor MDA were significantly correlated to size of intruder.

Blue tang were observed being attacked 18 times. Neither duration of attack nor MDA were significantly correlated to the size of intruder.

Discussion

Resource competition is fundamental in understanding reef community structure. Thresher (1976) found that over a broad range of species, size within a given species appeared unimportant to Threespot Damsel fish aggression intensity. In contrast, the current study found a high correlation between aggression intensity and intruding Stoplight Parrotfish size. Aggression intensity was measured using MDA and attack duration as a proxy for intensity. Similar to Thresher's (1976) results, the data shows no significant correlation exists between aggression intensity for the following species: Bicolor Damsel fish, Brown Chromis, and Blue Tang. While Thresher (1976) implemented model-bottles when determining his MDA therefore introducing possible manipulation effects, this study measured naturally observed MDA.

Aggressive behavior has been shown to be utilized by individuals to maximize reproduction and survival (Brown 1964). As long as the territory is

defendable, the value of site-dependent aggressiveness should tend to be in proportion to the intensity of competition (Brown 1964). Too much aggression when resources are plentiful would be maladaptive. A balance must be achieved between the advantages of acquiring food, mates, nesting areas, and protection of family, and the disadvantages of time, energy, and opportunity loss plus the risk of injury (Brown 1964). Aggression intensity in the Threespot Damsel fish may also be directly related to the amount of algae in the intruder's diet (Thresher 1976). Brown Chromis and Bicolor Damsel fish feed upon plankton and may therefore pose less of a threat.

Larger Stoplight Parrotfish have larger energetic demands and therefore must consume more than smaller individuals (Bruggemann 1994). The larger Stoplight Parrotfish were attacked with more vigor which suggested that larger size for this species poses a greater threat to the Threespot Damsel fish resources (Thresher 1976).

Intruding species where aggression intensity was not related to individual size (Brown Chromis, 7.62-13.97; Bicolor Damsel fish, 5.08-8.89 ; Blue Tang, 12.7- 25.4) had a much smaller size range than the Stoplight Parrotfish (12.7-45.72), so that the Threespot Damsel fish may not have been able to detect size

differences among intruders (Humann and Deloach, 2002).

Intricate interactions among multiple species are necessary for the stability of a highly diverse community such as a coral reef. Overexploiting such species may have cascading negative consequences for the entire system (Carr 2002). As key grazers, large herbivorous fish affect community stability; therefore their extinction can lead to coextinction of many other species (Sole and Montoya 2001). By regulating who has access to resources, Threespot Damselfish influence fish population dynamics. By decreasing the abundance of reef fish, destructive fishing practices could trigger a phase shift from a fish dominated to an algae dominated environment (Hughes 1994). Without herbivorous fish, algae grow uninhibited and eventually encase and suffocate corals (Hughes 1994). The interactions between key grazers, such as parrotfish, and fish that control what they eat, such as the damselfish, are therefore very important.

Members of the family *Scaridae* (Parrotfish) have been shown to reduce algal biomass and improve coral reef health by increasing recruitment and reducing mortality of corals (Brown 2006). By defending their algal lawn, Threespot Damselfish reduce herbivory, therefore creating areas of elevated algal biomass. Up to 25% of the reef area in Bonaire is highly defended by damselfish, but due to the presence of large numbers of scarids the algal biomass remains low outside of the damselfish territories (Brown 2006). Brown (2006) found that larger scarids (>20 cm) in Bonaire were unaffected by damselfish aggression. Therefore, fishing pressures that result in predator loss, which increases the number of damselfish, will only have a negative impact if scarid size is reduced as well (Brown 2006). Regulating fishing intensity and selectivity on coral reefs is crucial in maintaining damselfish/parrotfish dynamics. Understanding these interactions will be the key to success of conservation efforts in the future.

In conclusion, size of the Stoplight Parrotfish intruder was highly correlated to Threespot Damselfish aggression intensity, while other species observed had little correlation. This suggests that interactions between the Threespot Damselfish and the Stoplight Parrotfish are very influential in determining reef dynamics.

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Variation in Threespot Damselfish Aggression Using Models of a Conspecific, Predator, and Herbivore

Christine San Antonio

Abstract

The purpose of this research was to determine the level of defensive aggression of the threespot damselfish, *Stegastes planifrons*, when exposed to intruders of different species using models. Adult *S. planifrons* were exposed to models of a conspecific, an herbivorous fish, *Sparisoma viride*, and a predator, *Aulostomus maculatus*. Attack rates and retreat rates of *S. planifrons* were determined by observations during exposure to models. It was expected that aggression levels would be highest towards the conspecific model and lowest towards the predator model and that evasive behavior would be highest in the presence of the predator model and lowest with the conspecific. It was found that there is a significant difference in the level of aggression when encountering a predator versus a conspecific, showing more aggression towards the conspecific and more evasion towards the predator. No significant difference was found in the aggression levels shown between the predator and the herbivore. Exposure to the predator elicited the highest number of retreats, also showing a significant difference in the level of evasion when comparing all three models. The results suggest that *S. planifrons* are able to differentiate between intruder species and react depending on the level of threat posed and perhaps on what is most energy efficient.

Introduction

Damselfish are ubiquitous members of the fauna of coral reefs around the world (Allen 1998). The threespot damselfish, *Stegastes planifrons*, is known for its aggression towards intruding fish and is commonly found along the fringing coral reefs of Bonaire, N.A.; thus, making it an ideal research subject (Allen 1998). The normal lifespan of the *S. planifrons* remains unknown, although many can live for 10 to 12 years, spending only a few weeks as juveniles (Allen 1998). The *S. planifrons* juveniles are drastically different than adults in color, which diminishes with age. The appearance of males and females is similar and sex is difficult to distinguish except during annual spawning when the males typically develop more colorful courtship attributes to attract a female (Allen 1998).

Being diurnal and primarily herbivorous, *S. planifrons* spends most of the day maintaining and feeding in a personal filamentous algal garden; the area provides the damselfish with food, shelter and a place to spawn (Axline-Minotti 2003). *S. planifrons* defend gardens aggressively against intruders, despite being rather small. Averaging 5 to 12 cm in length (Hawryshyn 2004) *S. planifrons* rarely leave the algal patch unprotected except in the early morning when they vacate to be cleaned by gobies (Cheney 2001). During this time, foreign grazers often find their way to the garden and take advantage of the damselfish's absence (Cheney 2001). Banded sea snakes and trumpetfish are the natural predators of damselfish, however, it has been suggested that damselfish protect gardens just as aggressively towards predators as any other fish (Williams 1979).

S. planifrons is one of the few species of the Pomacentridae family that exhibits such highly aggressive defense of its garden territory; it is important to assess why this is and what the mechanisms are that drive variations in aggression levels (Allen 1998). *S. planifrons* is a key species to the coral reef ecosystem because it encourages algae growth in some areas while limiting growth in others by the selective removal of unwanted algal species (Allen 1998). The loss of their presence could induce an uncontrolled spread of certain algae or the death of other algae, both of which could be detrimental to the reef ecosystem (Weinheimer 2003).

In field studies, the aggressive behavior of *S. planifrons* differed between urchin species (*Diadema antillarum* and *Echinometra viridis*) showing that *S. planifrons* can differentiate between grazer species (Williams 1979). It was found that aggression levels of the *S. planifrons* increased as *D. antillarum* approached but then decreased with as *E. viridis* approached (Williams 1979). The change in the level of aggression based on intruder proximity and type suggests that similar results will be seen in research with intruding fish species.

The dynamics of the *S. planifrons* and *A. maculatus* predator prey relationship and *S. planifrons* avoidance behavior were examined in another research study (Helfman 1989). This study utilized models of foraging trumpetfish on live threespot damselfish subjects; the models were brought continuously closer to the threespot subject and the reaction was recorded. It was found that the prey individuals exhibited stronger avoidance the closer the model was brought; larger trumpetfish or ones in the strike posi-

tion posed more of a threat and resulted in greater avoidance in the subjects (Helfman 1989). Helfman's (1989) study tends to support this paper's hypothesis that there will be a greater number of retreats seen in the presence of a predator versus a conspecific or an herbivore.

In a separate study about the multidimensional polarization sensitivity in damselfishes, *S. planifrons* was one of three species studied; the results showed that the damselfish have the most complex polarization sensitivity recorded for any vertebrate (Hawryshyn 2004). This capacity could prove to be vital in mediating a visual communication network in damselfish within the coral reef environment (Hawryshyn 2004). Since damselfish tend to respond first to stimulations within the visual sense, this complexity could support the level and quickness of aggression that damselfish have towards oncoming intruders (Hawryshyn 2004). It is possible that a variation in intruder type, which causes a change in damselfish aggression, is directly related to the complexity of their visual sensitivity.

One study measured the aggressive behavior and density of *S. planifrons* and correlated the results to the level of biodiversity in a number of functional groups; implicating *S. planifrons* as an important member of the coral reef ecosystem and a potential keystone species (Axline-Minotti 2003). Determining the variation in aggression exhibited by *S. planifrons* towards intruders is critical to understanding its utilization of energy. *S. planifrons* requires energy for reproduction, feeding, cleaning and other aspects of general living (Böhlke 1994). The energy that *S. planifrons* employs in aggressively defending its territory is depleted from other aspects of its life cycle (Böhlke 1994). Energy allocation towards aggressive behavior may reduce growth rate or reproductive potential of *S. planifrons* compared to other less aggressive damselfish.

The purpose of this research is to determine the effects of variation in intruder type on the level of aggression that threespot damselfish employ while defending algal gardens. Mean attack rates and retreat rates in the presence of model conspecifics, herbivores and predators will be used to test the following hypotheses:

H₁: *S. planifrons* will show a range of aggressive behavior when a model intruder is presented. The highest level of aggression will be toward a conspecific, an intermediate level toward an herbivore and the least aggression toward a predator intruder.

H₂: *S. planifrons* will show a range of evasive behavior when a model intruder is presented. The low-

est level of evasive behavior will be toward a conspecific, an intermediate level toward an herbivore and the greatest evasion will be toward a predator intruder.

Methods

The research was conducted at Yellow Sub off the leeward side of Bonaire, Netherlands Antilles, (12° 09' 36.38" N, 68° 16' 55.43" W). Fifteen *S. planifrons* subjects were used in the study; repeated access to them was possible by using a site map constructed after the initial visit to each subject's habitat. The subjects chosen consisted of adult males and females that were 6 to 10 cm in length. Measurements were performed by matching the subject's length with a stationary object then measuring the object.

To examine the effect of intruder type on threespot aggression, each fish was presented with 3 different models: a predator, an herbivore and a conspecific. It was assumed that both males and females of the *S. planifrons* would show the same level of aggression. One model was randomly chosen to be used prior to each dive as were the 5 or 6 subjects that would be tested during that period until all models had been presented to all subjects. The model was passed in front of the subject for 10 s at a distance of approximately 30 cm from the respective garden (Figure 1). After a 30 s respite, the model was passed again in the same manner; this was repeated for a total of 5 times and took an average of 170 to 200 s. Time was kept using an underwater stop watch. The procedure was repeated for each of the models with all 15 subjects. During observations the number of attacks and the number of retreats by the subject were recorded.

The models were constructed using color prints of *S. planifrons*, *S. viride* and *A. maculatus* of appropriate sizes on waterproof paper. The model of the *A. maculatus* is approximately 75 cm in length, a size large enough to consume a 6 to 10 cm damselfish. The model of the *S. planifrons* was made to the same size specifications as the subjects being studied. The model of the *S. viride* was made to the average size of an adult male in terminal phase and is approximately 33 cm (Humann 2002). The form of each model was created by attaching balsa wood to the end of a clear plastic rod. Modeling clay was then added around this until the approximate size and shape of each fish was created. The waterproof pictures were then placed over the clay on both sides (the rod went through one side) and the edges of the paper were stapled together.

Statistical analyses were computed with Statview 5.0.1 software (SAS). The mean number of attacks of *S. planifrons* was compared among models using a

one-way analysis of variance (ANOVA) ($\alpha = 0.05$). The mean number of retreats by *S. planifrons* was also compared among model types using a one-way ANOVA ($\alpha = 0.05$). When a significant difference was detected in attacks or retreats using ANOVA, a post hoc analysis was conducted using Fischer's PLSD (protected least significant difference) test to determine where the differences were among intruder types.



Figure 1. Presenting the Trumpetfish predator model to a Damsel subject

Results

Attacks

Out of the 225 total swipes (75 per model) there was a total of 57 attacks by *S. planifrons*. Some individuals attacked the models several times per swipe while others did not attack at all. The greatest number of attacks was on the conspecific model (51), followed by the herbivore (6), and there were no attacks on the predator. The mean number of attacks on the conspecific model was 0.68 attacks/swipe and the mean number of attacks on the parrotfish model was 0.08 attacks/swipe (Figure 2).

ANOVA indicated that there was a highly significant difference among models, $p < 0.0001$ (Table 1). Post hoc analysis with Fischer's PLSD test showed that there was a significantly lower number

of attacks on the predator model when compared to the conspecific model, and that there were significantly less attacks on the herbivore model when compared to the conspecific model. However, there was no difference between the herbivore and predator models (Table 2).

Retreats

Out of the 225 swipes there was a total of 88 retreats by *S. planifrons*. For all 3 models, when the subject retreated it occurred only once per swipe. The greatest number of retreats was for the predator model (50), followed by the herbivore (28), then the conspecific (10). The mean number of retreats on the conspecific model was 0.13 retreats/swipe, the mean number of retreats on the herbivore model was 0.37 retreats/swipe and the mean number of attacks on the

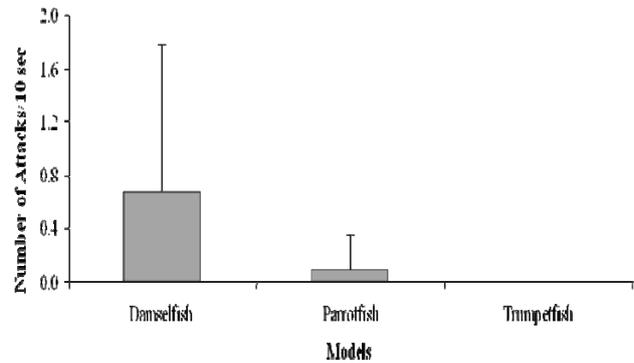


Figure 2. Mean number of attacks per model (\pm SD) by *S. planifrons* during a ten second exposure to 3 different fish models; a conspecific, an herbivore, and a predator.

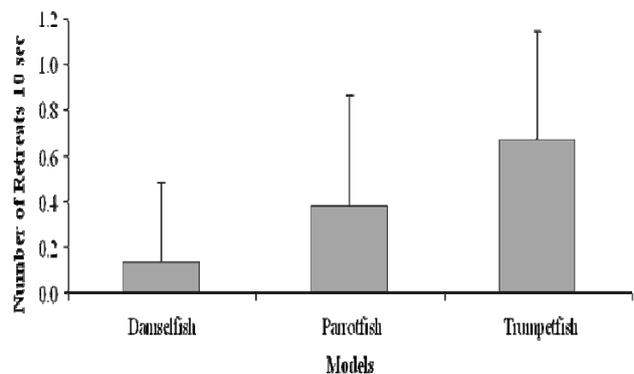


Figure 3. Mean number of retreats per model (\pm SD) by *S. planifrons* during a ten second exposure to 3 different fish models; a conspecific, an herbivore, and a predator.

Table 1. ANOVA comparing the mean (\pm SD) attacks by *S. planifrons* on the conspecific, herbivore and predator fish models ($\alpha = 0.05$).

	DF	SS	MS	F-Value	P-Value
Model	2	4.086	2.043	31.811	<0.0001
Residual	222	14.257	0.064		

Table 2. Post- hoc analysis using Fisher's PLSD of the number of attacks by *S. planifrons* on the conspecific (C), herbivore (H) and predator (P) fish models ($\alpha = 0.05$).

Comparisons	Mean Difference	Critical Difference	P-Value	Significant?
C, H	0.263	0.082	<0.0001	Yes
C, P	0.304	0.082	<0.0001	Yes
H, P	0.041	0.082	0.3181	No

Table 3. ANOVA comparing the mean (\pm SD) retreats by *S. planifrons* on the conspecific, herbivore and predator fish models ($\alpha = 0.05$).

	DF	SS	MS	F-Value	P-Value
Model	2	2.868	1.434	27.704	<0.0001
Residual	222	11.490	0.052		

Table 4. Post- hoc analysis using Fisher's PLSD of the number of attacks by *S. planifrons* on the conspecific (C), herbivore (H) and predator (P) fish models ($\alpha = 0.05$).

Comparisons	Mean Difference	Critical Difference	P-Value	Significant?
C, H	-0.124	0.073	0.0010	Yes
C, P	-0.276	0.073	<0.0001	Yes
H, P	-0.152	0.073	<0.0001	Yes

predator model was 0.67 retreats/swipe (Figure 3).

ANOVA indicated that there was a highly significant difference among models, $p < 0.0001$ (Table 3). Post hoc analysis with Fischer's PLSD test showed that there was a significantly higher number of retreats from the predator when compared to the conspecific model; there was a significantly higher number of retreats from the predator when compared to the herbivore model and there was a significantly higher number of retreats from the herbivore when compared to the conspecific (Table 4).

Discussion

Hypothesis H_1 , which stated that *S. planifrons* aggression levels would be different among the three models with the greatest aggression towards the conspecific intruder, the least aggression towards the

predator model and an intermediate level of aggression towards the herbivore model has been upheld by the results of this study. Additionally, hypothesis H_2 , which stated that *S. planifrons* avoidance levels would be different among the three models with the greatest avoidance toward the predator, the least toward a conspecific and intermediate level towards the herbivore was also upheld by the results of this study.

Helfman (1989) found that there was significant avoidance behavior shown by *S. planifrons* the closer a predator model was brought towards it and concluded that the *S. planifrons* exhibit greater avoidance reactions when the level of threat was greatest. The results of this study indicate that there is less aggression and more evasive behavior by *S. planifrons* in the presence of a predator model versus a conspecific model. Based on the results of this study and Helf-

man's (1989) study, it is clear that there is a strategic method employed by *S. planifrons* when defending territory. It is likely that the strong avoidance shown towards the trumpetfish model is indicative of an innate or learned survival strategy, in which the cost of leaving the algal garden exposed is less than the potential cost of exhibiting aggressive behavior and attacking a predator. The results support the idea that threespot damselfish are able to distinguish between intruder species, which was also found in the Williams (1979) study regarding the proximity of two different sea urchin species to threespot gardens. The ability to differentiate between intruder species allows this species to efficiently allocate their energy towards appropriate defense: *S. planifrons* will defend territory unless a greater threat is imposed at which time the threespot will retreat, conserving energy and avoiding an overtly life-threatening situation.

While the statistical analysis did not detect a difference in the level of aggression between the herbivore and predator models, the comparison of total retreats is a different story. There were nearly twice as many retreats from the predator model (50 retreats) as there were to the herbivore model (28 retreats). Statistical analysis showed a significant difference in the level of evasive behavior between the two models, thus, supporting the hypothesis that *S. planifrons* would show more evasion of the predator than the herbivore.

Williams (1979) concluded that *S. planifrons* is able to distinguish between intruder species. Therefore, it is reasonable to assume that the subjects recognized the herbivore model as having the same characteristics and physical appearance as a stoplight parrotfish, which commonly feeds on algae. Although there were more attacks on the herbivore than the predator, the difference was not significant. Perhaps more replication of the study would clarify the relationship.

The visual sense of *S. planifrons* was examined in the study by Hawryshyn (2003), which found that the damselfish have a strongly developed sense of visual perception and this may be critical to recognizing other fish species. However, it is possible that *S. planifrons* react to other fish based on other sensory perception such as olfactory stimulation in addition to visual cues. It was easy for the subjects to recognize the trumpetfish as a predator because of its unique elongated shape. The damselfish model was also the same size as the subjects with the same colors, which are unique to fish that size; therefore it seems likely that the subjects were able to depend on their visual perception alone when recognizing this model. The parrotfish model, however, is the common size for many *S. viride* but it is also the common size of sev-

eral other fish species that may have similar coloration. Because of this the subjects were not able to rely completely on their visual sense to identify the model and since it gave off no other sensory cues (olfactory stimulation) it is possible that the subjects never recognized the model as a stoplight parrotfish grazer and retreated from it rather than attacking it.

Another possibility for the low aggression levels towards the parrotfish model could be from an energy allocation strategy. *S. planifrons* recognizes that parrotfish are not their predators and will not likely attack them; also the parrotfish actually need to be close enough to the garden in order to eat from it. Therefore, it is possible that the subjects rarely attacked the parrotfish model because it remained approximately 30 cm away for the 10 second presentation and did not actually approach the garden; since it posed no immediate threat, the subjects conserved energy by not showing aggression.

The data also show that the number of retreats by *S. planifrons* is highest in the presence of a predator versus a conspecific or an herbivore. Out of the 75 swipes, there were 50 retreats seen with the trumpetfish model and only 28 and 10 seen with the parrotfish and damselfish models, respectively. There were significantly fewer retreats by *S. planifrons* when exposed to the damselfish model when compared to the trumpetfish or the parrotfish models. The results indicate that *S. planifrons* is able to clearly distinguish the trumpetfish as a predator that is potentially life-threatening and recognizes that the most efficient and appropriate allocation of energy during such an encounter is to retreat to safety.

Future analysis in this area could build on this study and the study done by Hawryshyn (2003) to discover the relative importance of other means of sensory perception used by *S. planifrons* to recognize fish species. Such information could provide further insight into individual and community interactions and social dynamics as well as look at what about certain organisms induce certain reactions in *S. planifrons*, for instance why do they attack humans diving on the reef if it is not benefiting species fitness?

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Juvenile French Angelfish Exhibit Cleaning Activity in Bonaire

Brian Reckenbeil

Abstract

Juvenile french angelfish, *Pomacanthus paru*, are known to be cleaner fish. Cleaning is an interesting mutualistic behavior between 2 individuals where 1 species, the cleaner, removes parasites off a client. In Bonaire however, little has been studied on *P. paru* specifically. A study of cleaner fish in general was performed in 1998 in Bonaire, but there was only 1 recorded incidence of *P. paru* cleaning 2 individuals. Juvenile french angels have however, been shown to be a significant part of the cleaner community in Brazil.

Data was collected 27 times, for a total of 9.6hrs of direct observation of juvenile french angelfish. The angels spent 19.5% of their time, 1.87hrs, collectively cleaning. Twenty four species were seen cleaned and another 4 species were spotted being serviced while not conducting research. A total of 168 individuals came to be cleaned over 186 separate cleaning sessions. When compared to other studies, these results show that at this study location in Bonaire, juvenile *P. paru* are an intricate part of the cleaning community.

Introduction

“The interactions between cleaner fish and its client fishes are a well-known example of interspecific mutualism” (Bshary and Grutter 2006). One animal receives food, and the other becomes cleaned. “Cleaner fishes generally occupy traditional sites known as cleaning stations” (Losey 1972; Arnal, et al. 2001) and then the cleaner “swims close and inspects the host and picks at its body surface” (Losey 1972) to remove parasites. The parasites that are removed are ingested by the juvenile cleaner which is part of its diet. “Juveniles acting as cleaners obtain only about 25% of their food by volume from picking parasites off fishes; the remaining 75% is filamentous algae” (Deloach and Humann 1999). At some time during development from juvenile to intermediate, *P. paru* becomes less dependent on parasites for food, which is thought to be when the juvenile grows to about 3in (7.6cm) (Deloach and Humann 1999).

Sazima (et al. 1999) studied *P. paru* juveniles in Abrolhos Archipelago, off eastern Brazil. From the results of 51hrs of SCUBA surveys, 31 species were found that frequented 24 *P. paru* cleaning stations. This information shows that in Brazil, *P. paru* exhibit cleaning behavior frequently, in contrast to Wicksten’s 1998 study. Her study found that two species of cleaner shrimp and three species of fishes commonly engage in cleaning behavior in Bonaire, Netherlands Antilles. *P. paru* was not one of these 3 fish listed as a common cleaner by Wicksten. In an attempt to address the discrepancy between these 2 studies, this study intends to survey juvenile *P. paru* in detail to determine its role as a cleaner in Bonaire. The data collected from this study was then compared to the previous studies of Wicksten, Sazima and other unpublished data collected in Bonaire.

Methods

Preliminary research before the start of this study was performed to find a site location with a high density of juvenile *P. paru* via personal diving observations. This location happened to be 1 mile north of Kralendijk, in the sandy waters off the Yellow Submarine Dive Shop pier. This location is also about 1 mile north of the location where Wicksten’s study was performed, Calabas Reef. The deepest station during this study was at 3m (10ft), but averaged 2.22m (7.2ft). Wicksten’s study however, only started at 3m, and went to a depth of 18m.

Six cleaning stations were visited throughout the study. Each cleaning station was observed for 20 minutes per visit. Physical characteristics were noted, such as depth of the station, topography, substrate, and visibility. Client species, size, duration of service, time of day, area cleaned, if other cleaners are present and their proximity and signals from either party were also all recorded in hopes to fill the void of information on *P. paru* in Bonaire. Sizes were compared to a meter stick marked in 10cm intervals which was placed on the ground near the station, so sizes of clients could be approximated.

Every time the cleaner changed clients, a new cleaning session was initiated. Observation of each cleaning session was recorded, commencing when the cleaner started eating from the client, not when the client arrived to be cleaned. When a client returned after a brief absence, it was recorded as a repeat visit (Schofield et al. 2006). Signals between cleaner and clients were recorded. The part of the body cleaned was recorded, such as tail, fins, sides, top, bottom, and head. Other cleaner species that were seen near the cleaner station, or also cleaning, were documented along with other clients present.

Table 1. Comparison of French Angel to other common cleaners looking at number of client species seen by cleaners, overall hours observed, hours cleaned, total percentage of time cleaning and new species/hr (clients/time). *Unpublished data by Luisa Velasquez

Cleaner Species	Client Species	# Hrs Observed	# Hrs Cleaning	% Time Cleaning	New Species/hr
French Angel	24/28	9.6	1.8700	19.5	2.50
Wicksten (3+)	42	100	Na	Na	0.42
Sazimas FA	31	51	Na	Na	0.61
*Pederson Shrimp	6	3.5	0.6580	20	1.71
*Gobies	13	1.25	0.3430	27	10.40
*Bluehead wrasse	1	0.75	0.0001	0.15	1.33

Results

The bottom contour of all 6 cleaning stations was sandy, which was also the case in Sazima's study. The juvenile angelfish were site specific, which means they do not swim far from the protection of their station. The 6 stations, 7 cleaners, were split evenly between natural coral heads and man made objects, such as concrete blocks or moorings. Most of the angelfish stayed within a 1m radius of their station, with only one instance of an individual swimming out in to the water column to clean (4m). Gobies, another cleaner fish family, were present near 5 of the 6 stations.

In 9.6hrs of underwater observations of juvenile *P. paru*, 24 species were observed to be cleaned and another 4 species (spotted moray eel [*Gymnothorax moringa*], bicolor damselfish [*Stegastes partitus*], brown chromis [*Chromis multilineata*] and permit [*Trachinotus falcatus*]) were spotted being serviced while not conducting research (see Figure 2 or Appendix 1 for client list). A total of 168 individuals came to be cleaned in over 186 separate cleaning sessions. Each cleaner spent a different portion of its time cleaning, but the 6 juvenile angelfish collectively spent 19.5% of their time cleaning. Eighty-two percent of the clients that were cleaned arrived specifically for cleaning, 13% did not intend to be cleaned, and 5% possibly came to be cleaned (Fig. 1).

Ocean surgeonfish were the most frequent visitors, with 50 cleaning sessions. The next most frequent visitors were stoplight parrotfish (19 sessions), then princess parrotfish and blue tang (15 sessions) and yellow goatfish (13) (Fig. 1).

Caesar grunts spent the most time at cleaning stations, consisting of 16.7% of cleaning activity. Banded butterfly fish spent the 2nd longest time at stations (15.33%). Ocean surgeonfish were 3rd (13.33%), while the blue tang were the next longest customers (11.07%). The caesar grunt, banded but-

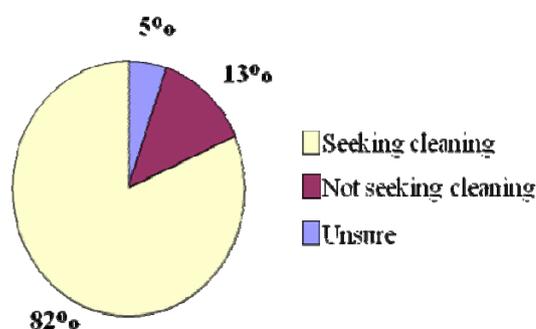


Figure 1. The cleaning intentions of clients.

terflyfish and blue tang had the top 3 longest average visit length per session. The ocean surgeon fish, which were the most common visitors (17.96%), ranked below the average visit length per session for the whole study (36.2%). (Appendix 1). Also in Appendix 1, it seems that the ecological niche of the clients are well rounded, and the cleaner doesn't focus primarily on 1 type of animal.

Discussion

This study showed that juvenile french angelfish clean many species in Bonaire. Some fish were very frequent visitors, such as the ocean surgeon fish. However, they did not have the longest cleaning time, which indicates that they have shorter visit times. In contrast, the caesar grunt arrived infrequently, but had a long cleaning session. All intended clients (82%) stopped very near the stations for the angels to clean, besides the yellowfin mojarra. It lingered about 30cm from the cleaner or its station, whereas all other species stopped extremely close.

The results of this study indicated that the most frequent visitors were the ocean surgeonfish, stoplight parrotfish, princess parrotfish and yellow goatfish,

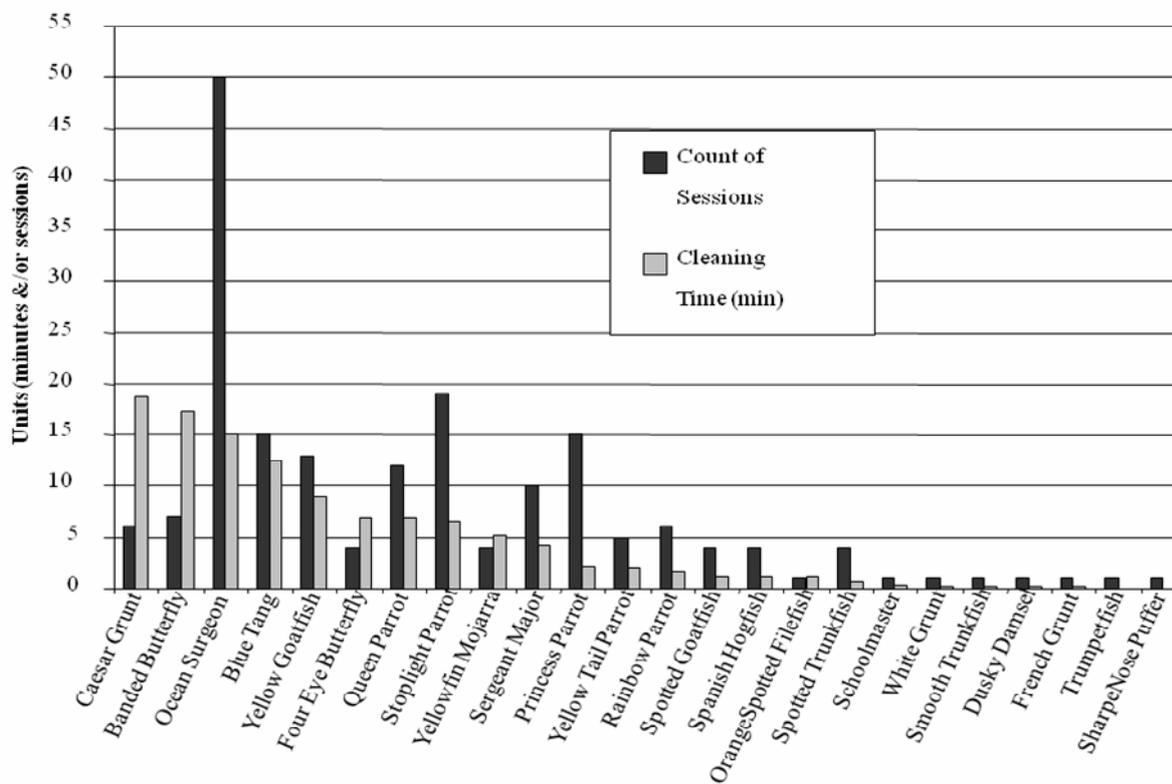


Figure 2. Relationship between number of cleaning sessions by species compared to the length of time each species was cleaned (minutes).

possibly because these species are often found in the shallows. The most frequent visitors in Brazil were the queen triggerfish and doctorfish (Sazima et al. 1999). Neither of these species were observed being cleaned in Bonaire, which may be because they are not very common on the reefs in Bonaire. For example, sightings of queen triggerfish in Bonaire are ranked at 2.7% occurrence by expert fish IDers at REEF. Conversely, 16 of the 24 species cleaned were marked at a sighting rate of over 90% per dive also by expert REEF IDers. This shows that the more common the fish are, the more likely it is that they may be observed during cleaning. With more survey time, more new species may be seen cleaned.

Wicksten's 1998 study included 100hrs of observations, finding 41 species of fish being cleaned by cleaner species such as shrimp, gobies, and juvenile spanish hogfish. Looking at the difference of survey depths, < 3m vs. > 3m, it appears that the prime habitat location for juvenile french angelfish acting as cleaners is not in the depths Wicksten studied. In comparison, this study length was 1/10th of Wicksten's, and 28 species were known to be cleaned by

only 1 cleaner species, *P. paru*. Comparatively, with only a fraction of the overall study time, a large number of species were seen cleaned, indicating that *P. paru* does have an impact as a cleaner near the Yellow Submarine Dive shop, Bonaire. Looking at the new species rate found per hour (total species seen/total survey time), the juvenile french angels in Bonaire have a much larger rate than either other study, 2.50 new species/hr vs 0.62 by Sazima and 0.42 by Wicksten's 3 cleaner species.

Comparing this data to unpublished data, from Luisa Velasquez at CIEE Research Station Bonaire, whom also collected information in Bonaire about cleaner species (Table 1), the juvenile french angelfish shows similarities to the Pederson cleaner shrimp, *Periclimenes pedersoni*. Both have a very close percentage of time spent cleaning, 19.5% and 20% respectively. *P. paru* actually has a larger rate of new species/hr, which shows that the cleaning angelfish may clean a larger number of species than the Pederson shrimp. Pederson shrimp are considered to be a big part of the cleaning system on the reefs. Gobies seem to be the lead cleaner, while blueheaded

wrasse hardly ever clean.

There were 45 individuals strongly believed to be repeat visitors revisiting a cleaner. This number is most likely a conservative estimate, given the fact that if a client swam far off and then came back, it may be mistaken for a new visitor. In addition, the same client fishes may visit the same cleaning stations on a daily basis and thus also be mistaken as different clients. Since this is the case, the exact number of individuals cleaned could never be determined. Repeat visitors indicate that the clients came back specifically to a known cleaning location. It would be interesting to see how often they frequented other species cleaning stations.

Two more stations were originally observed which contained the largest french angel cleaners (4 and 5cm). They lacked interest in cleaning, even when fish were swimming right next to them. It was witnessed that smaller juvenile angels would swim towards a fish that was nearby, and start cleaning it, which was not observed with these two fish. They spent 0.7% and 1.0% of their time eating parasites off fish respectively. According to Deloach and Humann (1999), *P. paru* grow out of their cleaning stage around 7cm. Interestingly, observations of these 2 individuals may show that their estimate may be slightly higher than the true cleaning threshold size. Since these fish were not representatives of the cleaner demographic, observations of these stations were terminated. For this reason, only 2 surveys were made at each of their locations, just to make sure it was not a one day occurrence. The data from these 2 locations was not used in this report.

When stations were not busy, the french angel would spend its time feeding on algae. On some occasions, when one individual arrived for cleaning, other clients would congregate around the cleaner, causing competition for the cleaner's service. 7 clients were once observed vying for the attention of the single angelfish at station 6. This shows that this cleaner was in high demand at the time.

This data shows that Juvenile *P. paru* are an important cleaner species around the Yellow Submarine Pier, equally as important as Pederson's cleaner shrimp, due to the large number of species cleaned and compared to the data of other cleaner species. 82% of the clients cleaned arrived specifically for cleaning, which indicates a high demand for cleaning services. On average, 1 individual was cleaned every 3 minutes, with an average cleaning time of 36 sec per client. From the data, it appears that the juvenile french angels spend about 19.5% of their time cleaning, which is a large portion of its day. No angelfish were seen on the reef, which may indicate that their distribution is limited by habitat. Therefore, while they fill an important cleaner role near the Yellow

Submarine reef in the shallows, they may not be significant on Bonaire as a whole, since the habitat in which they are found does not appear to be common. However, further research would clarify this.

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Appendix 1. Ranking of Client Species

Species	Time Cleaned (sec)	% of Cleaning	Count of Sessions	Average session length (Sec)	Client Niche	% Frequency in Bonaire (REEF)
Caesar Grunt	1125	16.69	6	187.5	Digging Invertevore	48.1
Banded Butterfly	1033	15.33	7	147.6	Coralivore	92.0
Ocean Surgeon	898	13.33	50	17.96	Herbivore	92.8
Blue Tang	746	11.07	15	49.73	Herbivore	98.1
Yellow Goatfish	539	8.00	13	41.46	Benthivore	97.7
Four Eye Butterfly	416	6.17	4	104	Coralivore	96.7
Queen Parrot	410	6.08	12	34.17	Herbivore	96.5
Stoplight Parrot	396	5.88	19	20.84	Herbivore	98.2
Yellowfin Mojarra	308	4.57	4	77	Benthivore	97.3
Sergeant Major	249	3.69	10	24.9	Herbivore	97.4
Princess Parrot	120	1.78	15	8	Herbivore	95.6
Yellow Tail Parrot	116	1.72	5	23.2	Herbivore	59.5
Rainbow Parrot	97	1.44	6	16.17	Herbivore	14.0
Spotted Goatfish	66	0.98	4	16.5	Benthivore	66.8
Spanish Hogfish	64	0.95	4	16	Carnivore	94.7
OrangeSpotted Filefish	63	0.93	1	63	Benthivore	61.6
Spotted Trunkfish	43	0.64	4	10.75	Benthivore	63.4
Schoolmaster	18	0.27	1	18	Carnivore	96.6
White Grunt	10	0.15	1	10	Digging Invertevore	1.8
Smooth Trunkfish	6	0.09	1	6	Benthivore	95.3
Dusky Damsel	6	0.09	1	6	Herbivore	59.5
French Grunt	5	0.07	1	5	Digging Invertevore	97.0
Trumpetfish	4	0.06	1	4	Carnivore	95.4
SharpeNose Puffer	1	0.01	1	1	omnivore	93.6
Grand Total	6739	100	186	36.2		

Size Distribution of *Spirobranchus giganteus* in Bonaire: Is There a Benefit of Recruitment to Live Coral?

Laura Nygaard

Abstract

Spirobranchus giganteus is a tube-dwelling polychaete more commonly known as the Christmas tree worm. *S. giganteus* larvae are planktonic, which is followed by benthic settlement and development into a sessile adult. It has been shown that chemical and physical cues produced by live coral and adult *S. giganteus* attract larvae to settlement sites. In fact, it has been postulated that there may be a mutualistic relationship between *S. giganteus* and live coral. However, settlement of *S. giganteus* on coral rubble has been noted in the field. The aim of this study is to investigate whether there is a relationship between size of *S. giganteus* and substratum settlement type on the coral reefs of Bonaire.

The hypothesis under examination in this study states that *S. giganteus* settled on live coral will be larger than *S. giganteus* settled on rubble. The measurement chosen for this study was the diameter of the orifice of the calcareous tube, since it has been shown that this is a good estimate for overall size of the polychaete. The diameter of the orifice of *S. giganteus* was significantly greater for individuals living on rubble (0.510 cm) than individuals living on live coral (0.457 cm). The species of coral that *S. giganteus* settled on also appeared to affect the orifice diameter. Individuals on *Agaricia agaricites* were significantly smaller than individuals settled on both *Montastrea annularis* and *Siderastrea siderea*. These results may indicate that the interactions between *S. giganteus* and live coral, such as extracoelenteric digestion and sweeper tentacles, may be disruptive enough to cause a lower size distribution of polychaetes on that substrate when compared to rubble.

Introduction

Spirobranchus giganteus, of the Class Polychaeta, lives in tropical and subtropical waters worldwide (Marsden and Meeuwig 1990, Dai and Yang 1995). *S. giganteus* reproduce via broadcast spawning, expelling their gametes into the water column. Within 24 hours of fertilization, *S. giganteus* become trochophore larvae, and move passively about on oceanic currents (Lacalli 1984, Marsden 1987, Hunte *et al.* 1990a, Marsden 1991). After the planktonic larval stage, the polychaete metamorphoses into the adult form and settles onto the substratum to begin a sessile benthic life (Marsden 1987, Hunte *et al.* 1990b, Hunte *et al.* 1990b, Marsden *et al.* 1990, Marsden 1991). The polychaete builds a calcareous tube directly onto the surface of a live coral colony (Dai and Yang 1995) or, in some cases, a non-living, sturdy substrate (personal field observations). If *S. giganteus* settles on live coral, the calcareous tubes become covered with live coral polyps as the coral continues to grow (Hunte *et al.* 1990a, Dai and Yang 1995, Nishi and Nishihira 1996).

The specific cues that attract larvae to particular settlement sites or to what extent the larvae are capable of responding to them is not clearly understood (Hunte *et al.* 1990b, Hunte *et al.* 1990b, Marsden *et al.* 1990, Marsden 1991). However, larvae of *S. giganteus* have been found to be capable of swimming constantly at speeds great enough to control their vertical position in conditions found in the ocean (Marsden 1987), and are further able to control their

vertical position by adjusting sinking rates (Pernet *et al.* 2006). Lab studies have also indicated that *S. giganteus* larvae respond selectively to light and chemical cues, such as dissolved materials that emanate from live coral and adult *S. giganteus* (Hunte *et al.* 1990a, Marsden *et al.* 1990, Marsden 1991).

Field observations have indicated that there are non-random distributions of *S. giganteus* in natural oceanic environments. In the Caribbean, a settlement preference for coral species such as *Diploria strigosa* and *Montastraea annularis* is exhibited (Hunte *et al.* 1990b, Hunte *et al.* 1990b, Marsden *et al.* 1990, Marsden 1991). It has been suggested that this preference is probably adaptive (Hunte *et al.* 1990a, Hunte *et al.* 1990b, Marsden *et al.* 1990). There are no studies on whether settling on live coral might convey an advantage to *S. giganteus*, or how this impacts the coral, but it has been postulated that the association between live coral and *S. giganteus* is mutualistic (Hunte *et al.* 1990a, Hunte *et al.* 1990b, Marsden *et al.* 1990, Dai and Yang 1995). The coral may provide support and protection for the polychaete, and *S. giganteus* may provide the coral polyps with better water circulation for feeding and a refuge from predators such as sea stars (Hunte *et al.* 1990a, Marsden *et al.* 1990, Hunte *et al.* 1990b, Dai and Yang 1995).

S. giganteus filter feed by preferentially selecting particles from the water with their two protruding radioles (Brusca and Brusca 2003). As the polychaete grows in size, the particles they collect progressively get bigger, ranging from those as small as bacterial

floc to as large as zooplankton (Toonen 2002). In order for *S. giganteus* to continue growth, particles of adequate size must be present in the water column (Toonen 2002). If there is no difference in particle sizes in the water column throughout the benthic habitat, then growth could be affected by substrate choice rather than food availability. Thus, provided the food particles present in the water column are uniform throughout the reef system in Bonaire, if a size difference between *S. giganteus* settled on live coral versus rubble substrates is found, it may indicate that interactions taking place between polychaete and settlement substrate may influence overall growth. For example, it may be possible for *S. giganteus* to exploit water currents produced by coral polyps for food collection, thus enhancing resources available for the polychaete to potentially delegate to growth.

The aim of this study is to investigate whether *S. giganteus* individuals grow to a larger size on live coral versus rubble substrates. The hypothesis being tested is that *S. giganteus* living on live coral will be larger than *S. giganteus* living on coral rubble. The hypothesis is formed based on the possibility of a mutualistic relationship between live coral and *S. giganteus* that would result in increased growth and thus larger body size for the polychaete. The size of the orifice of the calcareous tube of *S. giganteus* is a reasonable estimate for overall size of the polychaete (Nishi and Nishihira 1996) and is used in this study to compare size distribution. Thus, the relationship between size of *S. giganteus* and settlement substrate type will be investigated by comparing tube orifice diameters of *S. giganteus* settled on live coral to those settled on coral rubble.

Methods

Study sites

The study site was a central location on the west coast (leeward side) of Bonaire, Netherlands Antilles, near the Yellow Submarine Dive shop pier, extending about 500 m from the Harbor Village Marina to Playa Lechi. It is assumed that there is adequate water mixing in the water column surrounding the coral reefs of Bonaire, which would subject all individual *S. giganteus* to the similarly sized food particles, effectively eliminating this variable from limiting growth.

Survey methods

To ensure random sampling, random numbers were used to dictate the starting point for each survey. One random number yielded the point of entry from shore, while the other gave the depth contour at which the transect belt was conducted. The shore entry points were marked by the light poles situated

along the boardwalk, because they are approximately 25 meters apart and clearly visible from the water. These poles were assigned numbers between one and twenty-two, which were then entered into the random number function in Microsoft Excel to generate random shore entry points. The random depth contours surveyed were between 8 and 20 meters, in increments of two meters. Once the shore entry point was reached, a compass heading was taken and divers entered the water and swam down to the depth contour on the reef. The divers then turned 90 degrees to the left to begin the belt transect. The first 40 polychaetes encountered, 20 each on live coral and rubble, were measured for their orifice diameter in a two meter wide belt transect.

Substrate type for *S. giganteus* was classified as live coral if the calcareous tube was completely overgrown by live coral polyps and rubble if the calcareous tube was not overgrown by live coral and thus clearly visible. The orifice was measured after the polychaetes retracted their radioles. To accomplish this, the light levels and water column within the vicinity were altered by a simple movement of the diver's hand. With the orifice thus exposed, stainless steel Vernier calipers were used to measure the diameter to the nearest 0.05 cm. Finally, species of live coral was recorded, if applicable.

Statistical analysis

Statistical analyses were run using StatView version 5.0.1 (SAS) on a personal computer. A one-way ANOVA (analysis of variance) was used to test the difference in orifice diameter of *S. giganteus* settled on live coral versus rubble substrates. Secondly, the effect of live coral species on the orifice diameter of *S. giganteus* was compared using a one-way ANOVA followed by a post-hoc analysis. Fisher's PSLD (protected least significant difference) test was used to determine where there were differences between pairs of coral species.

Results

Orifice diameter of *S. giganteus* compared to substrate type

Five-hundred- and-fifty-eight individual *S. giganteus* were surveyed; 278 *S. giganteus* on rubble substrates and 280 *S. giganteus* on live coral. The average orifice diameter for *S. giganteus* on rubble substrates was larger (0.510 cm) than the average orifice diameter on live coral (0.457 cm) (Fig. 1). The ANOVA test indicated that the relationship was highly significant (Table 1).

Table 1. ANOVA table comparing the orifice diameter of *S. giganteus* on live coral and rubble substrates ($\alpha = 0.05$).

	DF	SS	MS	F-value	P-value
Substrate	1	0.388	0.388	18.524	<0.0001
Residual	556	11.649	0.021		

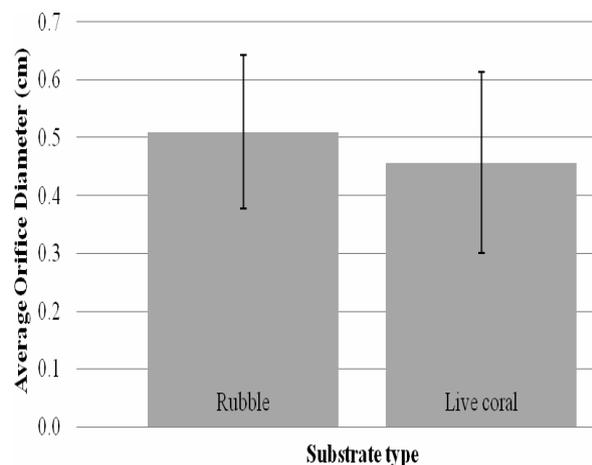


Figure 1. Average orifice diameter of *S. giganteus* (\pm SD) on live coral versus rubble substrates. Sample size (n): rubble=278, live coral=280.

Orifice diameter of *S. giganteus* on live coral substrate compared based on coral species

The live coral survey consisted of 280 *S. giganteus* settled on 9 different species of coral: *Agaricia agaricites*, *Diploria strigosa*, *Montastraea annularis*, *Montastraea cavernosa*, *Millepora alcornis*, *Millepora complanata*, *Porites astreoides*, *Siderastrea siderea*, and one unknown (Figure 2). The ANOVA test indicated that coral species was a significant factor ($p < 0.0006$). Fisher's post hoc analysis indicated that the average orifice diameter was significantly smaller for *S. giganteus* settled on *A. agaricites* (0.39 cm) when compared with *M. annularis* (0.47 cm), and *S. giganteus* on *A. agaricites* was significantly smaller than individuals on *S. siderea* (0.63 cm) (Appendix A). There was no significant difference reported between orifice diameters of *S. giganteus* settled on live coral when the other species were compared in pairs.

S. giganteus exhibited a settlement preference for *Montastraea annularis*, with 60.9 percent of the total polychaetes surveyed settling on that species of coral (Table 3), followed by *P. astreoides* (17.9 %) and *A. agaricites* (11.9%). The other coral species accounted for less than 2% of the total number of *S. giganteus* surveyed.

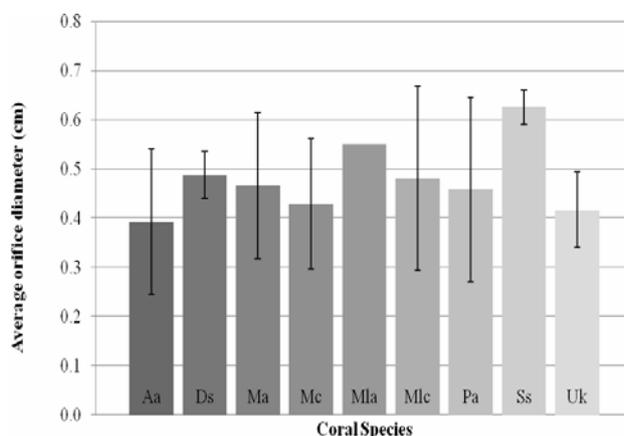


Figure 2. Average orifice diameter (\pm SD) for *S. giganteus* on live coral species: Aa=*Agaricia agaricites*, Ds=*Diploria strigosa*, Ma=*Montastraea annularis*, Mc=*M. cavernosa*, Mla=*Millepora alcornis*, Mlc=*M. complanata*, Pa=*Porites astreoides*, Ss=*Siderastrea siderea*, Uk=unknown. Sample sizes (n): Aa=33, Ds=4, Ma=170, Mc=7, Mla=1, Mlc=10, Pa=50, Ss=2, Uk=3.

Discussion

The overall size of *S. giganteus* appears to be influenced by substrate type. The polychaetes settled on coral rubble substrates were found to have a larger orifice diameter, which is known to be a good estimate for overall size (Nishi and Nishihira 1996). Previously it had been postulated that *S. giganteus* is an obligate associate of live coral (Marsden *et al.* 1990). Based on the results of this study, that relationship is now in question. It had also been postulated that the relationship between *S. giganteus* and live coral may be mutualistic (Dai and Yang 1995). While a mutualistic relationship may be possible, it appears that *S. giganteus* living on coral rubble have a larger orifice diameter, and thus a larger overall size, than those on live coral in Bonaire. Thus, given the results that *S. giganteus* are larger on rubble versus coral substrates, the possibility of a mutualistic relationship between *S. giganteus* and live coral is brought into question.

There are many aspects of the relationship between *S. giganteus* and live coral that warrant further investigation. It may be possible that live coral is actively employing defensive techniques, such as extra-coelenteric digestion and sweeper tentacles, against *S. giganteus* to try and break down the calcareous tubes that the polychaetes build on live coral polyps. All corals are able to exude digestive organs called mesenterial filaments through the mouth cavity or the

Table 2. ANOVA table comparing the orifice diameter of *S. giganteus* settled on 9 species of live coral ($\alpha = 0.05$).

	DF	SS	MS	F-value	P-value
Coral spp.	9	0.625	0.069	3.333	0.0006
Residual	548	11.413	0.021		

Table 3. Coral species distribution as related to number of *S. giganteus* surveyed (*n*), the percentage of *S. giganteus* settled on each species of coral based upon the total number surveyed (%), and average orifice diameter (*d*, in

Coral species	<i>S. giganteus</i>		<i>d</i>
	<i>n</i>	%	
<i>Agaricia agaricites</i>	33	11.9	0.392
<i>Diploria strigosa</i>	4	1.4	0.487
<i>Montastraea annularis</i>	170	60.7	0.466
<i>Montastraea cavernosa</i>	7	2.5	0.429
<i>Millepora alcicornis</i>	1	0.4	0.550
<i>Millepora complanata</i>	10	3.6	0.480
<i>Porites astreoides</i>	50	17.9	0.458
<i>Siderastrea siderea</i>	2	0.7	0.625
Unknown	3	0.9	0.417

body wall (Sebens and Miles 1988). Mesenterial filaments are a technique used to protect corals from overgrowth by other sessile benthic organisms (Lang, 1973). These filaments can be deployed within hours of first contact between two species of coral, and actively digest the tissues of opposing corals (Chornesky 1983). It seems reasonable that mesenterial filaments may be deployed by live corals against *S. giganteus* when it settles on live coral. Given the commonality of ions that are used to form the tube of *S. giganteus* and the coral skeleton, it may be possible that extracoelenteric digestion could damage the calcareous tube of the polychaete. This action may force *S. giganteus* to devote more energy towards maintaining the structure of its tube, and thus consume resources that could otherwise have been devoted to growth. In relation to the coral, expending excess energy to break down the tube may be expensive, and may divert energy away from other processes.

In contrast to mesenterial filaments, sweeper tentacles are not employed by all coral species, but development is known to be induced once contact with opposing sessile organisms is made (Chornesky 1983). Sweeper tentacles can be up to five times longer than normal feeding tentacles, and can cause tissue necrosis through contact due to the higher number of stinging nematocyst cells they contain (Sebens and Milies 1988). These tentacles may be employed

as a strategy for disrupting the growth of *S. giganteus*. *A. agaricites* is known to use this defense mechanism, whereas the presence of sweeper tentacles is not known to exist in *M. annularis* or *S. siderea* (Chornesky 1983). This is interesting to note, because the development of sweeper tentacles may be a contributing factor as to why the orifice diameter was found to be significantly smaller for *S. giganteus* settled on *A. agaricites* compared to that of *S. giganteus* settled on both *M. annularis* and *S. siderea*. When different scleractinian corals were compared for aggressiveness, it was found that *M. annularis* was highly aggressive, *A. agaricites* moderately so, and *S. siderea* not very aggressive (Dominguez and Horta-Puga 2001). It may be possible that sweeper tentacles are able to digest the calcareous tubes of *S. giganteus*, though to what extent needs further investigation.

The feeding strategies employed by live coral and *S. giganteus* also raise more questions. *S. giganteus* employ a filter feeding technique in which they generate their own feeding currents that drive water upward through the branches of the radioles (Brusca and Brusca 2003). It may be possible that the feeding currents generated by live coral polyps cannot be exploited by *S. giganteus*, and may in fact interfere with the feeding currents generated by *S. giganteus*. This could possibly make food collection less efficient for the polychaete when settled on live coral, and may

impair growth. This may result in smaller *S. giganteus* found on live coral compared to rubble substrates. It could be possible that *S. giganteus* on coral rubble have unimpeded access to food particles in the water column, and thus have increased feeding efficiency over those polychaetes settled on live coral.

In conclusion, the results of this study do not support the hypothesis that *S. giganteus* settled on live coral substrates will be larger than those settled on rubble substrates. There is a significant difference between the orifice diameters of *S. giganteus* settled on live coral versus rubble substrates, with larger polychaetes found settled on the latter. This study also found a significant difference in orifice diameter of *S. giganteus* settled on live coral between different species of coral. There was a difference between orifice diameter of *S. giganteus* settled on *A. agaricites* compared to *M. annularis*, and also *A. agaricites* compared to *S. siderea*. In both cases, *S. giganteus* were found to have smaller orifice diameters when settled on *A. agaricites*. More research is needed to explore what interactions are actually happening between *S. giganteus* and live coral.

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Appendix A.

Fisher's PLSD for Column 2

Effect: Column 3

Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
Aa, Ds	-.095	.162	.2491	
Aa, Ma	-.074	.058	.0132	S
Aa, Mc	-.036	.127	.5768	
Aa, Mla	-.158	.311	.3189	
Aa, Mlc	-.088	.110	.1198	
Aa, Pa	-.066	.069	.0611	
Aa, Ss	-.233	.223	.0409	S
Aa, Uk	-.024	.185	.7962	
Ds, Ma	.021	.155	.7865	
Ds, Mc	.059	.192	.5459	
Ds, Mla	-.063	.342	.7195	
Ds, Mlc	.007	.181	.9351	
Ds, Pa	.029	.159	.7153	
Ds, Ss	-.138	.265	.3081	
Ds, Uk	.071	.234	.5513	
Ma, Mc	.038	.118	.5311	
Ma, Mla	-.084	.307	.5913	
Ma, Mlc	-.014	.100	.7849	
Ma, Pa	.008	.049	.7440	
Ma, Ss	-.159	.218	.1521	
Ma, Uk	.050	.178	.5850	
Mc, Mla	-.121	.327	.4657	
Mc, Mlc	-.051	.151	.5026	
Mc, Pa	-.029	.124	.6394	
Mc, Ss	-.196	.245	.1162	
Mc, Uk	.012	.211	.9117	
Mla, Mlc	.070	.321	.6681	
Mla, Pa	.092	.309	.5584	
Mla, Ss	-.075	.375	.6940	
Mla, Uk	.133	.353	.4583	
Mlc, Pa	.022	.106	.6832	
Mlc, Ss	-.145	.237	.2296	
Mlc, Uk	.063	.201	.5366	
Pa, Ss	-.167	.221	.1375	
Pa, Uk	.041	.182	.6550	
Ss, Uk	.208	.279	.1433	

Reproductive Behavior in *Abudefduf saxatilis*: The Relationship Between Nest Location, Brood Size and Aggression

Sarah Marr

Abstract

This study investigated the reproductive behavior of the Caribbean Sergeant Major, *Abudefduf saxatilis*. The aim was to identify the possible relationships between nest locations, brood size and aggression rates in males when guarding their eggs. Surveys were conducted using Sergeant Major nesting aggregations located on a group of 5m deep mooring blocks on Bonaire, Netherlands Antilles. As brood size increased, aggression rates (attacks/min) also significantly increased ($R^2 = 0.0492$). The benefits of protecting the brood from intruders may outweigh the risks to the individual for large broods. Aggressiveness can also be a behavioral trait preferred by females when choosing a nest to lay their eggs. Therefore males who exhibit greater aggression may be more reproductively successful. Aggression rates significantly increased for individuals nesting on or near the upper level on the mooring blocks ($t = 0.00045$; $p < 0.05$). Although the number of other fish visiting the different areas of the mooring blocks was not counted, the general impression was that the upper portions of the blocks were subject to more traffic from other fish. The results support the finding that aggression rates increased for nests located in the higher positions because these males may have been given more opportunity to defend their eggs. No significant relationship was found between nest location and brood size. Nest location did not appear to be important in determining patterns of female egg-laying suggesting that male choice, rather than nest choice is the driving factor.

Introduction

Coral reefs are one of the most beautiful and threatened marine ecosystems on the planet. They are home to a diverse array of underwater life such as fish, algae, and corals (Morberg 1999). Perhaps one of the most obvious sights is the variety of fish that glide through the water column. A family often found in great abundance in the Caribbean Sea is Pomacentridae, which consists of many different species of damselfish. Fish in this family are noted for their relatively small size yet surprisingly territorial and aggressive behavior. Sergeant Majors (*Abudefduf saxatilis*) are approximately 15-18cm long with yellow coloration along the dorsal and white along the ventral section. There are also five prominent vertical black bands on the body (Deloach 1999). This species of damselfish normally occupies shallow areas, the forereef wall, and the lagoon portion of the reef (Ormond 1996). Sergeant Majors swim through the water column by propelling themselves with their pectoral fins (Myrberg 1967). The majority of Pomacentrids vigilantly guard their small gardens of turf algae which they utilize as a food source. However, Sergeant Majors do not defend turf gardens and only approximately ten percent of their diet consists of plant life (Deloach 1999). Instead, the majority of this species' diet is made up of benthic invertebrates, zooplankton, eggs and the occasional small fish. Another unique behavior of the Sergeant Major is its tendency to swim in schools for improved feeding efficiency, while most other damselfish tend to be solitary (Fishelson 1974).

Although Sergeant Majors do not display territo-

rial behavior around turf gardens, males become quite aggressive when guarding their nests of eggs. All species of damselfish are benthic egg brooders, laying their eggs on a hard substrate (Deloach 1999). To begin the course of reproduction the male Sergeant Major must first select a proper site on which to place his nest. The male Sergeant Major typically chooses a hard substrate and works to clear the substrate of unwanted debris, rubble, and other sea life by nipping with his mouth and fanning it with his fins to ensure a clean nest area (Fishelson 1970). Once the male has sufficiently cleared his territory for egg laying he must work to attract a female (Prappas 1991). Male Sergeant Majors in a reproductive state will take on a dark blue coloration (Bessa 2007). They initiate courtship behaviors by performing a "signal jump" which serves to grab a female's attention and to draw her to his nest site (Prappas 1991). This signal jump usually consists of the male damselfish swimming rapidly upward in an undulating manner and then returning to his nesting site (Prappas 1991). Once the female chooses a mate, she deposits her eggs by dragging her urogenital papilla along the substrate, followed by the male damselfish doing the same in order to fertilize them (Prappas 1991). Males must guard their nests from other opportunistic males who try to sneak in and deposit their gametes before the original male has a chance (Piciulin 2004). Damselfish can lay up to 20,000 eggs per nesting cycle. High fecundity has evolved to overcome high larval mortality rates (Robertson 1993, Deloach 1999). Once the eggs are fertilized, the male Sergeant Major cares for the nest and guards the eggs until they hatch. Males will

vigorously defend their fertilized eggs and are often successful at dispelling intruders, which can include conspecifics as well as other fish (Myrberg 1974). However, large groups of predators can overwhelm the damselfish's defenses (Foster 1987). Sometimes male Sergeant Majors have even been known to cannibalize their own eggs, a behavior scientists do not fully understand. It is speculated that filial cannibalism may be an act to offset the energetic costs of parenthood (Manica 2002, 2004, Cheney 2007). Conspecific rivalry occurs for nesting space, position on the reef, nest substrate type, and available females. All these factors ultimately influence reproductive success. The purpose of this investigation is to examine the relationship between nest location, size and male aggression in *Abudefduf saxatilis*.

Hypotheses

- H₀₁:** There is a significant difference between nest size and rate of aggression (attacks/min).
- H₀₂:** There is a significant difference in rate of aggression (attacks/min) between nests located in high or low nesting areas.
- H₀₃:** There is a significant difference in nest size between nests located on the upper side, lower side or top of the nesting areas.

Materials and Methods

Study Area

Observations were made at Yellow Submarine dive site (12°09'36.38"N, 68°16'55.43"W) in Bonaire, Netherlands Antilles. A 5m deep group of mooring blocks on the northern end of the shallow lagoon area was selected for observation. The mooring blocks

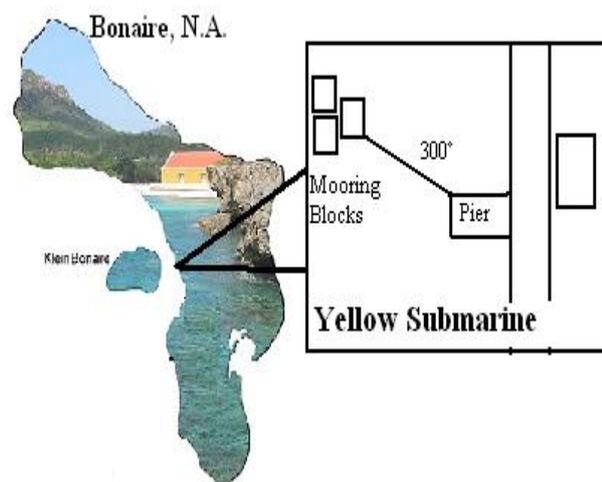


Figure 1. Site map of Bonaire and mooring block nesting area for Sergeant Major

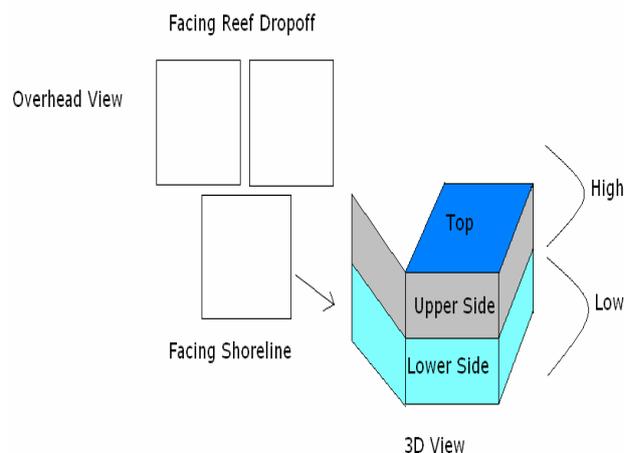


Figure 2. Spatial positioning of the mooring blocks used as nesting sites by Sergeant Majors. The 3D diagram of a mooring block shows the different nest location categorizations.

were visited repeatedly for the duration of the study (Fig. 1). Mooring blocks were laid in a triangular formation (Fig. 2) with nests located on all sides of the blocks. Mooring blocks were chosen as study sites because of their uniformity and ease of access from shore. Each mooring block was made of the same material and gave the same possible amount of space and substrate surface to each male looking for nest space. Each mooring block was also subject to the same environmental conditions such as currents and food supply. All observations were made using SCUBA.

Data Collection

For nest observed, the location on the mooring block was recorded on a detailed diagram (Fig. 2). The available space on the mooring blocks was divided into three possible locations: lower, upper and top (Fig. 2). Length and width of each nest were measured with a plastic ruler without harming the eggs and the area of the nest was calculated assuming a rectangular shape (which approximated the shape of most of the nests observed). Nest area was used as a proxy for brood size. Individual nests were observed for 3-minute intervals. During this time period all intra and inter-specific attacks by the male Sergeant Major were recorded. Behaviors counted as attacks included darting, nipping, and chasing the intruder away from the nest.

Data Analysis

Correlation coefficients were used to assess the relationship between average attack rate and brood size. A two tailed t-test, assuming unequal variance,

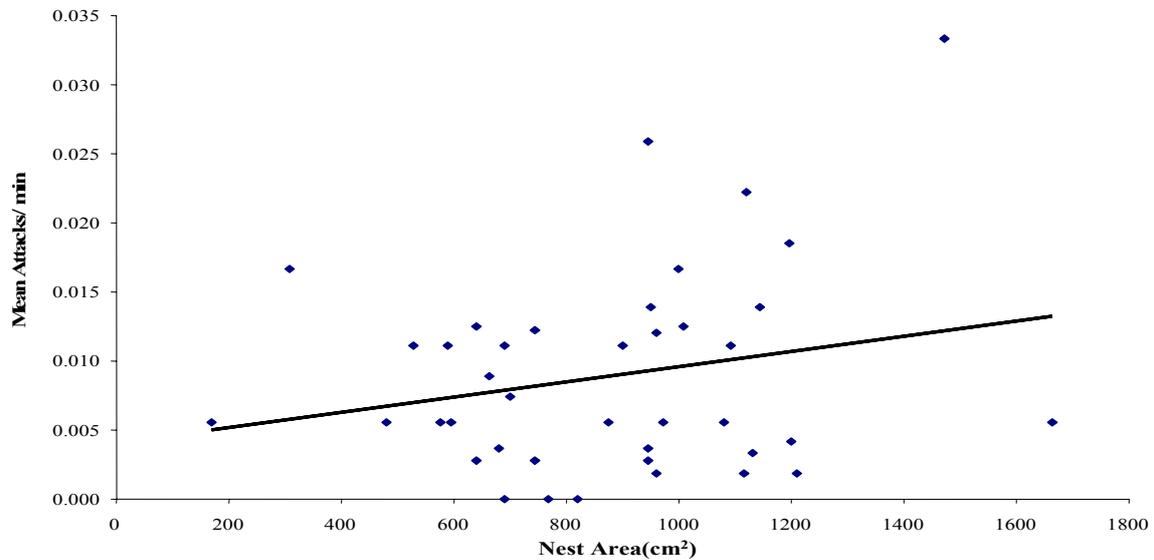


Figure 3. Relationship between Sergeant Major nest area and mean number of attacks per minute by the fish (n=40; $R^2= 0.0492$).

was used to test the difference in attack rate for fish with nests in high and low locations on the mooring block. A single factor ANOVA was used to test the differences between nest location and nest area (brood size).

Results

Nest Size and Aggression Rates

Forty nests (n=40) were surveyed during this study. There was a positive correlation between nest size and aggression rates. As nest area increased, aggression rates also increased ($R^2 = 0.0492$) (Fig. 3).

Nest Location and Aggression Rates

For the purposes of this analysis nest locations were further grouped together into “high” and “low” categories, rather than “upper side, lower side and top” (Fig. 2). There was a significant difference ($t= 0.00045$; $p<0.05$) in aggression rates between individuals nesting in the low and high positions of the mooring blocks. Individuals nesting higher on the mooring block showed a greater rate of attacks per minute (Fig. 4).

Nest Location and Nest Size

Nest locations (lower, upper and top) and brood size did not interact significantly (ANOVA; $p= 0.687$; $p>0.05$). The upper side position had the largest average brood sizes, followed by the top and lower side positions respectively (Fig. 5). It is possible that increased sample size may be needed to answer this

question with more confidence.

Discussion

Nest Size and Aggression Levels

Results supported the hypothesis that, as Sergeant Major’s nest area increases, so do the fish’s aggression rates toward intruders. These intruders included different species of fish as well as other Sergeant Majors. However, attacks toward conspecifics were not separated from attacks on other species in the dataset, which was a drawback of the study. The need for increased aggression by the guarding male due to the larger amount of eggs to protect fits with the idea that larger broods provide the individual with a higher chance of increasing his or her overall fitness, or reproductive success (Brown 1964). A large clutch of eggs indicates that the male has been reproductively successful in attracting females, and may indicate individual fitness (Brown 1964). Defending males must perceive the benefit of having more offspring as outweighing the cost of defending a large nest area. In addition, having more eggs in a nest can draw other Sergeant Major males who will attempt to parasitically fertilize the eggs in the larger nest (Picciulin 2004). Studies agree that being subject to increased parasitic intrusion leads to higher aggression levels from the individual guarding his nest (Picciulin 2004). Further interpretation for the positive correlation between nest size and aggression levels in the Sergeant Major resides in the possibility that males who have more attractive courtship dis-

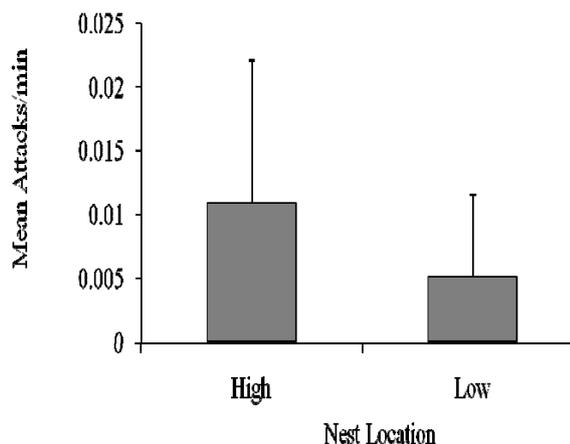


Figure 4. Relationship between nest locations and mean number of attacks per minute (n=40). There was a significant difference in aggression rates in the high nesting positions versus the low nesting positions ($t= 0.00045$; $p<0.05$).

plays and show more aggressive behavior are favorably selected by females for egg deposition. It appears that these males are thought to be more reproductively fit due to these behaviors (Brown 1964). Higher aggression rates may be a male selection criteria for females. Therefore males who display aggression ultimately end up with larger nests and likely higher reproductive fitness.

Nest Location and Aggression Rates

Males with nests located high on the mooring blocks had higher rates of aggression. This result maybe attributed to a greater amount of intruder disturbance in the high positions due to higher fish traffic in these areas. However, relative abundance of fish in the upper and lower areas around the mooring blocks was not measured. The general impression while observing the areas around the mooring blocks was that there was more fish traffic in the upper portion of the block, possibly bringing higher levels of disturbance to the upper nests. Guarding males will not show aggression unless there is an imminent threat which can be feasibly defended (Brown 1964). Those individuals with nests in the upper portions of the mooring block maybe have had more opportunity to display aggression and territorial behaviors than those individuals with nests on the lower area of the mooring block.

Nest Location and Nest Size

Results support the conclusion that nest location on the mooring blocks did not affect brood size. Nest area is really a measurement of egg patch size and it is related to deposition rates by females. Sergeant

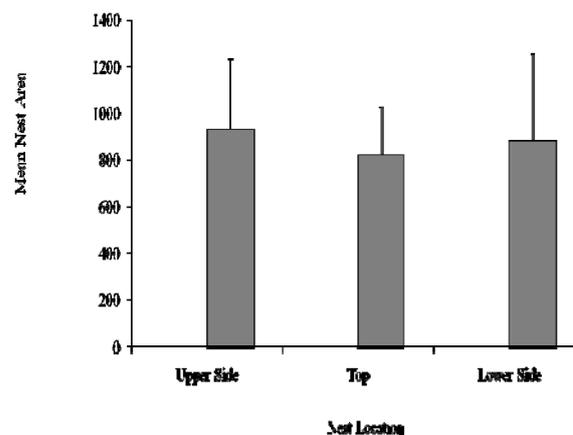


Figure 5. Nest area (brood size) and nest locations (n=40). There was no interaction between nest area and the different nesting location categorizations (ANOVA $p= 0.687$; $p>0.05$).

Majors nest on a lunar cycle, so it can be inferred that nests on the mooring blocks were started at approximately the same time (Foster 1987, Robertson 1990). Therefore, larger brood sizes may be an indication of female preference to a particular nest and may indicate a reproductively successful male with higher fitness. Results of this study would suggest that nest location does not influence female nest choice. A study on the implications of spatial nesting patterns of the Caribbean Sergeant Major found no female nest location preference between peripheral and central areas of a nesting aggregation (Foster 1989). This was attributed to a lack of predatory stresses in nesting areas. However there was a preference for nests which had another nesting neighbor in close proximity, meaning that nests that were closer together were chosen more often by females for egg laying (Foster 1989). Using this information it would be interesting to further investigate the effects of nest proximity on brood size in the Sergeant Major population in Bonaire.

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Effects of Human Recreational Activities on Seagrass Beds in Lac Bay, Netherlands Antilles

Davide Giardini

Abstract

Seagrass beds are important habitats associated with coral reefs. Seagrasses are nursery areas for juvenile fish, and they act as buffering zones by dissipating wave energy (Kemp, 2000). In the proposed study, human related impacts on seagrass beds were studied. Many issues affect seagrass beds health, such as water quality decline due to pollution, water temperature rise due to global warming, dragging of fishing nets, dredging, and human recreational activities (Kemp, 2000). This study aimed to measure the potential effects of human recreational activities on the seagrass beds in Sorobon on Lac Bay, Bonaire, an island of the Netherlands Antilles. In the first part of the study, the activities of windsurfers, swimmers, waders, kayakers, and others were monitored, and quantified. The intent was to determine which of these recreational activities may result in damage to seagrass beds in the study area. The second part of the study compared seagrass beds in areas exposed to high human activity to areas where human activities are less frequent, with the intent to assess the relation of health of the beds with high and low levels of human activities.

The results of this study show that there is a relationship between human recreational activities and the health of seagrass beds. In areas of high human disturbances, both seagrass percent cover and number of leaves are lower than in areas of low human disturbance. This study also shows that not all human interactions interact with the seagrass habitat in the same amount; different recreational activities interact with the seagrasses in different amounts.

Introduction

Mangroves, salt marshes, and seagrasses play a major role in the health of a tropical ecosystem (Eckrich et al. 2000, Kemp 2000, Shorth 1996). Seagrass beds host high levels of biodiversity and are responsible for a great percentage of the total coastal marine primary productivity (Kemp, 2000). Productivity of seagrass habitats enhances the biomass of coral reef fish communities (Kemp, 2000). The seagrass beds are also important shelter, nursery, and foraging areas for many reef fish, which spend their juvenile stages in the seagrass beds and then move on to the reef. (De Meyer, 2008). This is why fish abundance in the seagrass environment is higher than anywhere else (Kemp, 2000). Among the organisms that feed in this environment are marine turtles, in particular green turtles, protected as endangered species (De Meyer, 2008). In addition, seagrass beds reduce the impact of high wave energy to coastal areas by acting as buffering zones and by stabilizing the sea floor with their roots (De Meyer, 2008). They enhance the sedimentation and deposition of suspended particles, thus playing an important role against erosion and water column turbidity (De Meyer, 2008).

Lac Bay, on the windward shore of Bonaire, is the largest inland bay in the Netherlands Antilles, with a flooded area of 7.5 km (De Meyer, 2008). The bay is protected seaward by a fringing reef, which protects it from wave energy, but also allows a continuous water flow between the bay and the open wa-

ters. Because of its environmental importance, Lac Bay is one of the five RAMSAR sites on the island, thus protected by international laws (De Meyer, 2008). In addition to the environmental importance of Lac Bay, tourists are attracted to the bay because of its world-class windsurfing conditions. Other users of the bay include swimmers, kayakers, snorkelers, divers, and beach-goers in general. Most recreational activities in Lac Bay take place in the Sorobon area. The majority of human activity is concentrated at the two main recreational facilities: Jibe City and Bonaire Windsurf Place. Extensive seagrass beds of considerable size are located all along Sorobon beach in front of the facilities. Human interactions with seagrass beds occur throughout day (Personal observation). There is some concern regarding the health of seagrasses at Sorobon due to intense human activity. The purpose of this study is to quantify use of the seagrass beds by human recreational activities and to compare the health of seagrasses in a heavily used area with a less used area. The definition of seagrass health is based on parameters established by Wilzbach et al. (2000) and Beal et al. (2000): percent cover and leaves count.

The main hypothesis of this study is that human recreational activities have an impact on seagrass health. Specifically, I am comparing the percent cover of seagrasses and the number of leaves per meter square in a control area and a heavily disturbed bed.

Methods

The study took place at Sorobon beach, Lac Bay, Bonaire, in the Netherlands Antilles. Extensive seagrass beds flourish close to shore along the beach following the coast contour (Fig. 1). Three major seagrass beds are shown in Fig. 1, Seagrass Bed #1 (furthest right) measures 50 x 30 m; Seagrass Bed #2 (middle) measures 40 x 30 m; Seagrass Bed #3 (furthest left) measures 140 x 40 m. There are 2 objectives in this study: 1) to determine the amount of disturbances by different recreational groups, and 2) to compare seagrass condition in an area of high recreational use with one of low use.

Recreational Use

The goal of this part of the study was to determine the percentage of disturbances out of the total that arose from each one of the recreational activities that were occurring in the seagrass beds. Observations were made from a roof top with a good view of the seagrass bed being monitored. Every 5 minutes the number of subjects physically interacting with the seagrass bed was recorded along with the activity that was being engaged in by the person.

Activities were categorized as wading (walking through or standing on seagrass), swimming (moving through water by means of limbs with any sort of physical damage to seagrass), trampling by windsurfers (walking through seagrass by any individual carrying windsurfing equipment), scarring by windsurfers (physical interaction between surfboards' fin and the seagrass – sometimes viewed as long scars on seagrass beds), anchoring of windsurfing equipment (board-/sail laying abandoned on seagrass), and kayaking (paddling of kayakers through seagrass).

Health of Seagrass Beds

The intent of this part of the study was to determine the health of the high use bed at Sorobon compared to an adjacent bed with little recreational activity (the control site). The control site was chosen based on preliminary observations that indicated that there was little human recreational activities occurring in this seagrass bed. Percent cover and number of leaves per unit area were used as indicators of the health of the seagrass beds.

Percent cover of seagrass was estimated using a 1 m² PVC quadrat further subdivided into 10 x 10 cm (100 cm²) squares with string. Twenty samples were taken from randomly selected areas within each seagrass bed. The purpose was to measure whether there is a difference in seagrass percent cover between disturbed and controlled sites

Number of leaves per m² was also determined. At each of the 20 quadrats, 5 100 cm² squares were ran-



domly selected through a random-number generator and the leaves were subsampled within the squares. The purpose was to measure whether there is a difference in number of leaves per 100 cm² between disturbed and controlled site.

Figure 1. Google Earth view of the study area at Sorobon beach in Bonaire, Netherlands Antilles. Seagrass bed #1 is the control bed, seagrass bed #2 is the heavily used bed and seagrass bed #3 is the next bed located toward the opening of Lac Bay.

Results

Recreational Use

In total, 6 hours of observations were conducted and 436 disturbances to the seagrass beds related to hu-

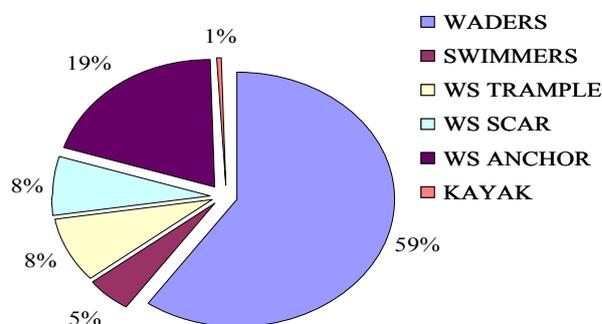


Figure 2. Percentage of total disturbances to

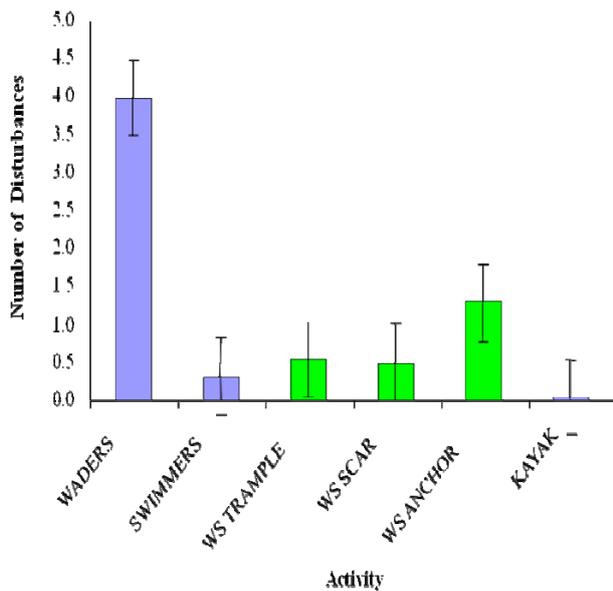


Figure 3. Mean disturbance by activity as determined by observation every 5 minutes.

man recreational activities were recorded. Human recreational activities physically interact with the seagrass beds in different amounts (Fig. 2). The total mean disturbance by waders out of all the recorded observations is the highest percentage (59%).

Anchoring of windsurfing equipment on seagrass beds was 19% of the total disturbances. Scarring by windsurfing over the beds and trampling by windsurfers were both 8% each out of the recorded interactions. Disturbances by kayaking was only 1% of the total.

The mean disturbance per 5 minute interval for each activity is presented in Fig. 3. Waders have the highest disturbance rate, with 4.0 interactions with seagrass beds every 5 minute. Anchoring of windsurfing equipment on seagrass beds occur 1.3 times per 5 minute. Disturbance due to trampling of windsurfers occurs 0.6 times every 5 minute. Disturbance due to scarring by windsurfers of seagrass beds occurs 0.5 times per 5 minute. Disturbance by kayakers is minimal, with 0.05 disturbances occurring every 5 minute.

The different disturbance activities were grouped into the two major recreational users of Sorobon; windsurfers and general beach-goers (Fig. 4). The mean of the disturbance activities per 5 minute for each recreational group was calculated using the following criteria: wading and swimming are activities in which beachgoers interact with the beds; trampling, scarring, and anchoring of equipment on seagrass are ways windsurfers interact. The mean disturbance per 5 minute interval by windsurfers (by factors of trampling, scarring, and anchoring) is 0.8. The mean disturbance per 5 minute interval by beach-

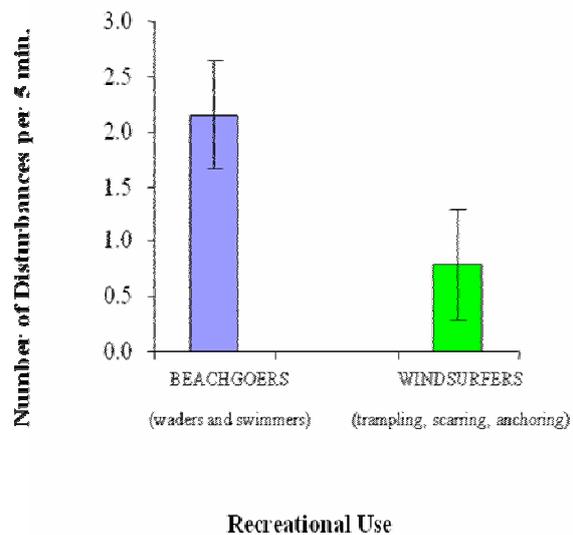


Figure 4. Mean disturbance by recreational users by group as determined by observation every 5 minutes.

goers (by factors of wading and swimming) is 2.2. Kayakers were not kept into consideration due to their low disturbance significance (3 kayakers reported out of 6 hours of observations).

Health of Seagrass Beds

The *disturbed site* (Seagrass Bed #2) was the site of highest recreational disturbance. The *control site* (far left side of Seagrass Bed #1) was the site of lowest recreational disturbance. The first parameter calculated was the percent cover of seagrass from the 20 samples from each one of the two sites. Percent cover was higher in the control site than the disturbed site (Fig. 5). Percent cover in the disturbed site was significantly lower (80.5) than the control site (96.3) based on a one-way analysis of variance (ANOVA, $\alpha = 0.05$). The statistical analysis was calculated using Statview version 5.0.1 (SAS).

The second parameter calculated was the number of leaves per 100 cm² in each of the two sites (Control vs. Disturbed). The mean leaves number is significantly higher in the control site than the disturbed site (Fig. 6). The number of leaves per 100 cm² in the control site was 172.9 whereas the number at the disturbed site was 87.1. The number of leaves per unit area at the control site was nearly double that of the disturbed site.

Discussion

The results of this study show that there is a relationship between human recreational activities and

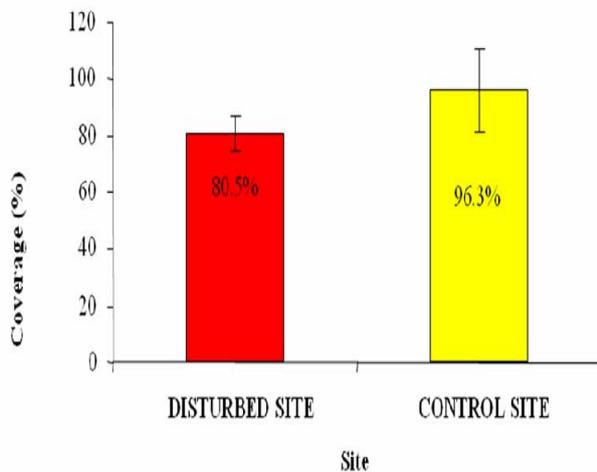


Figure 5. Percent cover of seagrass at Sorobon Beach, Bonaire.

seagrass beds health. In areas of high human disturbances, both seagrass percent cover and number of leaves are lower than in areas of low human disturbance. The results support the main hypothesis of this study; the seagrass beds at Sorobon on Lac Bay are negatively impacted by human interactions.

This study also shows that some activities occur at a higher percentage than others; wading is the highest percent use followed by anchoring of windsurfing equipment on the beds. Other windsurfing activities that occurred less often included trampling of the seagrass and scarring of the beds. Swimming and kayaking appear to be only minor uses, probably due to the fact that water depth on the seagrass beds is too shallow to allow these activities. Among all the categorized types of interaction, wading by beachgoers and anchoring of equipment by windsurfers are the major percent uses of the seagrass beds.

When windsurfing activities are separated from the other beach-going activities it appears that windsurfing occurs less often on a percentage use basis than the other user group. However, damage by each of the user groups was not quantified and it is possible that although windsurfing occurs at a lower percentage of the time that it may cause more damage. The other possibility is also possible, that the other user group could be causing more damage than windsurfers. It is clear that all the groups are impacting and damaging the seagrass bed at Sorobon and that the activities appear to be negatively affecting the health of the seagrass bed as indicated by the lower percent cover and number of leaves in the seagrass

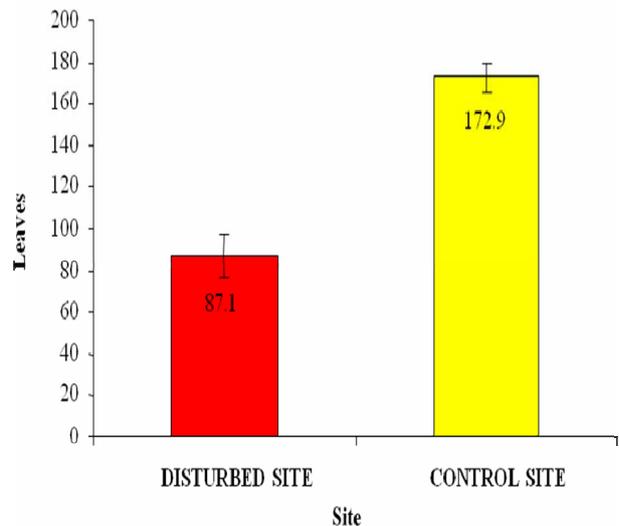


Figure 6. Mean leaves count per 100 cm².

bed with high recreational use.

There are only a few seagrass beds in Bonaire and due to the importance of seagrasses to the coral reef ecosystem; protection from recreational use may be warranted. The health of seagrass beds is much weaker in the bed with high recreational activity, when compared to the bed with low activity. Waders on the seagrass appear to be the highest contributing factor of disturbance. Anchoring of windsurfing equipment on the seagrasses for long periods of time is also a cause of concern. Among the broader water users of the area, general beach-goers have nearly 3 times higher percent usage when compared to windsurfers but the implications of that are not understood.

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The effects of storm damage on reef rugosity and coral species composition in Bonaire, Netherlands Antilles.

Jean Pearson

Abstract

Located below the hurricane belt in the Netherlands Antilles, the island of Bonaire is rarely affected by major storms and high-wave action. In a rare storm event in November 1999, waves generated by hurricane Lenny hit the leeward side of Bonaire causing significant damage to many of the shallow reefs. Shallow reef sites (5-10m) were significantly more damaged than sites at deeper depths (20m) and there was evidence of toppling, sedimentation, and smothering. Little is known about the patterns of successional recovery of corals following hurricane damage in the Caribbean. This study investigated reef rugosity and coral species composition at sites that were damaged by hurricane Lenny versus those that were undisturbed. More than 8 years after hurricane Lenny there was a significant difference in species composition at disturbed and undisturbed sites and a significantly higher rugosity index at undisturbed sites. The recovery success of coral reefs is affected not only by past disturbances, but also by present and future disturbances, both chronic and acute. Storm damage caused by hurricane Lenny may have affected the overall resilience of the reef to anthropological disturbances such as increased eutrophication and sedimentation as well as natural disturbances including global climate change.

Introduction

Although coral reefs of Bonaire, Netherlands Antilles are among the most diverse and well developed in the Western Atlantic region (Bries et al. 2004), coral cover in shallow reef zones has declined significantly since 1980 (Steneck and McClanahan 2005). Coral reef cover decline may be attributed to many environmental and physical processes including coral disease, human activities, global environmental changes, and storm damage (Richmond 1997).

In November 1999, hurricane Lenny passed 200 miles north of Bonaire leaving some reefs on the leeward side of the island severely damaged. The majority of the shallow corals at damaged sites were either covered with sand or deposited on the shoreline or the deeper reef by storm waves, leaving relatively bare substrates at depths shallower than 6 m (Eckrich, personal communication). Reefs were most significantly damaged along westward facing shores, but less affected where the reef was lateral to wave direction or protected by Klein Bonaire (Bries et al. 2004). Heaviest damage was reported along the northern half of the leeward coast (Bries et al. 2004).

Destructive waves associated with hurricanes often cause an increase in bare space and evenness on a reef (Woodley et al. 1981; Hughes and Connell 1999). Rugosity is a measure of evenness and refers to the overall "roughness" or vertical structure of the coral reef substrate and is linked to the complexity of the reef. A high rugosity index indicates high complexity of a reef which in turn may benefit coral recruitment and diversity due to increased types of habitat and places for settlement. This study investigates whether reef rugosity on the leeward side of

Bonaire is less at sites that were heavily damaged by storm waves compared to sites that were not.

Wave energy generated by hurricanes can significantly alter the community composition of reef corals (Woodley et al. 1981; Hughes and Connell 1999). As a result of hurricane Lenny, additional space has become available for settlement of corals, especially in the shallows (~10m) where waves scoured and uncovered a bare solid substratum (Bries et al. 2004). Although there is presumably less spatial competition at these sites, coral recruits are still exposed to waves, sedimentation, and grazing.

The success of coral recruitment by different species of shallow corals has a direct effect on the species composition of a reef. Studies have shown that the type of substrate as well as orientation of the substrate can affect growth and survival rates of coral recruits (Richmond 1997). Laboratory experiments have shown that coral recruits will not settle on loose sandy sediments when solid substrate is available for settlement (Richmond 1997). Other studies suggest that although growth rates are higher for larvae settled on top of the substrata, there is a higher rate of survival among those settled on vertical surfaces and undersurfaces (Richmond 1997; Arnold 2007). A reef with a higher rugosity index may have more perpendicular surfaces and undersurfaces, which have been shown to effect on the success of coral recruitment (Richmond 1997; Arnold 2007), and therefore storm-impacted sites with less rugosity may experience changes in community composition based on their level of recruitment success. According to a report by Bries et al. (2004), the ability of corals to re-colonize depends on the level of spatial competition between

coral and algae, and the availability of coral larvae. The report also suggested that branching acroporids that once thrived in the shallow reefs are unlikely to supply adequate larvae to take advantage of this new open space, and that other fast-growing corals such as *Madracis mirabilis*, or milleporids or agaricids, will. Likewise, a study by Woodley et al. (1981) on the effects of hurricane damage on the reefs of Jamaica found that the recruitment and growth of “hardier,” more fecund species such as *Montastraea annularis* and *Agaricia agaricites*, and encrusting corals may be more dominant in the recovery areas exposed to high wave action.

In a time when unprecedented numbers of coral reefs are declining, it is increasingly important to understand the different components involved in reef health and successful recovery. This study investigates whether storms diminish reef rugosity and affect coral composition in shallow reef zones. The hypotheses tested in this study were that reef rugosity would be less at storm impacted sites, and that coral composition would be different in speciation and abundances at sites that were greatly impacted by hurricane Lenny compared to those that were not. The findings of this study will allow for a better understanding of long-term recovery and changes in community composition of disturbed coral reefs and will facilitate the generation of additional questions concerning coral recovery success both locally and on a regional scale.

Methods

This study was conducted at 6 different sites on the leeward coast of Bonaire, Netherland Antilles. Data were collected from 3 sites that were greatly damaged by hurricane Lenny, and 3 sites that were not greatly affected (Eckrich, personal communication; Bries et al. 2004). Damaged sites included Bari’s reef, Lighthouse Beach, and Cliff, and undisturbed sites included Andrea II, Angel City, and Margate Bay (Figure. 1).

Greatly damaged sites were completely denuded of living corals and sites that were not damaged had an abundance of living shallow corals, including branching corals in the genus *Acropora*, as of December 1999 (Eckrich personal communication).

Abundances, sizes and species of corals were recorded using three randomly placed 10 m x 1 m belt transects at each site. A 10 m transect line was placed randomly on the substrate at a depth from 3 to 6 m and coral colonies were counted and identified. For each colony, the estimated maximum length, width and height was measured with a meter stick or small ruler and recorded. If the belt transect was estimated to be more than 20 percent sand cover, the transect

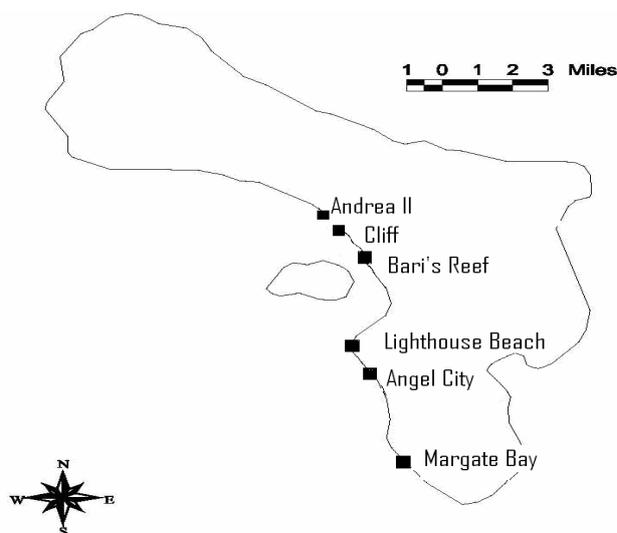


Figure 1. Damaged and undamaged sites on leeward coast of Bonaire, N.A.

line was moved approximately 10 m along the reef parallel to the shore and placed again on the substrate. Multiple transects from each site were taken by swimming an additional 10 fin kicks along the depth contour and starting a new transect line. Three transects were recorded at each damaged site, and due to time constraints, only two transects were recorded for each undamaged site.

At each site, rugosity was measured following methodology similar to CARICOMP (CARICOMP 2001). Two random rugosity measurements were made at each belt transect. A 10 m transect line was stretched taut across the contour of the reef as a guide. Rugosity was measured using a 4 m long brass chain (1.4 cm link size) marked every 10 links with zip ties. Rugosity was measured by laying the brass chain on the reef so that it had continuous contact with the substratum (CARICOMP 2001) and recording the entire length of chain necessary to cover the 10m horizontal distance. Rugosity is determined from the ratio of the length of chain used to 10m (a number greater than 1). The standard issue chain has links 1.4 cm long, so rugosity is calculated by multiplying the total number of links by 1.4 and dividing by 1000.

To determine if there was a difference in coral species composition between sites greatly impacted by hurricane Lenny and those that were not, a two-factor ANOVA was performed on the data in Stat-View. Using Microsoft Excel, a one-factor ANOVA was performed on the data to test if there is a significant difference in reef rugosity at sites damaged by Hurricane Lenny and sites that were not.

Results

Reef rugosity was significantly greater at sites that were not greatly damaged by hurricane Lenny (1.416) than sites that were (1.123, $p = 0.0096$) (Figure 2).

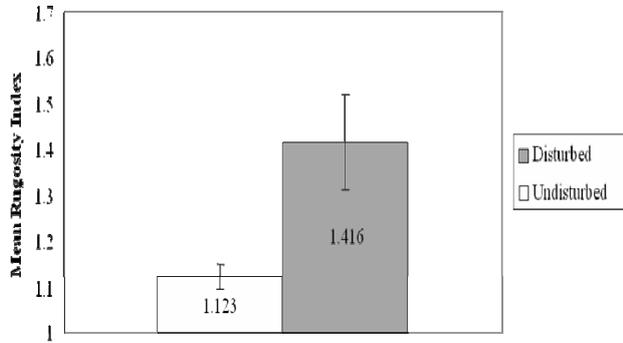


Figure 2. Differences in rugosity at disturbed vs. undisturbed sites ($p=0.0096$)

At damaged sites, 8 species of coral were recorded compared to 15 species recorded at undamaged sites. All the species found at damaged sites were also found at undamaged sites (Figure 3 and 4).

There was a significant difference in species composition between damaged sites and sites that were not damaged ($p=0.0004$) (Figure 5). It was found that *Montastraea annularis* and *Porites astreoides* were the most abundant species at undisturbed sites, whereas *Millepora complanata* and *Agaricia agaricites* were most abundant at damaged sites.

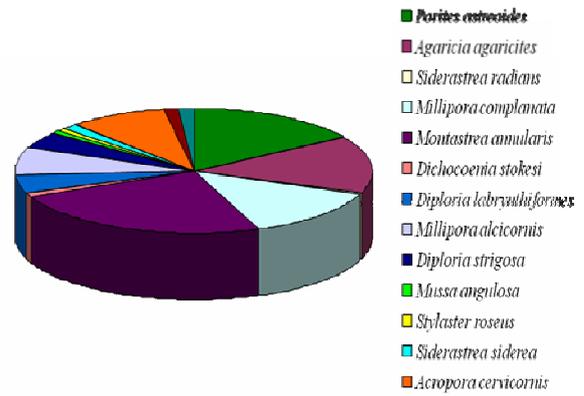


Figure 3. Species distribution at undisturbed sites on leeward shore of Bonaire, NA.

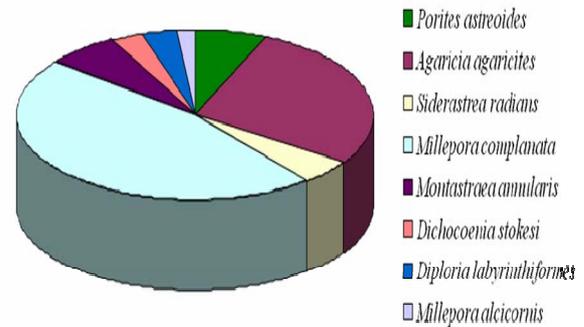


Figure 4. Species distribution at disturbed sites on Bonaire, NA.

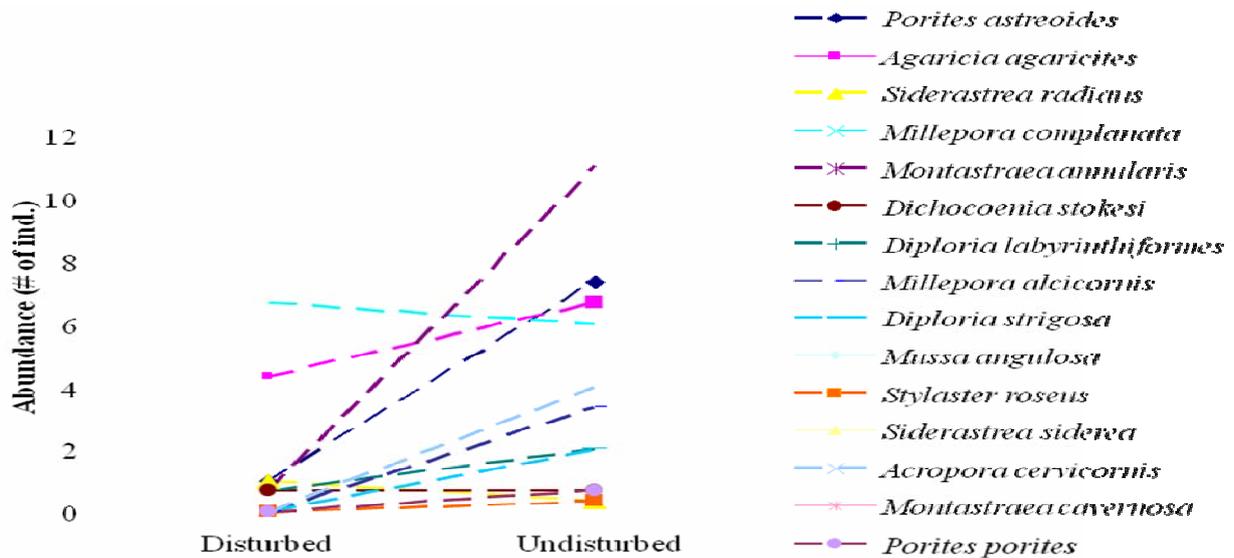


Figure 5. Species abundance at disturbed vs. undisturbed sites ($p=0.0004$)

Discussion

Although this study was conducted more than 8 years after hurricane Lenny passed 200 miles north of Bonaire, the destruction to the shallow reefs on the leeward shore was exceedingly evident. The rugosity of shallow reefs in Bonaire was significantly greater at undamaged sites than damaged sites.

More species of corals were found at undamaged sites and coral composition was significantly different



Figure 6. Transect taken at Andrea II (undisturbed) 4m



Figure 7. Transect at Bari's Reef (disturbed) ~4m

at damaged versus undamaged sites. Recovery times for reefs in the Caribbean that were completely destroyed are estimated to be at least 50 years based on restoration of pre-disturbance coral cover values (Brown 1997). However, the recovery of the reef is affected not only by previous disturbances, but also by present and future disturbances whether acute or chronic. Therefore, because of increased anthropologic disturbances that effect coral reef recovery and regeneration such as eutrophication and sedimentation, it is difficult to estimate recovery rates based on storm damage alone (Brown 1997).

The intermediate disturbance hypothesis proposed by Connell (1978), states that diversity is high-

est at intermediate levels of disturbance that prevent competitive exclusion by the dominant competitor but are too moderate to eliminate most species (Aronson 1995). Jackson (1991) suggests that diversity is maintained by disturbance and recruitment. Woodley et al. (1981) suggests that differing opportunities for sexual and asexual colonization caused by storm disturbance may result in differing successional communities. Coral communities at the damaged sites in Bonaire were dominated by milleporids and agaricids, suggesting that these species may recover more quickly after storms than species such as *Montastraea annularis*, *Porites astreoides* and acroporids that were found in abundance only at undamaged sites. Patterns of succession following disturbances mirror differences in recruitment, colonial propagation, growth rates, aggression, and resilience of different coral reef species against disease and physical disturbances (Jackson 1991). Woodley's observations that *Agaricia agaracites* would be one of the first species to recruit after hurricane damage in Jamaica was also found to be true for Bonaire, although contrary to his suggestions, *Montastraea annularis* was not found to be a dominating species at damaged sites at Bonaire. Similarly, Bries et al. were correct in suggesting that milleporids and agaracids would be the first to expand their coverage onto the new bare substrate, although their suggestion that *Madracis mirabilis* would be among the first to recruit was not supported in this study.

Although it may simply be that more time is required for coral communities at damaged site to return to their pre-disturbance state, it is possible that the species composition has been permanently transformed due to the intensity of the disturbance. It is also possible that the differences seen in species diversity between damaged and undamaged sites is because certain species of corals need a high level of rugosity or complexity to have successful recruitment.

It is also important to note that global climate change may decrease the pH and carbonate ion concentration levels of the oceans. Experiments have shown that decreases in pH inhibit coral accretion rates in laboratory studies (Orr et al. 2005). Disturbed sites that currently have construction projects on their adjacent shorelines might also have a slower rate of recruitment and recovery due to potential nutrient run-off and sedimentation. Although nutrients and sedimentation would have been factors that affect the health of the reef before hurricane Lenny, the damaged caused by Lenny may have reduced the resilience of the reef to other disturbances.

This study raises additional questions concerning the effects of subsequent storms on the health and

survival of the reefs. In the future, long-term studies of reef rugosity and coral composition could be undertaken along Bonaire's entire leeward shore.

Note: Because growth rates of corals in Bonaire are virtually unexplored, this study also looked at the size of abundant coral species at storm-impacted sites in Bonaire and provided an estimate of the rate of coral growth at shallow sites based on size-class observations of young corals at sites completely destroyed by hurricane Lenny. Using data from the four largest individuals of each abundant coral species at damaged sites, minimum coral growth rates were estimated. It was calculated that *Agaricia agaricites* has an annual growth rate of 0.91 cm, *Millepora complanata* grows approximately 2.94 cm/yr, *Montastraea annularis* 0.94 cm/yr and *Porites astreoides* 0.89 cm/yr.

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Ranking Herbivory in Coral Reef Fish

Alejandro Carrera

Abstract

Herbivory grazing patterns by parrotfish, family *Scaridae*, and surgeonfish, family *Acanthuridae*, were investigated on the leeward side of Bonaire, Netherlands Antilles. Due to overfishing, coral disease, declining water quality and global climate changes, coral reefs worldwide are in danger of undergoing phase shifts from coral-dominated to algal-dominated ecosystems (Hughes 2007; Nybakken 2001). When nutrient levels are high, algal communities are highly productive and may outcompete corals (Breeman et al 1994). In healthy coral systems herbivores suppress algal growth and are a key component in preventing phase shifts, thus managing reef resilience (Hughes 2007; Folk and Nystrom 2001).

This study measured herbivory rates and bite sizes of several species of coral reef fishes on the island of Bonaire, Netherlands Antilles. These measurements and species density data (Steneck 2005) were used to rank species according to their level of herbivory. The five selected herbivore species were the terminal and initial phase *Sparisoma viride* (Stoplight Parrotfish), terminal and initial phase *Scarus vetula* (Queen Parrotfish), terminal phase *Scarus taeniopterus* (Princess Parrotfish), *Acanthurus coeruleus* (Blue Tang), and *Acanthurus bahianus* (Ocean Surgeon). Although *Scarus vetula* has the highest grazing rate (# bites/min) and largest bite size (cm²), this study calculates that *Scarus taeniopterus*, due to large densities, are the primary consumers of algae in the waters of Bonaire (cm²/minute/species/100m²), followed by *Scarus vetula* terminal phase and *Scarus vetula* initial phase. As coral reefs are becoming more algal dominated due to nutrient enrichment, knowledge of herbivore ecology and management of herbivore populations is critical to understanding and protecting these threatened ecosystems.

Introduction

Coral reefs thrive in nutrient poor waters and although there are many species of reef-associated algae, algal biomass is limited by these low levels of nutrients and the high levels of herbivory of many reef fish and sea urchins (Nybakken 2001). High levels of herbivory allow corals to dominate the substrate and contribute to the health of coral reef ecosystems (Folk and Nystrom 2001). In modern times, overfishing and nutrient enrichment have led to phase shifts from coral-dominated reefs to algal-dominated reefs (Egan and Tellez 2005). In Jamaica, after an 80 percent reduction in biomass of families *Scaridae* and *Anthuridae* due to overfishing, rapid algal growth ensued, which had devastating effects on the coral reefs (Egan and Tellez 2005). It is proposed that even with nutrient enrichment, phase shifts from coral-dominated to algal-dominated systems may not occur on reefs systems with abundant and diverse herbivorous fish populations (Hughes 2007; Mumby 2004). In healthy coral systems, herbivorous fish biomass is negatively correlated with algal cover, and algae must be consumed in large quantities for herbivores to meet their growth and energy needs (Davis and Kerbs 2004). With coral reef ecosystems becoming dominated by algal growth an important question arises: What is the true effect of herbivores in maintaining algal growth at manageable levels?

In 2005 Dr. Robert Steneck investigated herbivory of reef fish in Bonaire, however bite size and grazing rates for each herbivore species was not

measured (Steneck 2005). Groups of algal consumers were investigated instead (acanthurids, scarids, and yellowtail damselfish; Steneck 2005). When comparing herbivores that remove a substantial amount of algal biomass in their feeding activity, Steneck (2005) found scarids to be the most dominant herbivores on the reefs of Bonaire.

sizes of fish species from members of the families *Scaridae* (parrotfish) and *Anthuridae* (surgeonfish) in Bonaire, Netherlands Antilles. These measurements, combined with species density data from a report by Steneck (2005), were used to rank herbivores according to the mean area of algae consumed per minute per species per 100 square meters. Members of the families *Scaridae* and *Anthuridae* are the most abundant roaming grazers on the reefs of Bonaire and are influential in controlling algal growth (Brostoff and Hixon 1996, Breeman et al 1994). *Scarids* and *Acanthurids* are classified as large herbivores, have extensive foraging ranges and are unaffected by most predators (Carpenter 1986). Although damselfish, family *Pomacentridae*, have the highest abundance on the coral reefs of Bonaire, they were not examined in this study due to their small size, territoriality, and diet of microscopic algae and invertebrates (Birkland 1997, Humann and DeLoach 1999, Steneck 2005). This study tested the null hypothesis is that there is no This study measured grazing rates and bite difference in herbivory among fish species in the families *Scaridae* and *Acanthuridae*. At a time

when the health of coral reefs worldwide is being threatened by eutrophication, information concerning herbivory, and the importance of herbivores in maintaining the health of coral reefs is necessary for biologists and marine park managers in their efforts to understand and protect these threatened ecosystems.

Methods

Grazing rates and bite sizes of herbivorous fish were recorded using visual techniques at two dive sites, Andrea II and Yellow Submarine dive shop, in Bonaire, Netherlands Antilles. Sites were chosen in order to obtain mean grazing rates and mean bite sizes for Bonaire, Andrea II having high fish abundances and Yellow Sub having low fish abundances (Joost DenHaan Unpublished data). All field observations were made from February 2008 through April 2008 on the leeward side of Bonaire.

Observations were made for three species of fish from family *Scaridae*: *Sparisoma viride*, *Scarus vetula*, *Scarus taeniopterus* and two of species from family *Acanthuridae*: *Acanthuridae coeruleus* and *Acanthus bahianus*. Data was collected for both the terminal and initial phase of *Sparisoma viride* and *Scarus vetula*. Collection times were chosen at random between 10:00 and 14:00. Adult individual fish were randomly selected within a 100 m² area of the shallow reef (5 m to 10 m depth). An individual fish was followed for one minute and number of bites was recorded. Also recorded were: time, date, depth, location, substrate bitten, number of damselfish attacks, estimated size and any other significant action such as spawning, actions of territoriality (i.e. chasing, being chased) or cleaning behavior. A 1 meter PVC pipe marked at 10cm intervals was used to estimate fish length (Steneck 2005). Bite size was determined using a clear plastic ruler with 1cm intervals, measuring longest width and greatest length for selected bites for each species. A minimum of ten (10) grazing rates and five(5) bite sizes were measured for each species.

For each species, or phase within a species, the mean bite size was multiplied by mean bites per minute to calculate the mean grazing rate (cm² algae consumed per minute). Mean grazing rate for each species, or phase within a species, was calculated for both sites and used to calculate the mean grazing rate for each species for Bonaire. Once mean grazing rates and mean bite sizes were calculated, fish density data was used to obtain grazing estimates for each species (or phase within a species) for the island of Bonaire. These results were then used to place the selected species, or phase of species, in a ranking of herbivory (cm²/min/species/100m²).

To test for significance the total amount of grazing for each species was calculated using abundance data from three randomly selected sites on the leeward coast of Bonaire (Windsock, Plaza and Forest; Steneck, 2005). These grazing calculations (cm²/minute/species/100m²) were used to rank fish species (and different phases and/or schooling behavior) in relation to their overall grazing ability on the island of Bonaire. A non-parametric Kruskal Wallace ranking test was performed and post-hoc paired comparison were also used to determine where the differences occurred (Espinoza et al 1979).

Results

At both dive sites, Yellow Sub (Table 1) and Andrea II (Table 2), *Scarus vetula* terminal phase had the largest mean grazing rates (28.82 and 30.27 m²/min/individual), and solitary *Acanthurus bahianus* had the lowest mean grazing rates (7.73 and 3.86 cm²/min/individual). When grazing rates from the Andrea II and Yellow Sub dive sites were averaged together (Figure 1), *Scarus vetula* terminal phase had the highest grazing rate at 29.54 cm²/minute/individual, while *Acanthurus bahianus* solitary had the lowest grazing rate at 7.8 cm²/minute/individual.

When bite size was examined, terminal *Scarus vetula* and *Sparisoma viride* clearly had the largest average bite size of all the species included in this study at 1.78 cm² and 1.61 cm² respectively. Even though family *Scaridae* had larger bite sizes than family *Acanthuridae* by an average of 0.94 cm², acanthurids had higher grazing rates than scarids with an average difference of 7.31 more bites per minute when solitary and 19.22 more bites when schooling (Tables 1a and 1b).

Mean densities (Steneck, 2005), grazing rates, and bite sizes were used to estimate the area of algae consumed per minute per species per 100 m². *Scarus taeniopterus*, was the fish species with the highest density included in this study (9.26 individuals per 100m²). When average densities are combined with grazing rates and bite sizes, there is a significant difference among species in the amount of herbivory (p=0.032, Table 2). *Scarus taeniopterus* is the species that consumes the most algae in Bonaire (164.83 cm²/minute/species/100m²). *Acanthurus bahianus* solitary was the species with the lowest density and had the lowest mean grazing rate (bite/min), resulting in this species being the smallest consumer of algae in this study (9.07 cm²/minute/species/100m², Figure 2).

Discussion

The purpose of this study was to rank herbivory among five species of herbivores in the coral reefs of Bonaire to help illustrate the impact they have on the

Table 1: The amount of algae a single individual will consume in a given minute on the reef at Yellow Submarine Dive shop.

	Average Bites Per minute	Average Bites Size cm ²	Bites/ cm ² x Min
<i>Sparisoma viride</i> -- Terminal	5.9	1.78	10.50
<i>Sparisoma viride</i> -Initial	8	1.27	10.16
<i>Scarus vetula</i> -Terminal	17.9	1.61	28.82
<i>Scarus vetula</i> - Initial	18.4	0.88	16.19
<i>Scarus taeniopterus</i>	13.6	1.22	16.59
<i>Acanthurus coeruleus</i>	21.4	0.55	11.77
<i>Acanthurus bahianus</i>	28.9	0.27	7.80

Table 2. The amount of algae a single individual will consume on the reef at Andrea II dive site

	Average Bites Per minute	Average Bites Size cm ²	Bites/ cm ² x Min
<i>Sparisoma Viride</i> -- Terminal	7.8	1.78	13.88
<i>Sparisoma Viride</i> -Initial	9.1	1.27	11.56
<i>Scarus vetula</i> -Terminal	18.8	1.61	30.27
<i>Scarus vetula</i> - Initial	18.9	0.88	16.63
<i>Scarus taeniopterus</i>	15.7	1.22	19.15
<i>Acanthurus coeruleus</i>	18.3	0.55	10.07
<i>Acanthurus bahianus</i>	14.3	0.27	3.86
<i>Acanthurus coeruleus</i> - Schools	32	0.55	17.60
<i>Acanthurus bahianus</i> - Schools	47.9	0.27	12.933

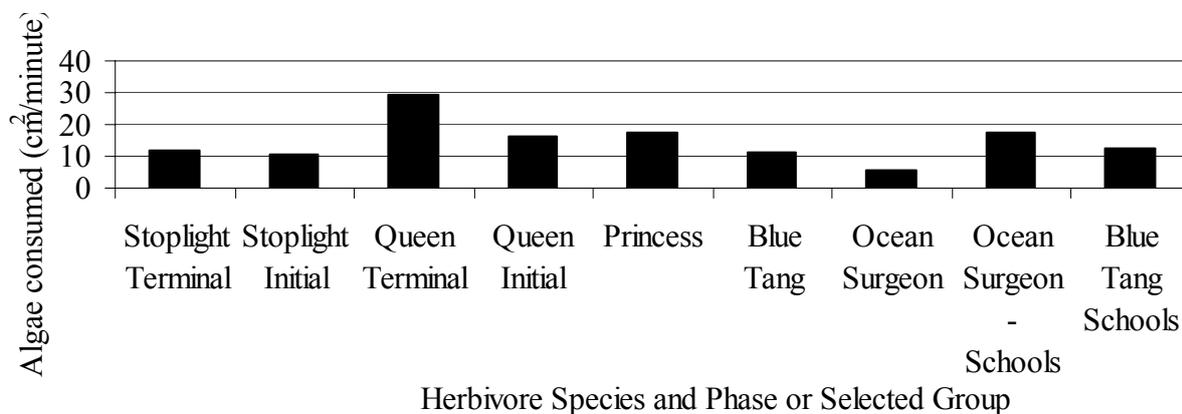


Figure 1: The total average grazing rates of Andrea II and Yellow Sub dive site. How much a single individual

Table 3: Results of the Kruskal Wallace ranking test, specifically the post – hoc analyses. This shows pair wise comparisons of herbivory between fish species K (Espinoza 1979). Any relationship with a K value over 2.89 is considered significant. The significant relationships are colored red. P=Princess, QI=Queen initial, QT=Queen terminal, ST=Stoplight terminal, SI=Stoplight initial, OS=Ocean Surgeon, BT=Blue Tang

	P	QI	QT	ST	SI	QS-School	BT-School	BT	OS
P	NA	1.19	3.89	5.82	7.17	8.61	8.81	10.15	10.35
QI		NA	2.54	4.47	5.82	7.26	7.46	14.39	6.3
QT			NA	1.77	3.12	4.57	4.76	6.11	6.3
ST				NA	1.19	2.64	2.83	4.18	4.37
SI					NA	1.29	1.48	2.83	3.02
OS- School						NA	0.04	1.39	1.58
BT- School							NA	1.94	1.39
BT								NA	0.4

counting for the least amount of algae being consumed (9.07 cm²/minute/species/100m², Figure 2).

Steneck (2005), using different methods, found scarids to be the most dominant herbivores on the reefs of Bonaire, supporting the findings of the current study. Furthermore, Steneck's 2005 results suggest that bites rates were independent of fish densities. The present study measured bite rates at a site with high fish abundances (Andrea II) and a site with low fish abundances (Yellow Submarine) and found little difference in bite rates between the two sites. These results suggest that bite rates may not vary greatly by site and may be independent of fish densities.

Mean grazing rates and bite sizes may be used with mean densities from various sites on Bonaire that were not included in this study to create a model that illustrates the importance of herbivores on the coral reef community. Before 1983, long-spined sea urchins, *Diadema antillarum*, were by far the most abundant and important herbivore species in the Caribbean (Breeman et al 1994, Lewis 2006, Michelle and Cowen 2006). Yet within two years an estimated 95 to 99 percent of *D. antillarum* died from a species-specific pathogen (Brostoff and Hixon 1996; Carpenter 1988). Due to the absence of their primary competitor, *Scaridae* and *Anthuridae* populations increased to fill the niche (Carpenter 1986). Data from this study may be used to illustrate the impact a single species of herbivore has on the corals reefs of Bonaire and the importance herbivores have on the health of reefs.

Scarus vetula terminal phase was found to be the largest consumer of algae per individual, consuming 29.5 cm²/minute/individual. If just two of these individuals were to be fished out, that would be: (29.5

cm²/minute/individual) x (600 minutes) x (365 days) x (2 fish) = 129210 m² algae not being consumed a year, just from two fish. An example like this could be used on a larger scale to help illustrate the impact of herbivores on the coral reef ecosystem

In the future more data should be collected from the different species and phases of herbivores to better understand their role in controlling algae. To ob-

Table 4: The final herbivory rankings. When abundance is taken into account, this number shows how much algae a given population will consume in a 100m² area.

	cm ² /min/ Species/100m ²
Princess (<i>Scarus taeniopterus</i>)	164.826
Queen Terminal (<i>Scarus vetula</i>)	89.812
Queen Initial (<i>Scarus vetula</i>)	49.892
Stoplight Terminal (<i>Sparisoma viride</i>)	40.499
Stoplight initial (<i>Sparisoma viride</i>)	36.064
Blue Tang Schools (<i>Acanthurus coeruleus</i>)	20.862
Ocean Surgeon Schools (<i>Acanthurus bahianus</i>)	20.117
Blue Tang (<i>Acanthurus coeruleus</i>)	12.941
Ocean Surgeon (<i>Acanthurus bahianus</i>)	9.071

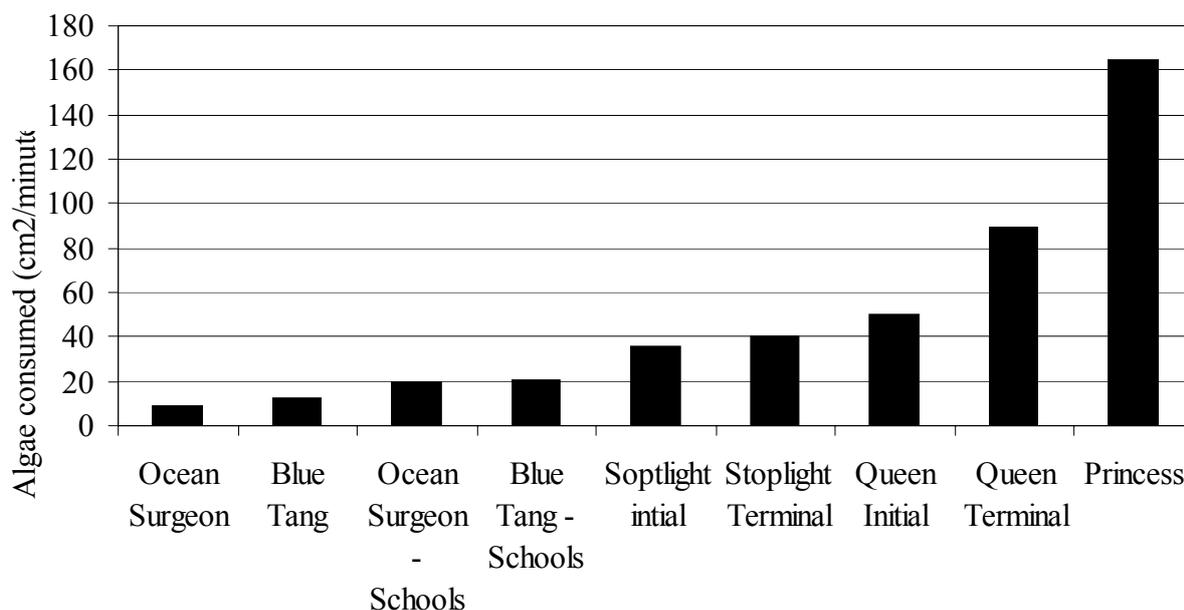


Figure 2. Final herbivory rankings (cm²/min/species/100m²). How much algae a single species of group of species, in 100 m², will consume in a minute.

tain more accurate rates and bite sizes, future research could be done throughout different times of the day, as opposed to the hours between 1000 and 1400 to eliminate any conflict with hours of mating or territory disputes when males might be grazing less (Clavijo 1983). These data, used in modeling, may be extremely helpful to coral reef resource managers, especially for use in determining fishing regulations.

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Diurnal Variation of Cleaning Intensity in Bonaire, N.A

Luisa Velasquez

Abstract

Cleaner species are believed to help maintain the health of client species by cleansing them of parasites, dead or infected tissue and debris which leads to healthier fish and in turn maintains the health of the entire ecosystem. Cleaning intensity may vary depending on several factors such as ectoparasite load, hunger levels of cleaners, and possible overlap of nocturnal and diurnal client species. Data on cleaning intensities during three different times of day (early morning, afternoon, and late evening) were collected for three different species of cleaners: *Periclimenes pedersoni*, juvenile *Thalassoma bifasciatum*, and *Gobiosoma spp.* in Bonaire, N.A. Research was conducted at the Yellow Sub dive site Bonaire, N.A. Analysis of the data collected during this study indicate that different cleaning species do in fact show significant differences in the amount of time they spend cleaning throughout the day. In addition, we found that the number of client species visiting the different cleaner species also varied, with *P. pedersoni* having the largest number of clients visiting and juvenile *T. bifasciatum* having the smallest.

Introduction

Cleaning is a mutualistic activity through which many different coral reef species have ectoparasites, dirt and debris removed by different species of shrimp or fish (Grutter, 1999). Three examples of cleaner species on Caribbean reefs are: Pederson shrimp (*Periclimenes pedersoni*), juvenile bluehead wrasse (*Thalassoma bifasciatum*) and gobies (*Gobiosoma spp.*). These three species are common in the Caribbean and have been shown in several studies to participate in the cleaning of various species of reef fish (Wicksten, 1998; Human & Deloach, 2002). Wicksten (1998) for example, observed cleaning behaviors in all three of these species (along with many others) in her study in Bonaire. This behavior is considered an example of mutualism because the cleaners benefit from a meal, while the clients are cleansed of diseased or injured tissue, unwanted food particles and parasites residing on their gills, mouths and exterior (Losey, 1972; Losey, 1974; Wicksten, 1998; Sikkell, Fuller & Hunte, 2000; Grutter, 2001). Studies in the past have even shown that the health of reef fish is in fact affected by parasites, demonstrating that fish populations can be negatively impacted by their presence (Jones & Grutter, 2006). For example, Collyer and Stockwell (2004) discovered that species of *Cyprinodon tularosa* were severely impacted by the presence of Diplostomatidae (a parasite).

Scientists have found that the amount of ectoparasites found on the client fish influences the amount of time spent on the client by the cleaner; if this is the case we expect that cleaning may be more intense in the morning hours after a long period has allowed for a large build up of parasites and debris (Sikkell, Fuller & Hunte, 2000; Becker & Grutter, 2005). Similarly, Becker and Grutter (2005) found that the hunger levels of cleaners affected the amount

of time spent cleaning. Observations of nocturnal species seeking cleaners have also been documented; Sazima et. al. (2005) describe the occurrence of *Pempheris schomburgki* (a nocturnal species) leaving their day time hiding place in order to be cleaned by *Thalassoma noronhanum* (a diurnal cleaner). This study indicates that cleaning may be important to at least some nocturnal species which helps to support the hypothesis that cleaning stations may be busier at dawn and dusk due to overlap of nocturnal and diurnal client species.

The goal of this study is to identify whether there is a time of day when cleaning stations are more active, due to either ectoparasite load, hunger levels of cleaners, activity level of clients or overlap of nocturnal and diurnal species during certain times of day. The null and alternate hypotheses in this study are as follows:

H₀: Time of day has no effect on cleaning activity.

H_a: Time of day has an effect on cleaning activity and as such will result in more intense cleaning occurring at certain times of day.

If cleaning intensity is not dependent on ectoparasite load we then expect to see no difference in intensity throughout the day. If intensity is dependent on the hunger levels of cleaner species we should see an increasing number of clients being rejected toward late evening. If intensity depends on the overlap of nocturnal and diurnal species then nocturnal species should be found at cleaning stations at dawn and dusk.

Methods

Site selection

Two dives were initially performed in order to identify possible study sites. After these two initial dives three sites which were in close proximity to one another were chosen, the sites selected were chosen because of the ease with which they could be relocated. The *Gobiosoma spp.* station was located 20 ft. down, the juvenile *T. bifasciatum* station was 25 ft down and the *P. pedersoni* station was 35 ft. down.

Experimental design

Cleaning stations were monitored at three different times of day: 6:30, 13:30, and 17:30. In each 15 minute session, the following data was collected: the species of the cleaner and client; the number of cleaners present; the duration of cleaning per client; the length of time the client spent at the station; the method in which cleaning was initiated and terminated; the areas of the client that were cleaned (i.e. head, sides, tail, fins, etc.); how many clients were present and finally, if there were any instances of aggression or competition. In addition, data on the direction of currents and topography was recorded. At each station prior to recording data a two minute acclimatization period was given in order to account for any disturbance caused by our arrival, the site was then continuously monitored for fifteen minutes.

Data analysis

The type of analysis chosen for the datasets of this study was a repeated measures ANOVA. The reason for this was that the same three stations were observed each time as opposed to randomly choosing sites to observe each time; the analysis takes this into account and removes a degree of freedom to compensate. Two separate data sets were analyzed. The first analysis tested to see if there was a difference in the mean number of clients attending the three stations throughout the day. In order to prepare the data for analysis, we took the mean of the number of clients which occurred during each fifteen minute session; next the data was transformed by adding 0.5 and taking the square root of that value.

The second analysis tested to see if there was a difference in the amount of time spent cleaning throughout the day among the three stations: in order to determine this, the mean of the ratio of time spent cleaning (amount of time cleaner actually spent cleaning client) to time spent waiting (amount of time client spent at cleaning station) for each 15 minute observation period was taken (view table 1 for ratios). The larger the ratio, the more interest the cleaner species had in cleaning and visa versa. After taking the average of each 15 minute time period per time of

day the data were transformed by taking the Arc Sin of the average.

Results

Analysis 1

This analysis tested the mean number of clients that approached cleaning stations during each 15 minute period. This analysis revealed a significant differences between cleaner species, with a greatest average number of clients visiting *P. pedersoni* and the least average number of clients visiting juvenile *T. bifasciatum*. No significant difference was found among the average number of clients visiting individual cleaners throughout the day (early morning, afternoon and late evening) (refer to table 2 for p-values). Although significant differences were not found with respect to time of day trends can be noted from the results. It seems that *P. pedersoni* has the greatest number of clients showing interest in the early morning and the least number of clients showing interest in the afternoon. The number of clients visiting *Gobiosoma spp.* follows the same trend as those of *P. pedersoni*, however there is less of a difference between the early morning and late evening. Juvenile *T. bifasciatum* on the other hand has the most clients showing interest during the afternoon followed by early morning. A bar graph of the data for this analysis (Figure 1) provides a clear representation of the results described.

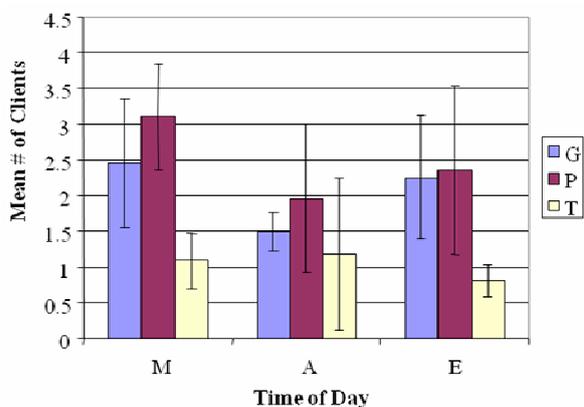


Figure 1. Bar graph for analysis 1; mean number of clients per fifteen minute sessions for each cleaner species by time of day. G = *Gobiosoma spp.*; P = *P. pedersoni*; T = *T. bifasciatum*. M=morning, A=afternoon, E=evening.

Analysis 2

Data analyzed was the ratio of time spent cleaning to time spent waiting by the client (Table 1). This test revealed that there is a significant difference between the three species (*Gobiosoma spp.*, juvenile *T. bifasciatum* and *P. pedersoni*) as well as for each individual species between the different times of day

(refer to table 2 for p-values). A bar graph of this analysis (Figure 2) revealed that *P. pedersoni* clean the most during the afternoon while *Gobiosoma* clean the most during the evening; although juvenile *T. bifasciatum* rarely cleans regardless of time of day, the analysis indicates that this species tends to clean the most during early morning hours. This data also indicates that *T. bifasciatum* demonstrated the least interest in cleaning (virtually none at all; all ratios in table 1 are zero), while *Gobiosoma spp.* demonstrated the most interest in cleaning (majority of the ratios in table 1 were high).

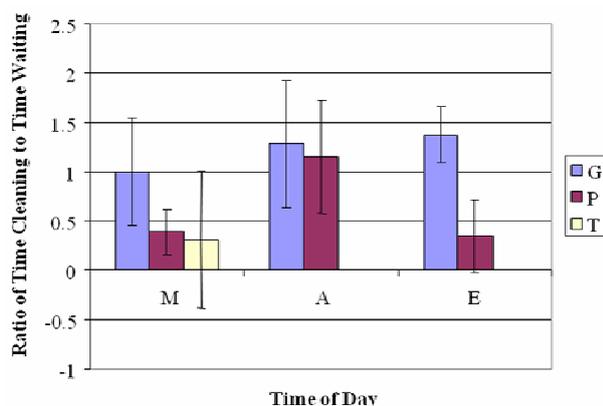


Figure 2. Bar graph for analysis 2, mean ratio of time spent cleaning to time spent waiting per fifteen minute sessions for each cleaner by time of day. G = *Gobiosoma spp.*; P = *P. pedersoni*; T = *T. bifasciatum*. M=morning, A=afternoon, E=evening.

Discussion

The first analysis of the data, which tested the relationship between the number of clients that visited each cleaning station in relation to the time of day and the species, provided significant results with regard to the mean number of clients visiting each individual cleaner. Although, the analysis did not show significance with regard to the time of day, a trend was seen. It is possible that with further data collection these trends may prove to be significant and provide stronger support of the hypothesis. The expectations were that cleaning intensity would vary depending on the time of day for each species of cleaner; perhaps more clients would appear during early morning because a longer period of time had gone by since they were last cleaned. The number of clients visiting would then perhaps decline throughout the day as they would already have been cleaned. These data indicate that variation does in fact exist depending on the time of day for each species. However the reason for this variation is unknown; though it may have to do with differences in the diurnal patterns of the different clients visiting the different cleaners.

The second analysis, which tested the relationship between the ratio of time spent being cleaned to time spent waiting for the client in relation to time of day and species, revealed a significant difference between the three species with regard to time of day. These data support the alternate hypothesis and demonstrate that the three different cleaner species are

Table 1. Ratios for second analysis. M = Early morning; A = Afternoon; E = Late evening

	M	A	E
<i>P. pedersoni</i>	0.511905	0.600000	0.000000
<i>P. pedersoni</i>	0.442282	0.398268	0.478244
<i>P. pedersoni</i>	0.635071	1.000000	0.000000
<i>Gobiosoma spp.</i>	0.875000	0.125000	1.000000
<i>Gobiosoma spp.</i>	0.115385	1.000000	1.000000
<i>Gobiosoma spp.</i>	0.951923	1.000000	0.879782
<i>T. bifasciatum</i>	0.000000	0.000000	0.000000
<i>T. bifasciatum</i>	0.000000	0.000000	0.000000
<i>T. bifasciatum</i>	0.000000	0.000000	0.000000

Table 2. P-values for analyses 1 and 2

	Cleaner spp.	Time of Day	Cleaner spp. with Time of Day
Analysis 1	<0.0001	0.1453	0.4906
Analysis 2	<0.0001	0.2507	0.0497

showing a varying interest in cleaning throughout the day. Reasons for this are unknown, *T. bifasciatum* has been observed readily cleaning at other sites around Bonaire (L. C. Velasquez personal observation). This species was observed foraging at the location of this study, therefore it is possible that it is more cost efficient for the species in this area to forage in the water column than to wait for clients to show interest.

Similar studies have focused on the relationship between the load of ectoparasites on clients and the amount of time clients spent at cleaning stations, whether or not cleaning is in fact a mutualistic interaction, and whether cleaning intensity changes with time of day (Sikkel, Fuller & Hunte, 2000; Grutter, 2001; Côté & Molloy, 2003; Collyer & Stockwell, 2004; Jones & Grutter, 2005). Côté and Molloy (2003) found that duration of cleaning did not necessarily reflect the amount of ectoparasites present on the client. Although significantly longer cleaning periods were observed to take place during the morning, when ectoparasite loads were heaviest, they observed equally long cleaning periods during the afternoon (Côté & Molloy, 2003). The results of this study are somewhat consistent with their results in that significantly larger numbers of clients showed interest during early morning for both *Gobiosoma spp.* and *P. pedersoni*, however longer cleaning periods in the early morning were only observed in *T. bifasciatum*. This may indicate that clients, at least those visiting *Gobiosoma spp.* and *P. pedersoni*, do in fact have larger loads of ectoparasites in the morning (as observed by Côté & Molloy (2003)). However cleaning intensity is not solely dependent on the clients need to be cleaned but also on other factors such as the interest of the cleaner. Therefore, when attempting to determine how cleaning intensity varies throughout the day the diurnal patterns of parasites, clients and cleaners must be taken into account.

Studies which support the hypothesis that client cleaner interactions are mutualistic support the possibility that cleaning intensity therefore may vary throughout the day depending on the levels of ectoparasites present on clients. Such studies include that of Collyer and Stockwell (2004) who found that parasites are in fact costly to the species they infect therefore indicating that cleaners serve an important purpose in coral reef ecosystems. Alexandra Grutter (2001) found that clients with larger loads of ectoparasites spent longer periods of time at cleaning stations.

Research on cleaner species in their natural environments is important due to the pressure of the ornamental aquarium industry on their collection; Chockley and St. Mary (2003) explain that field studies are

important for identifying the possible reciprocal effects of thinning or completely eradicating cleaner species. Thinning of cleaner species could result in a reduction of the local fish population or a decrease in the fitness of the local fish population (Bshray, Oliveira, Oliveira & Canário, 2007). This would be a serious issue resulting in an overall decrease in the quality of the habitat; lower numbers of herbivorous fish (such as parrot fish) results in an increase in algal growth along with increase in coral death (Hughes et al., 2007).

Modifications or improvements which could be made to this experiment include the collection of more data observing from a further distance so as not to disturb typical client cleaner interactions may also improve the study. Other studies which could be of interest include whether or not nocturnal species are cleaned and if so (no nocturnal species were observed visiting cleaner stations in this study), when; the variation in cleaning intensity/interest between different populations of juvenile *T. bifasciatum* in Bonaire; the frequency with which cleaners eat live tissue in comparison to ectoparasites. It would also be interesting to determine whether or not every species on the reef is getting cleaned.

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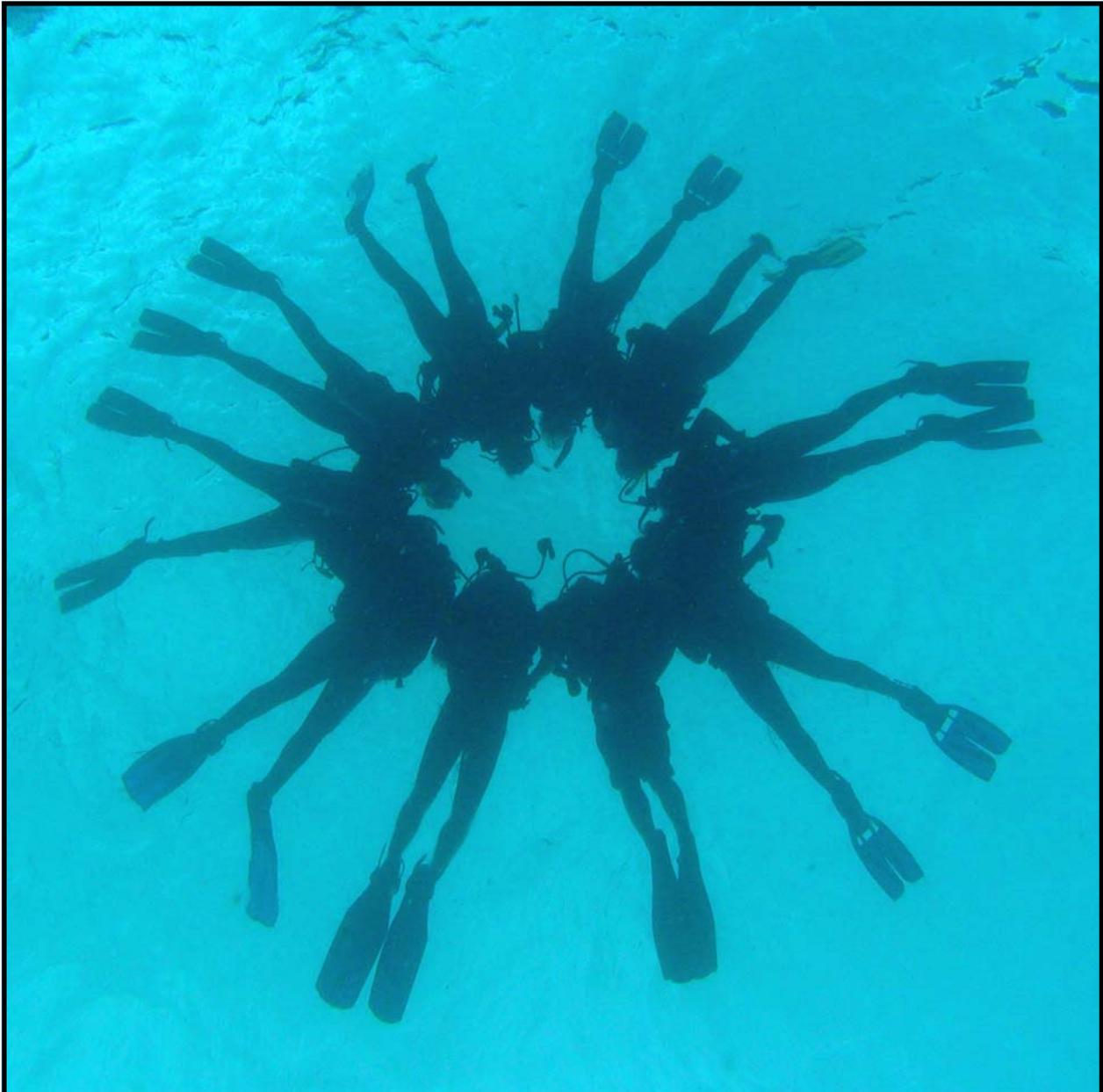
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"Never doubt that a small group of thoughtful, committed people can change the world. Indeed, it is the only thing that ever has."

- Margaret Mead