

Physis

Journal of Marine Science

Vol. V Spring 2009

CIEE Research Station Bonaire

Physis

JOURNAL OF MARINE SCIENCE

CIEE Research Station Bonaire
Tropical Marine Ecology &
Conservation Program
Vol. V Spring 2009

PHOTOGRAPHS:

Front cover: Marylou Hildebrand

Foreward: Julie Sickels

Profile Pictures: Rita Peachey & Amanda Hollebhone

Intern Page: Rita Peachey & Julie Sickels

Table of Contents (top to bottom): Alissa Rickborn,
Anna Malek, Julie Sickels, Katie Kirschbaum, Julie
Sickels, and Marylou Hildebrand

Inside back cover: Amanda deVillers, Marylou
Hildebrand, Anna Malek, Anouschka van de Ven, and
Kenny Grillo

Back cover: Anouschka van de Ven

φύσις

Physis has meant many things to many people. First used by the Greeks to describe the tendency of living things to grow unaided by external forces, physis has evolved to symbolize nature's unyielding power. This power describes the self-sustaining and eternal persistence of nature in a chaotic and uncertain world. Today especially nature must be appreciated for her ability to persist in an era in which it would seem that natural processes succumb to human influence.

It is in these turbulent times that we turn to nature to gain a broader understanding of the world around us. This journal presents our six individual efforts to appreciate and study the diverse environments in Bonaire. Our studies have taken us from the salty mudflats of salinas to the deep benthos of the coral reefs and from the silty water of the mangroves to the rocky beaches of the western coast. Despite the diverse range of research topics, we have come to gain a deeper understanding of not only our island and our environment, but also of the blue waters that lay beyond it. As Jacques Cousteau once said,

“From birth, man carries the weight of gravity on his shoulders. He is bolted to earth. But man has only to sink beneath the surface and he is free.”

Throughout the last fifteen weeks, we have experienced the freedom nature has to offer, and grown not only as scientists but as individuals. As our time on the island comes to a close, we continue the quest for knowledge and experience and leave Bonaire with all that it has taught us. We leave Bonaire with Physis.

Enjoy!

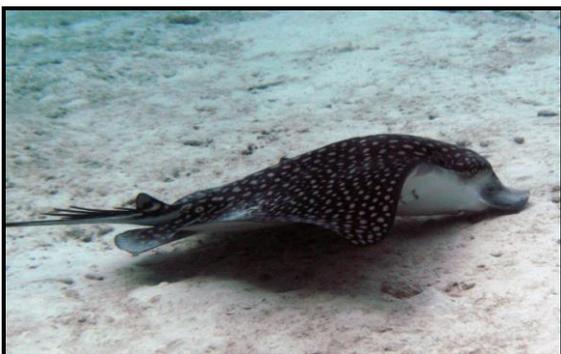
Marylou Hildebrand

Alissa Rickborn

CIEE Bonaire, Spring 2009



FOREWORD



The Council on International Educational Exchange (CIEE) is an American non-profit organization with 118 study abroad programs in more than 40 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 now nearly 3 years old and is an example of CIEE's 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 Diving, Human Ecology, Marine Resource Management and Independent Study. In addition to a full program of study, this program provides dive training that prepares students for certification with the American Academy of Underwater Scientists, a leader in the scientific dive industry, at their home universities.

The proceedings of this journal are the result 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 7 April 2009 at the CIEE Research Station in Bonaire.

The Independent Research Advisors for the projects published in this journal were: Rita B.J. Peachey, Ph.D, and Amanda Hollebhone, Ph.D. Caren Eckrich M.S. is CIEE's Dive Safety Officer and assists students with questions and approves dives for Independent Research. Amanda deVillers and Anna Malek worked as research interns for CIEE assisting the students in field work. Brief biographies of the advisors and interns are presented on the next page.

CIEE STAFF

Dr. Rita Peachey is the Resident Director in Bonaire. She received her B.S. in Biology and M.S. in Zoology from the University of South Florida and her Ph.D. in Marine Science from the University of South Alabama. Her research interests include coral biology and how UV affects the early stages of life in the ocean. In addition, she has studied how pollution can enhance the detrimental effects of sunlight on larval crabs, corals and oysters. Rita has years of experience conducting ecological research in a variety of ecosystems such as oyster reefs, seagrasses, coral reefs, and mangrove swamps.

Primary advisees: Marylou Hildebrand, Nathan Landry, and Michelle von Sternberg.



Rita Peachey, Ph.D
Resident Director

Caren Eckrich is the Assistant Resident Director and, as a resident of Bonaire for the last nine years, she brings local experience and a wealth of information on diving and marine ecology in Bonaire. She is a SCUBA instructor and has taught Marine Ecology in Puerto Rico, Curacao and Bonaire. Her educational background includes a B.S. in Wildlife and Fisheries from Texas A&M University and a M.S. in Biological Oceanography at the University of Puerto Rico in Mayaguez. Caren's research interests include fish behavior, seagrass ecology, sea turtle ecology and coral disease.



Caren Eckrich, M. S.
Assistant Resident Director,
Diving Safety Officer

Dr. Amanda Hollebhone is the Marine Conservation Biology faculty at CIEE Bonaire. She received her B.S. in Biology from the UNC Chapel Hill and Ph.D. in Marine Ecology from the Georgia Tech and has recently taught in the Biology Department at Georgia Southern University. Amanda's research interests lie in the areas of reef community ecology and invasive species with her dissertation research focusing on the population dynamics and pre- and post-settlement ecology of a non-native porcelain crab in the oyster reefs of Georgia, USA. Amanda has had several years of experience conducting research in marine ecosystems of the southeastern US including mud flats, salt marshes, oyster reefs, and offshore reefs, as well as in the mangrove forests, seagrass beds, and coral reefs of Florida and the Bahamas. *Primary advisees: Katie Kirschbaum, Julie Sickels and Alissa Rickborn*



Amanda Hollebhone, Ph. D
Tropical Marine Conservation
Biology Professor

INTERNS

Amanda deVillers was the Teaching Assistant for Scientific Diving and Cultural and Environmental History of Bonaire and the co-TA for Independent Research. Amanda recently graduated from Moravian College in Pennsylvania with a Bachelor of Science degree in Biology. She is a former student of the CIEE Bonaire program and is a PADI Rescue Diver. Amanda has conducted research in coral reef fish diversity, ecology of aquatic microorganisms, and freshwater ecology. She will be attending the University of Guam in the fall to pursue a Masters in Biology while working as a research assistant in the marine lab. Her future goals are to earn a Ph.D in Marine Biology and begin a career in research and education.



Amanda deVillers

Anna Malek was the Teaching Assistant for Coral Reef Ecology, Tropical Marine Conservation Biology as well as Independent Research. Anna earned her Bachelor of Science degree through the University of New Hampshire, with a focus in Marine and Freshwater Biology. As an undergraduate, Anna carried out research involving the health of captive sea turtles in Zanzibar, Tanzania, cyanobacterial contamination of New Hampshire lakes, oceanographic monitoring in the Gulf of Maine as well as community dynamics within the rocky intertidal. While in Bonaire, Anna conducted research on sedimentation, nutrient loading and enterococcal bacteria on Bonaire's reefs. Starting in the fall, Anna will pursue her Ph.D at the University of Rhode Island Graduate School of Oceanography.



Anna Malek



STUDENT PROFILES



**ALISSA
RICKBORN**
Biology
*Arizona State
University
Tempe,
Arizona*



**KATIE
KIRSCHBAUM**
Environmental
Science
*University of
Minnesota
St. Paul,
Minnesota*



**MICHELLE VON
STERNBERG**
Marine Biology
*Eckerd College
Houston,
Texas*



**NATHAN
LANDRY**
Marine Biology
*University of
Massachusetts
Dartmouth
Worcester,
Massachusetts*

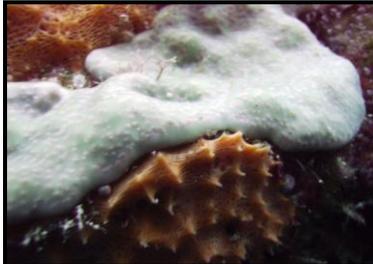


JULIE SICKELS
Marine Biology
*Eckerd College
Easton,
Pennsylvania*



**MARYLOU
HILDEBRAND**
Ecology, Behavior,
& Evolution
*University of
California San Diego
Mountain View,
California*

TABLE OF CONTENTS



Caribbean Map

Linda Kuhnz.....1

Competition for space in benthic environments: the allelopathic and overgrowth responses of native sponges and a non-native ascidian on a coral reef in Bonaire, NA

Alissa Rickborn2

Are different feeding strategies utilized by the bar jack (*Caranx ruber*) related to foraging success in coral reef habitats?

Michelle von Sternberg.....10

The salinas of Bonaire: How does bird activity impact epi- and infaunal communities?

Julie Sickels.....14

Which is more attractive to juvenile fish: availability of food or the complexity of habitat in the mangroves of Bonaire, NA?

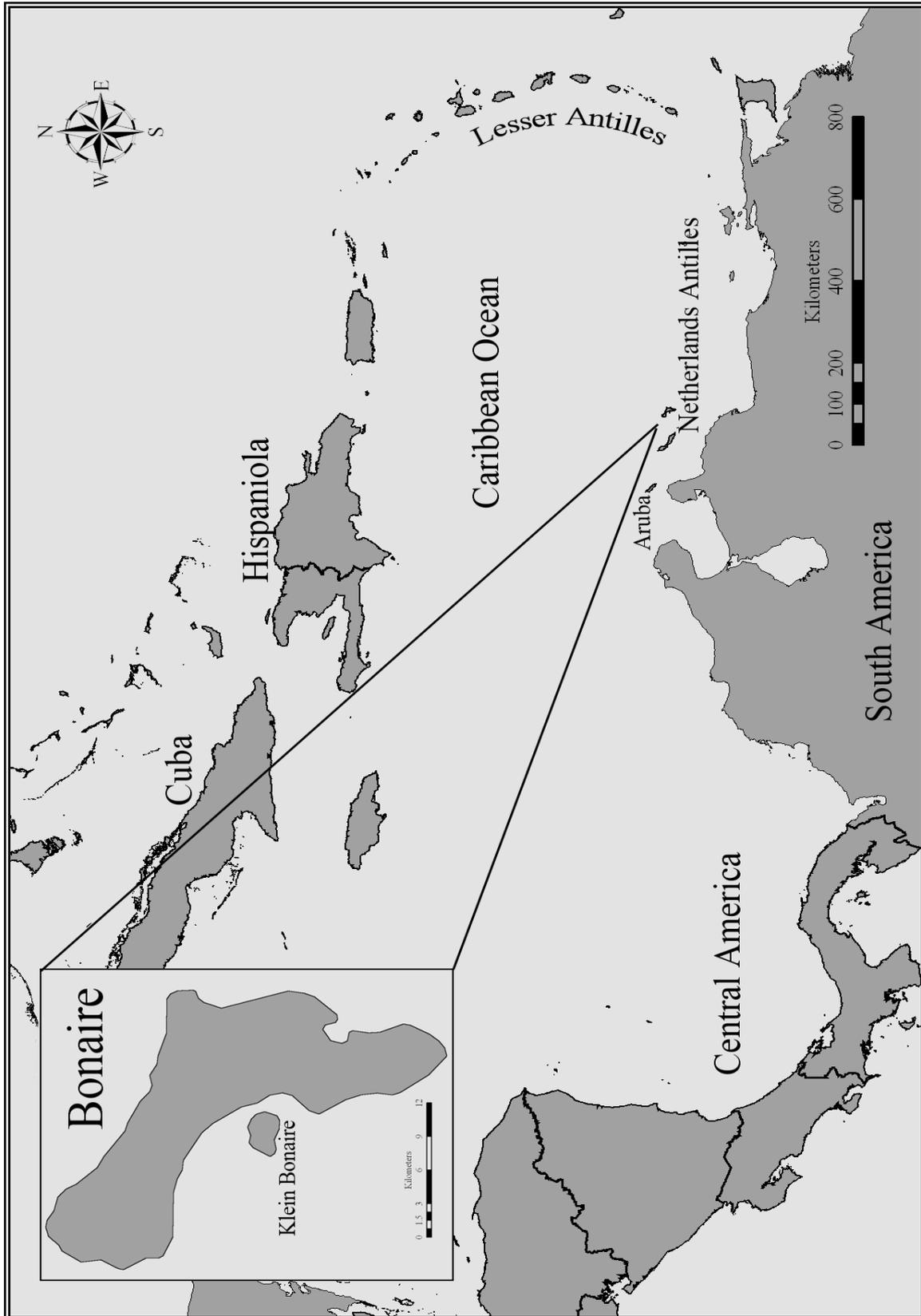
Katie Kirschbaum20

Risky business: ecological trade-offs of subtidal foraging behavior in parrotfish (*Scaridae*)

Nathan Landry.....27

Comparison of epibionts between green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) sea turtles in Bonaire, NA

Marylou Hildebrand.....32



Competition for space in benthic environments: the allelopathic and overgrowth responses of native sponges and a non-native ascidian on a coral reef in Bonaire, NA

Alissa Rickborn*
Arizona State University

Abstract

This study explores the competitive and allelopathic interactions of native sponges and the non-native ascidian, *Trididemnum solidum*, in the space-limited coral reef environments of Bonaire, NA. The study had two main goals: (1) to identify native sponge species and provide estimates of sponge and *T. solidum* percent cover, and (2) investigate the allelopathic and overgrowth responses of native sponges and *T. solidum* when they are engaged in spatial competition with each other. Belt transects and modified nearest-neighbor methods were used to quantify abundance, species diversity, and interactions between native sponges and *T. solidum* at the Karpata dive site on Bonaire. Overall, it was found that percent cover of sponges significantly increased with depth while percent cover of *T. solidum* varied among depths, reaching a maximum at 11 – 15 m. Twenty-two species of sponges were recorded with species composition and abundance varying among depths while diversity among depths was not significantly different ($p = 0.880$). It was found that percent cover of *T. solidum* had a significant effect on the number of contact interactions. A closer look at contact interactions revealed that *T. solidum* frequently (87.5 % - 100.0%) overgrew sponges and caused tissue necrosis but was itself never observed to be overgrown. Staged interactions between two abundant encrusting sponges (*Ulosa ruetzleri* and *Halisarca sp.*) and *T. solidum* showed that native sponge growth is impaired by the ascidian and that *T. solidum* uses allelopathy when expanding its colonies. As described by this study, the success of *T. solidum* in its expanded range may provide support for two additional hypotheses: the evolution of increased competitive ability hypothesis, which attributes the success of non-native species to their increased ability to overgrow native organisms, and the novel weapons hypothesis which explains that non-native species are successful because they harbor allelopathic chemicals that native organisms have not evolved defenses for.

Introduction

Coral reef communities are inhabited by a diverse array of sessile organisms including corals, algae, sponges, and ascidians which dominate the benthic landscape, covering all available substrata from sand to coral rubble (Jackson 1977). Due to the immobile nature of these creatures, spatial competition is important in structuring coral reef communities and in many cases determining the recruitment and survivorship of representative organisms (Dayton 1971, Jackson and Buss 1975, Jackson 1977). Sessile organisms compete for space in a variety of ways. Some of these mechanisms include overgrowth (Jackson and Buss 1975), growth patterns (such as encrusting and vertical growth; Engel and Pawlik 2005), and allelopathy (Jackson and Buss 1975, Aerts and van Soest 1997, Aerts 1998, Thacker et al. 1998, Engel and Pawlik 2000).

The competitive and allelopathic abilities of coral, sponges, and colonial ascidians have been studied extensively. Jackson and Buss (1975) tested the chemical extracts of allelopathic compounds derived from nine sponge species and two colonial ascidians. They found that 56% of the sponges and 50% of the colonial ascidians produced allelopathic chemicals. Aerts (1998) found that sponges are important space competitors

in high coral cover areas (> 25% cover) and that “aggressive sponges” (sponges that are frequently found as epibionts on neighbors) possess biologically active chemicals that can damage, kill, or deter overgrowth by other benthic organisms. Engel and Pawlik (2000, 2005) showed the direct effects of allelopathic extracts on sponges. They found that 30% of tested Caribbean sponge species inhibited overgrowth of other organisms (e.g., *Rhaphidophlus juniperinus*, *Aplysina archeri*, and *Aplysina cauliformis*) via the production of allelopathic chemicals (see also Thacker et al. 1998). While they attributed the ability of sponges to resist overgrowth to the production of allelopathic chemicals, they found that the ability of sponges to overgrow other sponges was determined by morphology. For example, they found that the encrusting sponge, *Scopalina ruetzleri*, was 90x more effective at overgrowing other sponges than the tubular and turbinata species (e.g., *Ircinia strobilina*).

Trididemnum solidum has also been observed to over grow other organisms. Bak et al. (1981) described the rapid *in situ* growth of the colonial ascidian over coral and sponges. Upon further investigations of the overgrowth, they found that chemical extracts of *T. solidum* had resulted in tissue damage, bleaching, and necrosis on overgrown coral, suggesting that the ascidian used allelopathy in addition to overgrowth strategies to

*alissa.rickborn@asu.edu

expand its colonies. Comparable laboratory tests with the extracts of other colonial ascidians (e.g., *Diplosoma listerianum*) showed similar results on overgrown organisms (Jackson and Buss 1975, Engel and Pawlik 2000).

In addition to allelopathy, the spatial dominance of *Trididemnum solidum* may also be attributed to its growth rates. For example, *T. solidum* was found to have a growth rate of 10 cm month⁻¹ on the island of Curacao, Netherlands Antilles (Bak et al. 1996). This rapid growth rate far exceeded the expansion capabilities of native corals such as *Montastrea annularis* and *Montastrea faveolata* which grow about 1 mm month⁻¹ (Cruz-Pinon et al. 2003). Over a 15 year monitoring period on Curacao's reefs, the abundance of *T. solidum* increased 900% and the rapidly expanding population had covered all formerly available rock substrata and some scleractinian corals (mainly *Montastrea annularis*) (Bak et al. 1996). *T. solidum* was also found to lack predators in its invasive range, have a lifespan exceeding 15 years, and regenerate quickly from artificial lesions (Bak et al. 1981). These features, combined with the fact that *T. solidum* has a rapid growth rate as well as allelopathic capabilities, may indicate that competition for space is increased on reefs where *T. solidum* is present (Bak et al. 1996).

Trididemnum solidum has also been observed on the coral reefs of the Southern Caribbean island of Bonaire, NA (e.g., Karpata dive site, 12° 13' 10.36" N, 68° 21' 8.13" W; personal observations of E. McGrath and R. Peachey 2008 and A. Rickborn 2009). Preliminary assessments of abundance of *T. solidum* on Bonaire revealed that the organism was restricted to the northern most point of the island and that it occurred in maximal abundance at 19 m depth (McGrath and Peachey 2008). McGrath and Peachey (2008) demonstrated the effectiveness of physical removal of the colonies as a potential management strategy for the Bonaire National Marine Park; they found that the physical removal of *T. solidum* from the substrate effectively reduced total percent cover for up to four weeks.

The occurrence of *Trididemnum solidum* on Bonaire provides a unique and relatively unstudied opportunity to investigate the potential spatial competition between native sponges and this non-native ascidian, both of which have been shown to display spatial dominance and allelopathic abilities (Jackson and Buss 1975, Bak et al. 1981, Engel and Pawlik 2000). The study had two main goals: (1) to identify native sponge species and provide estimates of sponge percent cover and density as well as quantify *T. solidum* percent cover, and (2) to investigate the allelopathic and overgrowth responses of native sponges and *T. solidum* when they are engaged in spatial competition with each other. It was predicted that (1) the allelopathic and

overgrowth behaviors of sponges and *T. solidum* would be similar to those found in *in situ* competition studies with other colonial ascidians and coral reef sponges and (2) that the presence of *T. solidum* would increase the frequency of competition between sponges and the non-native ascidian (Jackson and Buss 1975, Bak et al. 1996, Engel and Pawlik 2005).

Materials and Methods

Observational

Observations of *Trididemnum solidum* distribution and abundance and sponge species abundance and diversity took place at the Karpata dive site on Bonaire, NA. This site was chosen because there is an obvious presence of both *T. solidum* and sponges (A. Rickborn personal observation). Over the course of the study, twenty-one 30 m belt transects were analyzed. As sponge diversity has shown to be depth dependant (e.g., *Desmapsamma anchorata* is found in highest abundance at 5 m and is usually not found at other depths; Aerts and van Soest 1997), transects were run at three depth ranges, 5 – 10 m, 11 – 15 m and 16 – 20 m in order to sample a wide variety of sponges. A 1 m² quadrat (which was divided into one-hundred 10 cm grids) was placed at 3 m intervals along each haphazardly placed transect line. At each interval, *T. solidum* and sponge percent cover was estimated and sponges within the quadrat were identified, counted, and photographed. The photographs were used to confirm sponge identity in the laboratory.

In order to determine competitive interactions among native sponges and between *Trididemnum solidum* and native sponges, a modified nearest-neighbor method as described by Engel and Pawlik (2005) was used. In each quadrat (as described previously) all *in situ* sponge interactions were recorded and photographed. Four quadrat grids were randomly chosen to select three interaction pairs; sponges in closest proximity to these grids were regarded as "focal sponges". The focal sponges were used as indicators of interaction which was defined as the presence of any sponge or colony of *T. solidum* within 5 cm of the edge of the focal sponge. This distance was selected because Turon et al. (1996) has shown that allelopathic interactions become insignificant, or nonexistent, between sessile benthic marine organisms when they are > 5 cm apart (see also Engel and Pawlik 2005). The proximity of sponges or *T. solidum* to the focal sponge was grouped into one of 6 categories: (1) proximal - the focal sponge was ≤ 5 cm from the edge of a *T. solidum* colony or another sponge (no contact), (2) contact without interaction - focal sponge was in contact with *T. solidum* or another sponge but no overgrowth or tissue necrosis was observed, (3) overgrowth - the

focal sponge was being grown over by *T. solidum* or another sponge, (4) growing over - the focal sponge was growing over *T. solidum* or another sponge, (5) tissue necrosis - the focal sponge had or was causing tissue death, and (6) no interaction - the randomly chosen square in the quadrat either did not contain a sponge, or the sponge was not interacting (i.e., the nearest sponge or colony of *T. solidum* was > 5 cm away).

Statistical analysis of observational data

The mean percent cover of sponges and *Trididemnum solidum* was separated into three categories according to depth (5 – 10 m, 11 – 15 m and 16 – 20 m) as well as organism type (sponge or *T. solidum*). A two-way ANOVA was applied to assess any significant differences in percent cover between sponges and *T. solidum* as well as among depths. The diversity of sponges was determined from the abundance and identification data using Simpson's reciprocal index of diversity. A one-way ANOVA was used to assess differences in diversity among depths. Major interaction categories (no interaction, proximal, and contact) were also separated according to depth and a one-way ANOVA was run for each category. These interactions were then broken down into the frequency of sponge - sponge and sponge - *T. solidum* interactions to assess the frequency at which *T. solidum* was interacting with sponges.

Staged interactions

Staged interactions between native sponges and *Trididemnum solidum* were used to determine the direct overgrowth and allelopathic responses of these two organisms when they were engaged in competition for previously occupied space. Preliminary observations showed that two encrusting sponges, *Ulosa ruetzleri* and *Halisarca sp.*, were most abundant and involved in more contact interactions with *T. solidum* than other sponges documented at Karpata. These similarities in abundance and morphology between the two sponges and *T. solidum* made them ideal candidates for staged interactions because the similarities removed predisposed advantages in the overgrowth ability of any one organism (Engel and Pawlik 2005).

Fourteen interactions between *Trididemnum solidum* and *Ulosa ruetzleri* (n = 10) or *T. solidum* and *Halisarca sp.* (n = 4) were haphazardly chosen by releasing a 450 g lead fishing weight 1 m above the benthos in the 11 – 15 m depth range at Karpata. If the weight did not land directly on a contact interaction between the chosen sponges and *T. solidum* the next contact interaction due north and at the same depth of the weight was chosen. At each interaction *T. solidum* was cut (with a dive knife) 3 - 5 cm away from the edge of the sponge and was marked by a numbered tag and a

fluorescent zip-tie. All staged no-contact interactions were monitored for 12 days. The data acquired was organized into three qualitative categories: (1) sponge growth – growth of the focal sponge was observed, (2) *T. solidum* growth – growth of *T. solidum* was observed, and (3) re-contact – the sponge and *T. solidum* grew back to contact each other. These data were used to assess the differences in potential allelopathic and overgrowth behaviors of the two native sponges in the presence of the non-native ascidian.

Results

Abundance and diversity

Overall, 4.16% or 8.74 m² of the total 210 m² benthic space surveyed at Karpata was covered by either a native sponge or *Trididemnum solidum* (Fig. 1). Of the total percent cover, sponges covered a mean area of ~ 3.80 m² (1.81% ± 0.19% SE) while *T. solidum* covered ~ 4.93 m² (2.35% ± 0.22% SE) (Fig. 1). A two-way ANOVA of organism type (sponge vs. ascidian) and depth range showed significant differences between organism type, among depths, and between depth and type (p < 0.001, p < 0.001, p = 0.004, respectively). Sponge percent cover increased with depth while *T. solidum* percent cover varied among depths, reaching maximum cover at the 11 – 15 m range (Fig. 1).

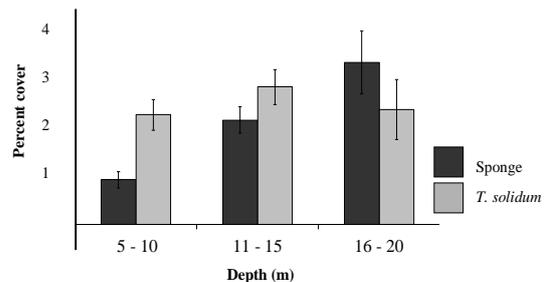


Figure 1. Mean percent cover of sponges and *T. solidum* for three depth ranges at Karpata with error bars representing standard error (SE). There are significant differences between type (sponge or *T. solidum*) (p < 0.001), depth (p < 0.001), and type x depth (p = 0.004).

In the 100 m² area surveyed for sponge abundance and diversity, 201 individuals composing 22 distinct species of sponge were recorded. The number of sponge species varied among depths with 15 species at 5 - 10 m, 11 species at 11 - 15 m and 15 species at 16 - 20 m; not all sponge species were found at each depth and the number of sponge individuals was found to increase with increasing depth (Fig. 2). Overall, the three most abundant species across all depths were *Ulosa ruetzleri* (58 individuals), *Halisarca sp.* (40 individuals), and *Ectyoplasia ferox* (22 individuals) (Fig. 2).

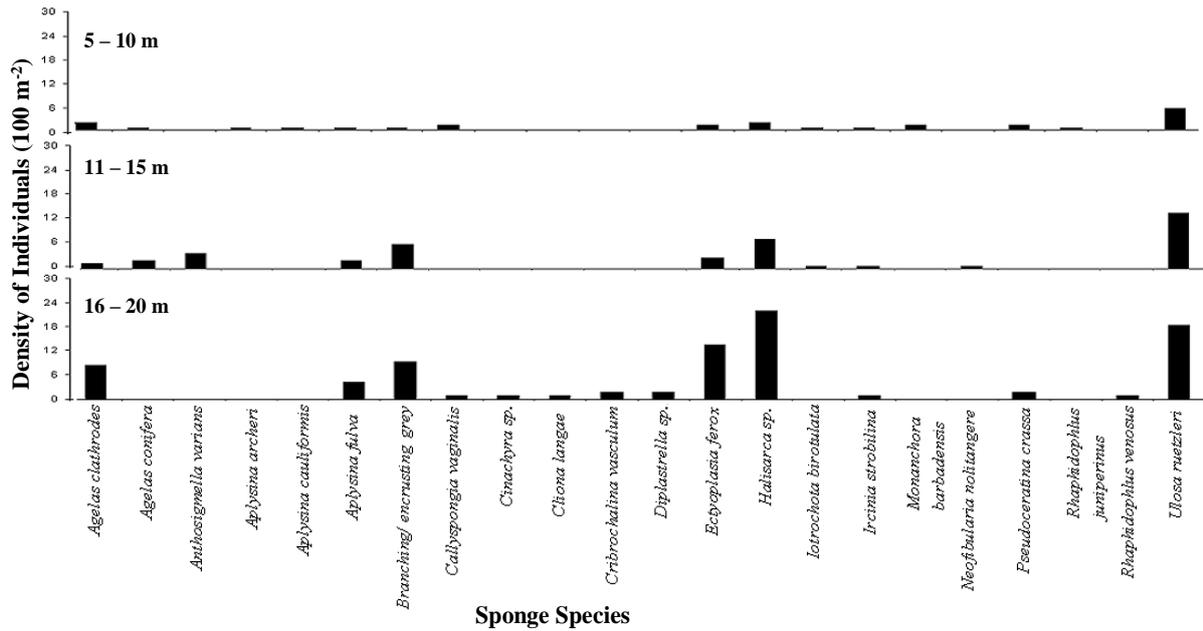


Figure 2. Density of sponge individuals ranging from 0 – 30 individuals 100 m² for three depth ranges (5 – 10 m (top), 11 – 15 m (middle), and 16 – 20 m (bottom)) at Karpata. All 22 species observed are listed on the x axis. Not all species were found at each depth (0 values).

While most of the sponges (68.9%) occurred at least twice during observations, the least abundant species *Rhaphidophylus juniperinus*, *Aplysina archeri*, *Aplysina cauliformis*, *Rhaphidophylus venosus*, *Cinachya sp.*, *Cliona langae*, and *Neofibularia nolitangere* were recorded only once (Fig. 2). With increasing depth, sponge diversity was a mean 4.05 (± 1.03 SE), 4.57 (± 0.44 SE), and 4.92 (± 0.28 SE), respectively (Fig. 3). Although the diversity of sponges shows a weak increasing trend, the difference among depths was not significant ($p=0.880$).

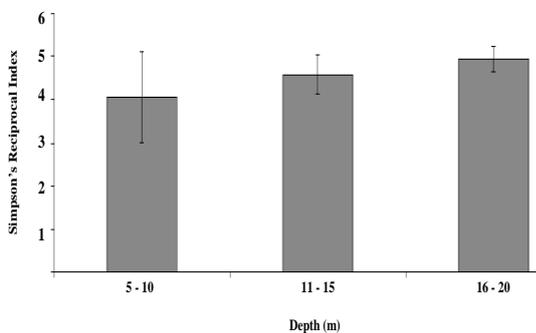


Fig. 3

Figure 3. Mean diversity of sponges for three depth ranges at Karpata. Error bars represent standard error (SE). Diversity was calculated using Simpson's Reciprocal Index of Diversity ($1/D = \sum (n/N)^2$). Changes in diversity between depths are not significantly different ($p = 0.880$).

In total, 480 interactions among sponges and between sponges and *Trididemnum solidum* occurred within the 120 m² of benthic area

monitored. The majority of potential interactions that occurred were “no interactions” with frequencies ranging from ~75.5% - 94.4% depending on depth (Fig. 4). Interaction categories included proximal and contact which composed ~1.9% - 8.8% and ~ 3.8% - 18.4% of all interactions depending on depth, respectively (Fig. 4). One-way ANOVAs for each interaction type revealed a strong trend of increasing proximal interactions ($p = 0.074$) and a significant difference in contact interactions ($p = 0.014$) among depths.

For the proximal and contact interaction categories, sponge - sponge interactions represented a minority (~ 16.7% - 33.3% for proximal and ~ 26.0% - 45.0% for contact) of total interactions documented at the most shallow depth ranges. However in the 16 – 20 m range, sponge - sponge interactions occurred as a majority of all interactions with frequencies of ~ 64.3% for proximal and ~ 64.0% for contact (Fig. 4).

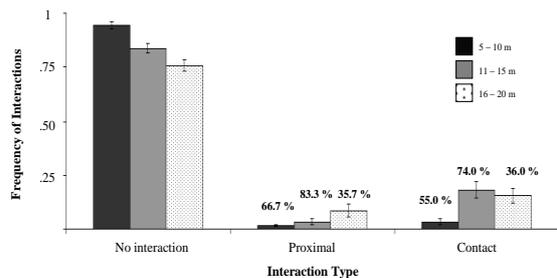


Figure 4. The mean frequency of interactions among sponges and between *T. solidum* v. sponges with error bars representing standard error (SE). The percent of interactions between *T. solidum* and sponges is represented by a % number above each bar. ($p = 0.074$ proximal, $p = 0.014$ for contact).

Conversely, interactions between sponges and *Trididemnum solidum* composed a majority of proximal and contact interactions at the shallowest depths but only accounted for a minority of all interactions at 16 - 20 m (Fig. 4).

A closer look at the contact interactions between sponges and *Trididemnum solidum* showed that a majority of all interactions occurred when *T. solidum* was over-growing sponges (~ 87.5 % - 100% for all depths, Fig. 5). Contact without interaction was found to decrease with depth and tissue necrosis was found to vary among depths, peaking in the 11 – 15 m range (~ 66.7%, Fig. 5). In all 60 interactions that occurred in the study, *T. solidum* was never reported to be “overgrown” by a sponge (Fig. 5).

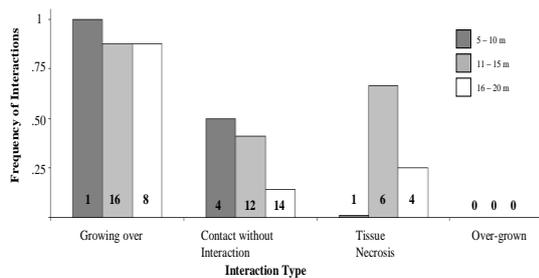


Figure 5. Breakdown of the frequency of contact interactions between *T. solidum* and sponges where *T. solidum* is reported to be overgrowing, contacting without interacting, or causing tissue necrosis on the focal sponge. Error bars represent standard error (SE). The numbers inside the bars represent the number of replicates for each interaction. Note that *T. solidum* was never observed to be over-grown.

Staged interactions

Staged interactions between *Ulosa ruetzleri* and *Trididemnum solidum* (n = 10) resulted in sponge growth 80% of the time, *T. solidum* re-growth 50% of the time, and re-contact of both organisms 10% of the time (Table 1). Interactions between *Halisarca sp.* and *T. solidum* (n = 4) showed sponge growth in 25% of interactions, *T. solidum* re-growth in all interactions, and the re-contact of both organisms in 50% of the interactions.

Discussion

A diverse array of sessile organisms such as corals, sponges, ascidians and algae recruit and grow on the benthos of coral reef communities. However not all substrata are suitable for each organism and due to the sessile nature of many reef creatures, competition for resources such as space is high (Dayton 1971, Jackson and Buss 1975, Jackson 1977). The ability of an organism to obtain space through competition has been found to influence individual survival, recruitment, and community structure (Dayton 1971, Jackson and Buss 1975). The findings of the current study

largely support this idea. I found that sponge percent cover significantly increased ($p < 0.001$) with depth (Fig. 1), which corresponds with a strong trend ($p = 0.074$) of increasing proximal interactions among sponges (Fig. 4). These results suggest that the higher the percent cover of sponges, the greater the probability that they will be engaged in competitive interactions.

While this trend is apparent for sponge-sponge proximal interactions, the introduction of the non-native ascidian *Trididemnum solidum* adds a new layer to the story. I found that *T. solidum* occurred at maximal percent cover at the 11 – 15 m depth range (Fig. 1). This is consistent with the finding that a majority of all proximal (83.3%) and contact (74.0%) interactions between sponges and *T. solidum* occurred at this depth (Fig. 4). However, because this trend of sponge – *T. solidum* dominated interactions is also apparent at 5 – 10 m (which had the lowest total percent cover of *T. solidum*), I cannot conclude that higher percent cover of *T. solidum* is responsible for increased proximal and contact interactions between the two organisms (Fig. 1). Instead interactions between sponges and *T. solidum* might be influenced by the total percent cover of sponges. I found that at depths with the highest percent cover of sponges (16 – 20 m), the two organisms were less likely to interact (Figs. 1 and 4). This may be simply because *T. solidum* does not grow as well at deeper depths, or that sponges in higher percent cover are able to out compete the ascidian for space. In addition, this change in the frequency of interactions between organisms cannot be attributed to differences in sponge diversity because I found that diversity was the same among depths ($p = 0.088$) (Fig. 3). Thus I conclude that high percent cover of *T. solidum* and low percent cover of sponges result in an increase in frequency of interactions between the two organisms. This finding may have long term implications for the native sponge community because competition between *T. solidum* and sponges may result in a potential shift in the composition and distribution of native sponges.

The methods of competition and the varied abilities of sponges to resist overgrowth observed in this study support previous findings. Engel and Pawlik (2000, 2005) described methods of competition between sponges and colonial ascidians. They found that when engaged in competition for space, sponges will act as epibionts, literally climbing atop their competition. They also describe the ability of sponges and colonial ascidians to produce allelopathic chemicals that cause tissue necrosis in their opponent (see also Jackson and Buss 1975, Thacker et al. 1998).

In this study I found that sponges and *Trididemnum solidum* compete in similar ways. Analysis of interactions was limited to contacts between *T. solidum* and sponges because a majority of all interactions that occurred were in this category (Fig. 4). Sponges were often grown over by *T. solidum* (87.5 % - 100.0% among depths) but were never found as epibionts (over-growing) on the ascidian (Fig. 5). In addition, both organisms were found to cause tissue necrosis to varying degrees, suggesting that they both produced allelopathic chemicals to deter overgrowth (Jackson and Buss 1975, Engel and Pawlik 2000) (Figs. 5 and 6).

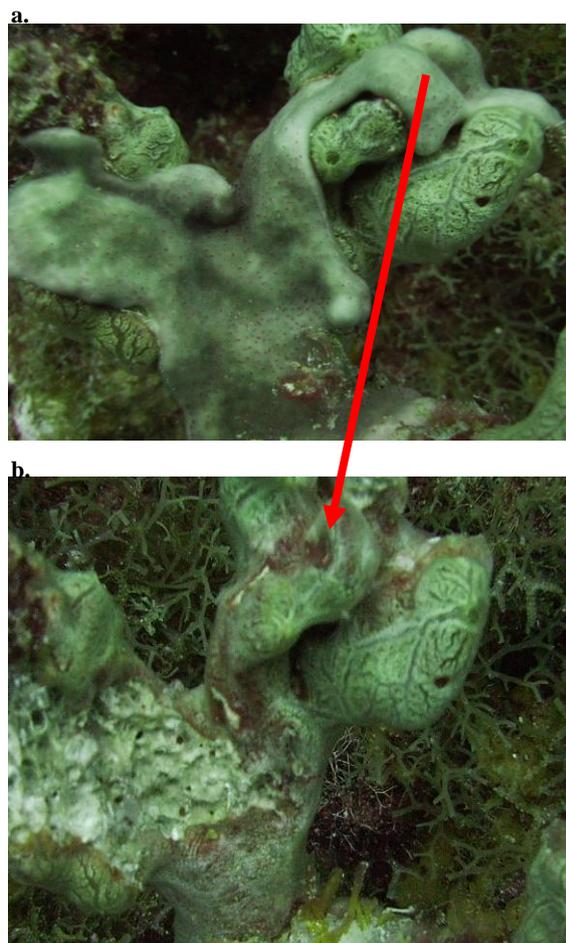


Figure 6. (a) *Halisarca sp.* before removal of *T. solidum* and (b) after removal. Arrow indicates tissue necrosis.

A prominent peak in the frequency of tissue necrosis on sponges occurred at 11 – 15 m. This pattern in necrosis cannot be attributed to sponge diversity (Fig. 2 and 3). Instead this increase may be correlated with higher percent cover of *T. solidum* and thus increased competition for space (Fig. 1). This idea is supported by the work of Jackson and Buss (1975) as well as Engel and Pawlik (2000), who have shown that both sponges and colonial ascidians produce more allelopathic chemicals when stressed by increased spatial competition.

The results of this study also demonstrated the competitive superiority of *Trididemnum solidum* that was first described by Bak et al. (1981) on Curacao, NA. They found that over a 15 year monitoring period the number of *T. solidum* colonies had increased over 900%, expanding to cover all available substrata including live coral and sponges. My results also demonstrate the superior overgrowth ability of *T. solidum* as it was found to overgrow sponges and yet never be overgrown (Fig. 5). While Bak et al. (1981) suggested that a rapid growth rate of 13 cm month⁻¹, a lack of predators in its non-native range, and the daily production of free swimming larvae gives *T. solidum* a competitive advantage, my results suggest that its encrusting morphology also contributes to the ascidians dominate epibiontic growth. This idea has been supported previously in work with encrusting sponges which were found to frequently overgrow other sponges with tubular and turbinate morphologies (Engel and Pawlik 2005).

The results of the staged interactions between *Halisarca sp.* or *Ulosa ruetzleri* and *Trididemnum solidum* reinforced the suggestion that there is competition for space between sponges and *T. solidum* on the benthos of Karpata. The space cleared by the removal of *T. solidum* was repopulated after only 12 days; if space was not an important resource, the two organisms might not have invested energy into expanding into the newly cleared area. Although the cleared space was re-grown over in all interactions, I found that the frequency of growth of sponges and *T. solidum* varied among interactions between the non-native ascidian and the two sponge species (Table 1).

Table 1. The results of staged interactions between *T. solidum* and *Ulosa ruetzleri* (n = 10) and *T. solidum* and *Halisarca sp.* (n = 4) for three qualitative categories. Categories include: sponge growth- growth of the sponge after removal of *T. solidum*, *T. solidum* growth- re-growth of the ascidian after its removal, and re-contact- the combined growth of the sponge and/or *T. solidum* that resulted in reestablished contact with the other organism.

Interaction	<i>Ulosa ruetzleri</i> v. <i>T. solidum</i>	<i>Halisarca sp.</i> v. <i>T. solidum</i>
Sponge growth	80%	25%
<i>T. solidum</i> growth	50%	100%
Re-Contact	10.0%	50.0%

While this could be in part due to the low number of replicates (n = 14) visual evidence strongly suggests a species-specific response to the presence of the *T. solidum*. While tissue necrosis was often observed on *Halisarca sp.* after removal of *T. solidum* (Fig. 6), the sponge tissue of *U. ruetzleri* found under *T. solidum* was consistently healthy (intact) (Fig. 7).

Further studies in a better controlled laboratory setting may help support this observation. In addition, studies testing the direct effects of potentially allelopathic compounds of *T. solidum* on sponges could be conducted in order to observe different impacts of tissue necrosis between species. Studies of this type have already been conducted for sponges and colonial ascidians (see Jackson and Buss 1975 and Engel and Pawlik 2000) but never in the scope of native vs. non-native allelopathic competition.

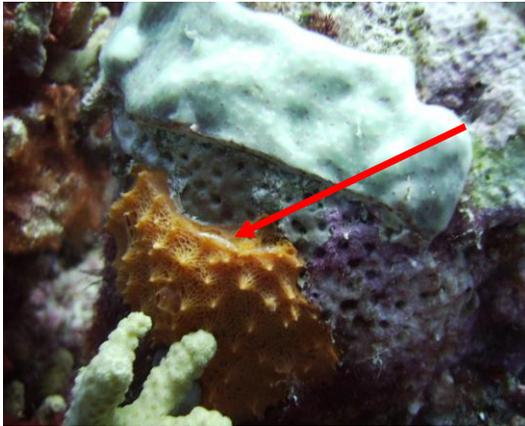


Figure 7. *Ulosa ruetzleri* after removal of *T. solidum*. Arrow indicates intact tissue.

Through this study the success of the invasive colonial tunicate *Trididemnum solidum* in its expanded range was demonstrated through both observation and experimentation. I found that *T. solidum* uses both overgrowth and allelopathy to effectively and rapidly expand its colonies (Fig. 5 and 6). However, the fact that the non-native ascidian uses both these strategies to expand its range raises more questions. The “evolution of increased competitive ability” (EICA) hypothesis attempts to explain the success of invasive plants in non-native environments (Blossey and Nötzold 1995). It states that when invasive plants are released from their natural predators and pathogens they can invest more energy in size expansion or rapid reproduction, thus giving them a competitive advantage over native plants (Blossey and Nötzold 1995, Callaway and Ridenour 2004). This hypothesis has been demonstrated in garden plant species (Blumenthal and Hufbauer 2007) and kudzu, *Pueraria montana* (Callaway and Ridenour 2004). The invasive behavior of *T. solidum* fits this model as it has no known predator in its invasive range, grows rapidly when compared to other native benthic organisms, and produces free swimming pelagic larvae once a day (Bak et al. 1981).

The allelopathic behaviors of *T. solidum* also fit another component of EICA – the “novel weapons” hypothesis. The novel weapons

hypothesis attributes the success of invasive plants to their production of allelopathic chemicals that negatively affect native species (Callaway and Ridenour 2004, see also He et al. 2009). The allelopathic chemicals used by the invasive species are different from the local co-evolutionary trajectory which gives the invasive plant a competitive advantage over native flora. As was demonstrated by both observation (Figs. 5 and 6) and staged interactions (Table 1) there was strong evidence that *T. solidum* uses allelopathy to expand its colonies. Given this new information, the growth patterns of *T. solidum* may not only support EICA and novel weapons hypotheses but also provide one of the first examples of these hypotheses in a marine setting.

Overall this study successfully provided initial estimates of abundance, diversity and density of sponges on a reef where *Trididemnum solidum* is present, quantified the abundance *T. solidum*, and investigated the allelopathic and/or overgrowth responses of native sponges and *T. solidum* when they are engaged in spatial competition. In light of these successes, the study demonstrated that allelopathic and overgrowth behaviors of sponges and *T. solidum* are similar to those found in other *in situ* competition studies, and the presence of *T. solidum* does, in fact, increase competition for space between itself and native sponges, potentially altering the structure and distribution of the native sponge community via selective competition. Additionally, this study raises questions for further research on whether the competitive success, growth patterns, and allelopathic abilities of *T. solidum* can be used to support the evolution of increased competitive ability and novel weapons hypotheses. In conclusion, by studying and understanding how invasive species alter historically isolated environments such as the sponge communities in Bonaire, NA, we can better understand how unique ecosystems persist in an ever changing and uncertain world.

Acknowledgements

I would like to thank Arizona State University for providing funding towards my study abroad experience, Dr. Amanda Hollebhone for her guidance and advice, the CIEE staff (Amanda deVillers and Anna Malek) for research and diving support, my fellow classmates for their help during the reviewing process, and of course, my family and friends for providing encouragement and support every step of the way.

References

Aerts, L. A. M. 1998. Sponge/coral interactions in Caribbean reefs: analysis of overgrowth

- patterns in relation to species density and cover. *Marine Ecology Progress Series* 175:241–249.
- Aerts, L. A. M. and R. W. M. van Soest. 1997. Quantification of sponge/ coral interactions in a physically stressed reef community, NE Colombia. *Marine Ecology Progress Series* 148:125–134.
- Bak, R. P. M., D. Y. M. Lambrechts, M. Joenje, G. Nieuwland, and M. L. J. van Veghel. 1996. Long-term changes on coral reef in blooming population of a competitive colonial ascidian. *Marine Ecology Progress Series* 133:303–306.
- Bak, R. P. M., J. Sybesma, and F. C. van Duyl. 1981. The ecology of the tropical compound ascidian *Trididemnum solidum*. II. Abundance, growth and survival. *Marine Ecology Progress Series* 6:43–52.
- Blossey, B., and R. Nötzold. 1995. Evolution of increased competitive ability in invasive nonindigenous plants: a hypothesis. *Ecology* 83:887–889.
- Blumenthal, D. M., and R. A. Hufbauer. 2007. Increased plant size in exotic populations: A common-garden test with 14 invasive species. *Ecology* 88:2758–2765.
- Callaway, R. M. and W. M. Ridenour. 2004. Novel weapons: invasive success and the evolution of increased competitive ability. *Frontiers in Ecology and the Environment* 2:436–443.
- Cruz-Pinon, G., J. P. Carricart- Ganivert, J. Espinoza-Avalos. 2003. Monthly skeletal extension rates of the hermatypic coral *Montastrea annularis* and *Montastrea faveolata*: Biological and environmental controls. *Marine Biology* 143:491–500.
- Dayton, P. K. 1971. Competition, disturbance, and community organization: the provision and subsequent utilization of space in a rocky intertidal community. *Ecological Monographs* 41:351–389.
- Engel, S. and J. R. Pawlik. 2000. Allelopathic activities of sponge extracts. *Marine Ecology Progress Series* 207:273–281.
- Engel, S. and J. R. Pawlik. 2005. Interactions among Florida sponges. I. Reef habitats. *Marine Ecology Progress Series* 303:133–144.
- He, W. M., Y. Feng, W. M. Ridenour, G. C. Thelen, J. L. Pollock, A. Diaconu, R. M. Callaway. 2009. Novel weapons and invasion: Biogeographical differences in the competitive effects of *Centaurea maculosa* and its root exudates (\pm)-catechin. *Oecologia* 159:803–815.
- Jackson, J. B. C. 1977. Competition on marine hard substrata. The adaptive significance of solitary and colonial strategies. *The American Naturalist* 111:743–767.
- Jackson, J. B. C. and L. Buss. 1975. Allelopathy and spatial competition among coral reef invertebrates. *Proceedings of the National Academy of Science, USA* 72:5160–5163.
- McGrath, E. and R. Peachey. 2008. The colonial tunicate *Trididemnum solidum* in the Bonaire National Marine Park: Colony removal as a potential management strategy. *International Coral Reef Symposium: Poster Presentation*.
- Thacker, R. W., M. A. Becerro, W. A. Lumband, and V. J. Paul. 1998. Allelopathic interactions between sponges on a tropical reef. *Ecology* 79:1740–1750.
- Turon, X., M. A. Becerro, M. J. Uriz, and J. Llopis. 1996. Small-scale association measures in Epibenthic communities as a clue for allelochemical interactions. *Oecologia* 108:351–360.

Are different feeding strategies utilized by the bar jack (*Caranx ruber*) related to foraging success in coral reef habitats?

Michelle von Sternberg*
Eckerd College

Abstract

Foraging success is affected by choice of feeding association, color phase, and habitat type. Bar jacks (*Caranx ruber*) exhibit a number of feeding associations, changes in coloration from silver to dark brown/black, and utilize different habitat types within the fringing reef ecosystem for feeding. The objective of this study is to determine if foraging success is affected by 1) feeding association utilized (individual, conspecific, or multispecies groups) 2) color (black or silver) or 3) habitat type (reef flat or reef slope). Observations of *C. ruber* were conducted at two dive sites on the fringing reef of Bonaire using SCUBA. The number of bites min^{-1} was used as a measure of foraging success. Analysis of results shows that *C. ruber* has significantly greater foraging success when feeding alone and in multispecies groups as opposed to feeding with conspecifics. Dark brown/black *C. ruber* have double the feeding rate as that of silver and habitat type did not have an effect on *C. ruber* foraging success. In conclusion, foraging success of *C. ruber*, measured in bites min^{-1} , is affected by choice of feeding association and coloration, but is not affected by choice of habitat.

Introduction

Animals utilize a diverse range of feeding strategies to improve foraging success (Holekamp et al. 1997, Diamant and Shpigel 1985). For example, mountain lions, lynx, and tigers are solitary hunters (Hornocker 1969), while hyenas hunt in groups of conspecifics (Holekamp et al. 1997). Fish feed in multispecies associations with monkeys by following the monkeys along river banks (Sabino and Sazima 1999). Reef fish, in particular, employ a variety of unique feeding behaviors including multispecies feeding associations, color change, and habitat selection (Strand 1988, Deloach and Humann 1999, Palma and Ojeda 2002). Groupers and wrasses, utilize multispecies foraging practices to gain access to prey organisms living in the substrate (Strand 1988). Reef fish benefit from multispecies feeding groups as the associated species flush out prey items from crevices that are otherwise inaccessible, providing access to a broader range of prey items (Silvano 2001, Diamant and Shpigel 1985).

The bar jack (*Caranx ruber*) is common to the southern Caribbean (Humann and Deloach 2002); feeding primarily on fish and occasionally invertebrates (Baird 1993). *C. ruber* forages alone (Fig. 1), in groups of conspecifics (Fig. 2), and in multispecies associations with goatfishes, southern stingrays, eels, and octopuses (Fig. 3) (Deloach and Humann 1999). In Belize, *C. ruber* benefits from multispecies foraging associations with puddingwife wrasses (*Halichoeres radiatus*) by increasing feeding rates (Baird 1993). One of the goals of this study was to determine the effect that group feeding strategies have on *C. ruber* foraging success off the coast of Bonaire. I hypothesize that

C. ruber has greater foraging success when feeding in multispecies groups than when feeding with conspecifics or when feeding alone because *C. ruber* will gain access to prey items that are disturbed by the multispecies group.

Another feeding strategy reef fish employ to improve foraging success is to change color (Kaufman 1976). For example, sit-in-wait predators, such as flounders, frogfishes, and scorpionfishes, use color to disguise themselves from prey (Deloach and Humann 1999). *C. ruber* changes from silver (Fig. 2, Fig. 3) to dark brown or black (Fig. 1) when near the bottom (Deloach and Humann 1999). I hypothesize that *C. ruber* will have greater foraging success when dark brown/black than when silver because of increased crypsis to prey while feeding.

Foraging success can be affected by the habitat in which an organism is feeding (Palma and Ojeda 2002). For example, *C. ruber* forages on organisms on the reef flat (Fig. 3), which is characterized by sandy substrate with sparse coral heads, or the reef slope (Fig. 1, Fig. 2), which is characterized by numerous species of corals and sponges. Type of habitat affects prey abundance, and type (Eklöv 1997), which may have an influence on foraging success. Due to the increase in topographical complexity of the reef slope, I hypothesize that *C. ruber* will have greater foraging success on the reef slope compared to the reef flat. To determine if multispecies associations, color alteration, and habitat type increase foraging success, the feeding rates of *C. ruber* will be used as a proxy for foraging success.

*vonstempl@eckerd.edu



Figure 1. Dark brown/black *Caranx ruber* feeding alone on the reef slope at the Yellow Sub dive site off the leeward coast of Bonaire.



Figure 2. Silver *Caranx ruber* feeding with a conspecific on the reef slope at the Yellow Sub dive site off the leeward coast of Bonaire.



Figure 3. Silver *Caranx ruber* feeding in association with a sharptail eel (*Myrichthys breviceps*) on the reef flat at the Yellow Sub dive site off the leeward coast of Bonaire.

Materials and Methods

Study Sites

The sampling sites for this study are located on the west coast (leeward side) of Bonaire, Netherlands Antilles, at the dive sites Yellow Sub (12°09'36.39" N, 68°16'55.33" W) and Donkey Beach (12°07'59.37" N, 68°16'54.56" W), with the majority of observation dives at Yellow Sub. The topography is very similar at both sites with the reef slope averaging 13 m and the reef flat averaging 4 m in depth.

Behavioral Observations

Dives were carried out over a period of three weeks from mid-March through the first week of April. Each dive began with a 30 minute observation period on the reef slope, followed by a 30 minute observation period on the reef flat. Five minute observations were made of individual *C. ruber*. However, some individuals were swimming so fast that they could only be followed for a short period of time. Feeding association, color, habitat type, number of bites, and time observed were recorded for each *C. ruber*. A bite was defined as any time *C. ruber* took a bite on the substrate or made an obvious snap into the water column. Sometimes *C. ruber* swam slowly, opening and closing its mouth continuously; this was not considered a bite. When *C. ruber* switched feeding associations, for example, from solitary to a multispecies feeding group, the new time was recorded and each account was counted as a separate observation. Number of bites and observation time were converted into feeding rates (bites min^{-1}).

Statistical analysis

StatView version 5.01 was used to run statistical analyses. A one-way ANOVA tested the differences in feeding rates for each of the feeding strategies: feeding associations, color, and habitat. Fisher's PLSD (protected least significant difference) test was used to detect differences among each of the feeding associations: solitary, conspecific and multispecies groups.

Results

Fourteen dives were conducted during this study, with a total of 128 observations of *C. ruber* feeding behavior ($n=128$). In 76 observations *C. ruber* was feeding alone, in 26 *C. ruber* was feeding with conspecifics, and in 26 *C. ruber* was feeding in multispecies groups.

Feeding associations

There was a significant interaction between feeding association (solitary, conspecific, and multispecies) and feeding rate (One-way ANOVA; $p=0.004$) (Fig. 4a). *C. ruber* in solitary and multispecies feeding groups had greater foraging success than when feeding in conspecific groups. There was a significant difference between solitary (1.4 ± 2.1) and conspecific feeding rates (0.1 ± 0.3) (Fisher's PLSD; $p=0.003$) and between multispecies (1.8 ± 2.4) and conspecific feeding rates (0.1 ± 0.3) (Fisher's PLSD; $p=0.002$). Solitary and multispecies feeding rates were similar (1.4 vs. 1.8 , respectively) and no significant difference was found (Fisher's PLSD; $p=0.423$).

Color alteration

Color has a significant affect on feeding rates of *C. ruber* (One-way ANOVA; $p < 0.001$) (Fig. 4b). Dark brown/black *C. ruber* had more than double the feeding rate of silver *C. ruber* ($2.2 \text{ bites min}^{-1}$ compared to 0.8).

Habitat selection

Habitat type did not have a significant affect on foraging success (One-way ANOVA; $p = 0.644$) (Fig. 4c). Mean feeding rates of *C. ruber* on the reef flat ($1.4 \text{ bites min}^{-1}$) and the reef slope ($1.2 \text{ bites min}^{-1}$) were very similar.

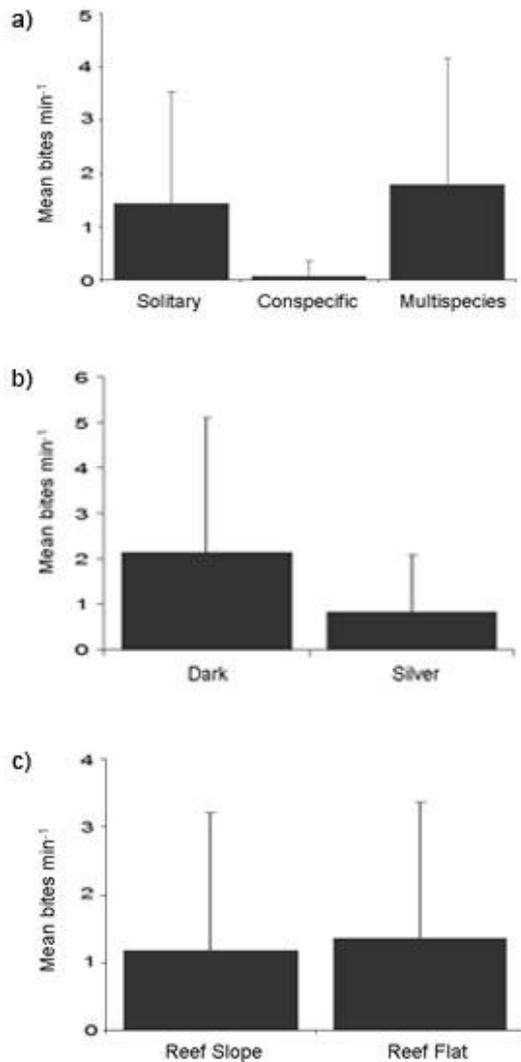


Figure 4. Mean feeding rates (bites min^{-1}) (\pm SD) of *Caranx ruber* when feeding a) alone, with conspecifics, and in multispecies groups b) when dark brown/black vs. silver and c) on the reef slope and the reef flat in fringing reef ecosystems at 2 dive sites off the leeward coast of Bonaire, Netherlands Antilles.

Discussion

The purpose of this study was to examine the relationship between foraging success of the bar

jack (*C. ruber*) and three factors (feeding association, color, and habitat). *C. ruber* had higher foraging success when feeding in a multispecies group or when feeding alone than when feeding with conspecifics. Dark *C. ruber* had higher foraging success than the silver phase and habitat choice had no effect on foraging success.

Feeding associations

Although it is thought that groups of fish usually benefit most from homogeneous groups (Ward et al. 2002), *C. ruber* had the lowest feeding rate in conspecific groups (Fig. 4a). The lower feeding rate may be due to intraspecific competition. For example, when *C. ruber* feeds with a conspecific, the individuals would be competing for the same prey.

C. ruber may have greater feeding rates in multispecies associations than in conspecific groups because the associations can provide access to a greater range of prey items. For example, horse-eye jacks (*Caranx latus*) gain access to benthic fishes when feeding in associations with eels and octopuses (Silvano 2001). Multispecies associations may also be beneficial because *C. ruber* may be using less energy while feeding with other species as opposed to foraging in conspecific groups or alone. I observed that *C. ruber* usually hovers above the multispecies group (Fig. 3) whereas solitary *C. ruber* expends greater energy swimming around the reef searching for food.

Many times, *C. ruber* would chase away other *C. ruber* approaching their multispecies association, but sometimes approaching *C. ruber* would take over the association by chasing the former away. Baird (1993) observed similar acts of aggression by *C. ruber* toward conspecifics that tried to join associations with puddingwife wrasses (*Halichoeres radiatus*). *C. ruber* is protecting the association showing that it is a beneficial resource worth expending energy to defend.

During this study, *C. ruber* was most often observed feeding alone (76 accounts compared to 26 observations for both conspecific and multispecies groups). Solitary feeding does not require forming an association and foraging success was not different from when feeding in multispecies groups. However, *C. ruber* may exploit multispecies feeding groups when possible due to the added benefit of other prey not available outside the association.

Color alteration

The hypothesis that dark *C. ruber* will have greater foraging success than silver was supported. Dark brown/black *C. ruber* had feeding rates double that of silver (Fig. 4b). This may be due to an increase in the degree of crypsis from prey. For example, hogfish employ a solid, light coloration in the water column, but change to a darker coloration

with a bar pattern when near the bottom (Deloach and Humann 1999). This enables hogfish to blend in with gorgonians and other vertical bottom structures when they are feeding (Deloach and Humann 1999).

Habitat selection

The hypothesis that *C. ruber* foraging success is greater on the reef slope than on the reef flat was not supported by this study. No difference was found between the feeding rates of *C. ruber* in the 2 habitats (Fig. 4c). *C. ruber* foraged alone, with conspecifics, and in multispecies groups on the reef slope and the reef flat, and both colors, silver and dark, were found in both habitats. Similar feeding rates may indicate that there are equivalent food resources in both habitats.

In conclusion, *C. ruber* had greater foraging success when feeding alone or in multispecies groups compared to conspecific groups. Dark *C. ruber* had double the feeding rates of silver *C. ruber*, and habitat type did not affect foraging success.

Acknowledgements

I would first like to thank Dr. Rita Peachey for her advice and encouragement through out my project and the CIEE staff for their support. Thank you to Anna and Amanda for helping me out and answering all my questions. Thank you to Marylou, Katie, Julie, and Nate for being my dive buddies! Thank you to STINAPA and DROB for letting me conduct research in the marine park and to Yellow Sub dive shop for always being so helpful. Thank you to Eckerd College for funding and CIEE for creating such a wonderful program. Lastly, thank you to my family for making this opportunity possible.

References

- Baird, T. 1993. A new heterospecific foraging association between the puddingwife wrasse, *Halichoeres radiatus*, and the bar jack, *Caranx ruber*: evaluation of the foraging consequences. *Environmental Biology of Fishes* 38:393-397.
- Deloach, N. and P. Humann. (1999). *Reef fish behavior: Florida, Caribbean, Bahamas*. Jacksonville: New World Publications.
- Diamant, A. and M. Shpigel. 1985. Interspecific feeding associations of groupers (Teleostei: Serranidae) with octopuses and morey eels in the Gulf of Eilat (Aqaba). *Environmental Biology of Fishes* 13:153-159.
- Eklöv, P. 1997. Effects of habitat complexity and prey abundance on the spatial and temporal distributions of perch (*Perca fluviatilis*) and pike (*Esox lucius*). *Canadian Journal of Fisheries and Aquatic Sciences* 54:1520-1531.
- Holekamp, K., Smale, L., Berg, R., and S. Cooper. 1997. Hunting rates and hunting success in the spotted hyena. *Journal of Zoology* 242:1-15.
- Hornocker, M. 1969. Winter territoriality in mountain lions. *The Journal of Wildlife Management* 33:457-464.
- Kaufman, L. 1976. Feeding behavior and functional coloration of the Atlantic Trumpetfish, *Aulostomus maculatus*. *Copeia* 1976: 377-378.
- Palma, A. and F. Ojeda. 2002. Abundance, distribution and feeding patterns of a temperate reef fish in subtidal environments of the Chilean coast: the importance of understory algal turf. *Revista Chilena de Historia Natural* 75:189-200.
- Sabino, J., and I. Sazima. 1999. Association between fruit-eating fish and foraging monkeys in western Brazil. *Ichthyological Exploration of Freshwaters* 10:309-312.
- Silvano, R. 2001. Feeding habits and interspecific feeding associations of *Caranx latus* (Carangidae) in a subtropical reef. *Environmental Biology of Fishes* 60:465-470.
- Strand, S. 1988. Following behavior: interspecific foraging associations among Gulf of California reef fishes. *Copeia* 1988:351-357.
- Ward, A., Axford, S., and J. Krause. 2002. Mixed-species shoaling in fish: the sensory mechanisms and costs of shoal choice. *Behavioral Ecology and Sociobiology* 52:182-187.

The salinas of Bonaire: how does bird activity impact epi- and infaunal communities?

Julie Sickels*

Eckerd College

Abstract

Predators can play an important role in shaping prey community structure and function through direct and indirect top-down effects. Bird predators in particular can decrease lower trophic level populations in a variety of habitats from terrestrial soils to coastal sediments. In the unique, high salinity salina habitats of Bonaire, NA top-down effects may be present as a result of the migratory bird community consuming epi- and infaunal organisms. In this study, I assessed the make-up of the bird community feeding in three salinas (Marina, Sorobon, City Shop) through morning and evening observations as well as the epi- and infaunal organisms of salina sediments through coring. The birds found to utilize the sediments of the salinas for feeding included flamingos, reddish egrets, great egrets, snowy egrets, great blue herons, plovers, and willets; different species richness per site. The coastal succulent, *Sesuvium portulacastrum*, and seagrass occupy the salinas from approximately 1%-8%. Snails were found in the sediments of all 3 locations (Sorobon $24.9 \pm 7.6 \text{ m}^{-2}$, Marina & City shop $0.3 \pm 0.58 \text{ m}^{-2}$) and fiddler crabs ($8.93 \pm 4.05 \text{ m}^{-2}$) were found only at the Marina site. In addition, I attempted to understand how the birds may structure infaunal communities through their feeding habits by using field-based feeding preference choice assays. Five plots, separated into four squares containing crabs, snails, plants, and a control (one per square), were placed at each of the three previously chosen monitoring locations. The plants and snails were not consumed in the experimental food assays, but approximately 90% of the crabs were consumed. The crab densities and percent plant coverage in the control plots remained constant to the original data collected, suggesting the feeding assay plots didn't have an affect on the predators feeding. The presence of crabs at Marina and snails at Sorobon may be supported by the differences in sediment composition. Sediments at Marina were found to be composed of more coarser-grained particles versus the sediments at Sorobon which are more fine-grained particles. This may suggest that bottom-up effects may impact, shape the epi- and infaunal communities where potential predators are present.

Introduction

Top-down effects of predators may be significant in shaping ecological community structure and function through direct and indirect processes. The influences vary among habitat types depending on what predators are present and what they prey on (Posey et al. 2002). For example, herbivory on seagrasses by dugongs has been shown to have negative direct impacts on seagrass productivity and growth through consumption as well as negative, indirect effects on the infaunal community by removing and consuming extensive patches of seagrass, disturbing the sediments (Nakaoka 2005). As a result of overfishing cod stocks in the northern Atlantic, cod populations decreased significantly, and populations of cod's preferred prey, shrimp, snow crab, and lobster increased in abundance (Worm and Meyers 2003). As a result of this study Worm (2003) concluded that predators can suppress lower trophic levels in ocean food webs and also suggested the same effect in lakes, streams, and other inhabited bodies of water.

Shorebirds in particular, are a prevailing part of shallow water estuarine areas, feeding primarily on fish and macro invertebrates (Erwin 1996). Shorebirds also have direct effects on their

prey through consumption and may indirectly affect other epibenthic predators such as shrimp by decreasing prey availability through the physical disruption of sediments when feeding (Mendonca et al. 2007). In Maine, gulls are capable of lowering densities (83 crabs km^{-2} in one diurnal tidal cycle) of sessile and slow-moving invertebrates (e.g., crabs) through consumption (Ellis et al. 2004). Birds may even act as habitat modifiers rather than exploitative competitors for small herbivorous crustaceans in rocky inter-tidal habitats. By reducing the larger crab populations, the algal community increases in percent cover, in turn providing more food for smaller crustaceans and gastropods (Masakazu et al. 2005).

On the island of Bonaire, NA, there are unique salina habitats, which are shaped by limestone, causing the soil to poorly retain water. Precipitation directly runs off into the ocean or into these temporarily flooded hypersaline lake. Salinas are known to support fish populations and act as nesting and feeding grounds for many migratory birds (Jago et al. 2006), including the great egret (*Ardea alba*), reddish egret (*Egretta rufescens*), snowy egret (*Egretta thula*), and great blue heron (*Ardea Herodias*) (J. Sickels personal observation). These birds have been documented to feed mostly on shrimp, crabs, insects, and fish (Post 2008), although the degree to which we find

*sickelja@eckerd.edu

these prey in the waters and sediments of Bonaire's salinas has been relatively unknown.

In this study I addressed the following questions: (1) What is the composition of bird communities utilizing the salina habitats of Bonaire? (2) What organisms are living on and in salina sediments? (3) Do birds prefer particular food options on and in the salina sediments, and (4) Are the birds structuring infaunal communities through their feeding habits?

Materials and Methods

Observational:

In order to assess the make-up of the epi- and infaunal communities in the "inter-tidal zone" (between the waterline and dry land) of Bonaire's salinas, three 10m long transect lines were haphazardly placed within 10m of the waterline along the shores of three salinas located at the Harbor Village Marina (12°16'53.00N, 68°28'36.80"W), Sorobon (12°12'03.30N, 68°24'11.10W) and City Shop (12°13'90.60N, 68°27'29.70W) within 10m of the waterline. A 1/16 m² quadrat was placed at five randomly chosen points along each transect line. The percent cover of plants per quadrat was estimated with a grid of 16 squares placed on top of the quadrat. The density of organisms living in the sediments was determined by taking one random core (10cm long x 6.5cm diameter PVC pipe) from each quadrat. These sediments were returned to the lab sieved (100µm mesh), and all organisms preserved in 70% ethanol for further identification.

In addition, the bird community actively using the "inter-tidal" zone of the salinas was identified. For the purposes of this study, I focused on any bird actively feeding or searching for food (pecking at the sediment) in this zone. During three morning (10:00) and three afternoon (15:00) sessions, I identified and counted birds feeding in the "inter-tidal" zone of the three salina study sites described previously. I allowed for a 10-15 minute acclimation period to ensure the birds were not influenced by my presence and then observations were made for 30 minutes using binoculars. This data may suggest the reasons for patterns in prey spp.

Upon preliminary observation of the salinas, the sediments at each of the study sites appeared to have different composition. Sediment type could influence the organisms present. In order to determine sediment composition, I collected 5 cores (see previous methods) at each study site, directly adjacent (<1/2m away) to the experimental assay plots (see methods below). Each core was returned to the lab in plastic bags, dried at 41°C for 72 hours, crushed with a metal spoon into fine particles, sediments from the 5 cores were pooled according to site, and mixed. Three grams from

each core were weighed (Mettler Toledo X5205) and sifted through a 30µm sieve. The resulting particles (<30µm) were weighed and their percent composition of the 3g sample was determined. The remaining portion of each 3g sample was added to 200mL of tap water. A 1mL aliquot was then pipetted onto a counting cell and observed under a compound microscope (LOMO NXE0184). The first 100 particles within a randomly chosen cell were counted and placed into size categories (30-50µm, 50-100 µm, 100-250 µm, 250-500 µm, and >500µm). The data were analyzed with a 2-way ANOVA to determine if each site and/or size range had a significant impact on the percent composition of sediments.

Experimental:

In order to assess the feeding preferences of the birds documented in the exposed sediments of the salinas and how their activities may affect epi- and infaunal community structure, I established experimental choice feeding preference assays in the field (similar to the methods of Erickson et al. 2008). Food choices were based upon the data I obtained from the transect monitoring described previously. At each of the three chosen salinas, five food arrays were established in haphazardly located, roped-off 1 m² plots (divided into 4 squares) just above the waterline. Each square of each plot was randomly seeded with either fiddler crabs, snails, or plants, based on natural densities from the core data. An open, unseeded square was included as a control to compare with the original, infaunal core data. Fiddler crabs (*Uca spp.*) were tethered using monofilament line (15cm long), and Crazy glue (following similar methodology as described in Hollebone and Hay 2007). Two crabs were anchored in one square of each plot with tethers tied to the rope defining the boundary of the plots. The tethered fiddler crabs were kept in the lab for 72 hours, having all tethers stay on. Snails (*Brachypodella gibbonsi* and *Microceramus bonairensis*) were also tethered using the same technique. Five snails were used in each plot at the Marina and City Shop locations, while 10 were used at the Sorobon site due to higher natural densities. Plants that were already rooted in the sediments of the plots were physically pulled out so that the resulting cover resembled the mean percent cover found during initial monitoring (Sorobon: ~1% sea grass, Marina: ~8% *Sesuvium portulacastrum*, and City Shop: ~2% *Sesuvium portulacastrum*). All of the plots were monitored and photographed on the second and fourth day following the initiation of the experiment. The experiment was repeated for a second time with newly tethered crabs and snails. The results from both trials were combined. All of the crab tethers were collected on the fourth day and grouped into four categories: consumed (holes or carapace

missing), molted (just top carapace, no bite marks), lost legs (dead with only missing limbs), and dead (whole, no evidence of predation). The condition of the snails and plants was also documented. A 2-way ANOVA was used to determine if experimental fiddler crabs were significantly affected by site and/or fate. The unseeded, control square was tested by taking one random core in each control square, using the previously described methods.

Results

Bird Community

The bird observations showed that 5 bird species (greater flamingo, great egret, snowy egret, reddish egret, and willet) were commonly found at the City Shop site, 3 species (greater flamingo, reddish egret, and great blue heron) at the Sorobon site, and 5 species (greater flamingo, great egret, great blue heron, reddish egret, and plover) at the Marina site that actively fed in the “inter-tidal” zone from February to April 2009 (Fig. 1). All of the documented birds are known to be predators of organisms such as crustaceans and fish (Post 2008). Willets and the greater flamingo may be considered omnivorous.

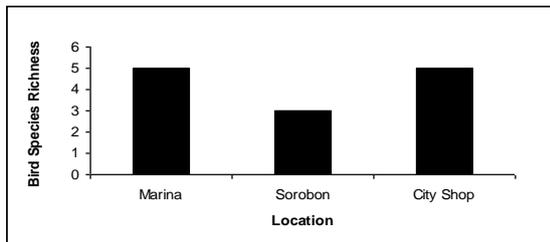


Figure 1. Species richness of birds observed feeding in the “inter-tidal” zone at the Marina, Sorobon, and City Shop sites.

Epi- & Infaunal Communities

Plants were present at all monitoring locations, although their composition differed. *Sesuvium portulacastrum* was present at the Marina and City Shop sites at $8.33 \pm 10.4\%$ and $2.08 \pm 3.61\%$ mean cover, respectively. *Sesuvium portulacastrum* was not found in the monitoring zone at the Sorobon site, but seagrasses were found at $1.25 \pm 2.17\%$ cover (Fig. 2). A 1-way ANOVA showed no significant differences in percent plant cover due to site ($p=0.400$). Fiddler crabs (*Uca spp.*) were

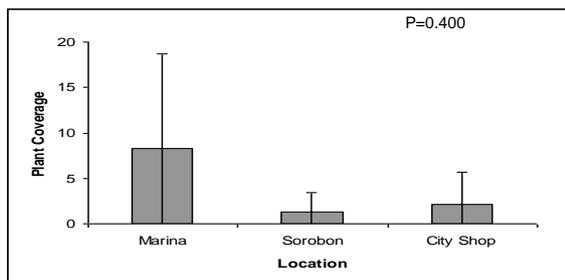


Figure 2. Mean percent plant coverage (\pm SD) at Marina, Sorobon, and City Shop study sites. Data was analyzed using a one-way ANOVA ($p=0.400$).

found only at the Marina location at densities of $8.93 \pm 4.05 \text{ m}^{-2}$, whereas snails (*Brachypodella gibbonsi* and *Microceramus bonairensis*) were present at all three locations with densities of $24.9 \pm 7.6 \text{ m}^{-2}$ at Sorobon and $0.3 \pm 0.58 \text{ m}^{-2}$ at Marina and City Shop (Fig. 3). A 2-way ANOVA showed that there was a significant difference in the densities of crabs and snails due to site ($P<0.001$).

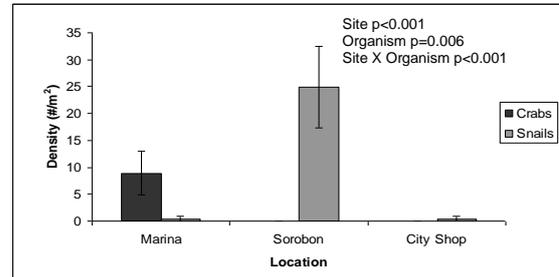


Figure 3. Mean density of crabs and snails (\pm SD) documented at Marina, Sorobon, and City Shop study sites. Densities were compared using a 2-factor ANOVA (Site $p<0.001$, Organism $p=0.006$, Site x Organism $p<0.001$).

Sediment

Analysis of sediment particle size showed that percent composition varied significantly among salina locations (Fig. 4). Marina sediments composed of more larger coarse-grained particles ($>100\mu\text{m}$) than Sorobon sediments which were composed of more smaller particles ($<50\mu\text{m}$). The composition of sediments from the City Shop site was intermediate to those of Marina and Sorobon (Fig. 4). A 2-factor ANOVA showed that the sediments of the three study sites differed significantly in their composition (site $p=0.745$, particle size $p<0.001$, site x particle size $p<0.001$).

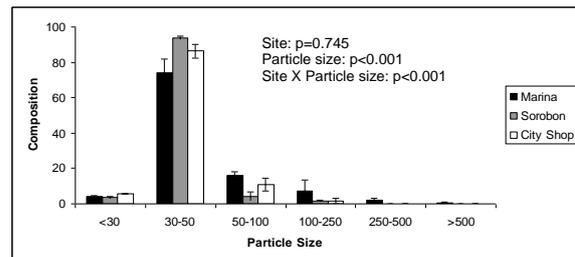


Figure 4. Mean percent composition of particle sizes (\pm SD) from sediments at Marina, Sorobon, and City Shop study sites. The particles were categorized as $<30\mu\text{m}$, $30\text{-}50\mu\text{m}$, $50\text{-}100\mu\text{m}$, $100\text{-}250\mu\text{m}$, $250\text{-}500\mu\text{m}$, and $>500\mu\text{m}$. The data was analyzed using a 2-factor ANOVA (Site $p=0.745$, Particle size $p<0.001$, Site x Particle size $p<0.001$).

Feeding Assays

The feeding assays provided data on the epi- and infaunal communities; are there predators present, consuming these organisms? At all the locations snails were never consumed and the percent cover of plants remained constant from March 18-29, 2009. Only 2% of the tethered snails actually survived possibly due to close proximity to the waterline, found at the Marina Site. However, the fiddler crabs were consumed at all of the locations within the first 4 days during both trials. A crab was considered consumed if it was hollow, had holes poked out, or had carapace detachment

(Fig. 5a, b). Consumption was highest at the Marina site ($35 \pm 22\%$), followed by the Sorobon ($30 \pm 11\%$) and City Shop sites ($25 \pm 25\%$). At Sorobon I found the highest percentage of crabs ($20 \pm 11\%$) with missing limbs, followed by $5 \pm 11\%$ at City Shop and 0% at the Marina (Fig. 6). Molting (Fig. 5c, d) occurred more at the Marina site ($25 \pm 25\%$), compared with City Shop ($15 \pm 22\%$), and Sorobon ($10 \pm 13\%$).

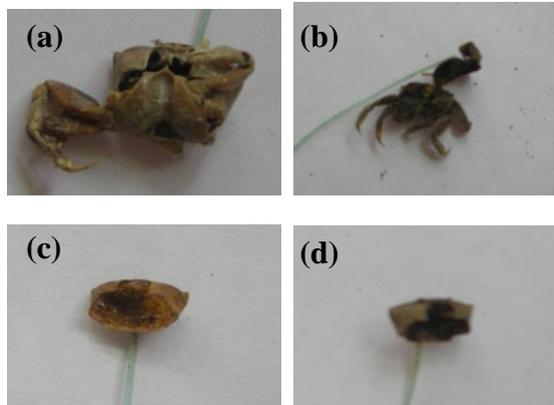


Figure 5. Representative remnants of tethered crabs considered to be (a) & (b) consumed and (c) & (d)

Crab mortality from desiccation occurred at frequencies of $45 \pm 21\%$ and $35 \pm 29\%$ for the City Shop and Sorobon sites, respectively whereas only $5 \pm 11\%$ of the crabs at the Marina were lost this way. The crab and percent plant cover in the unmodified, control square for each assay plot stayed constant with the beginning evaluation. The only notable difference in the cores was an increase in the density of snails at Sorobon from 24.9 ± 7.6 per m^{-2} to 62.0 ± 69.0 per m^{-2} (Fig. 7). In addition, from the initiation of the feeding assays, March 18, 2009 until March 29, 2009, the waterline at the Sorobon site receded $\sim 32m$ from the plots.

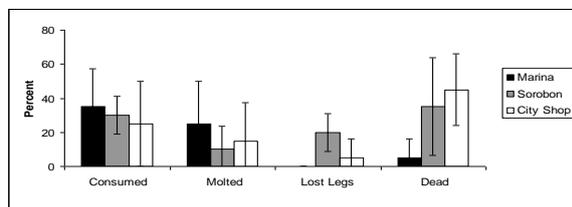


Figure 6. Mean percentage of tethered fiddler crabs (\pm SD) consumed, molted, missing limbs, and dead (whole) at the Marina, Sorobon, and City Shop study sites. Data pooled from two, 4 day long trials.

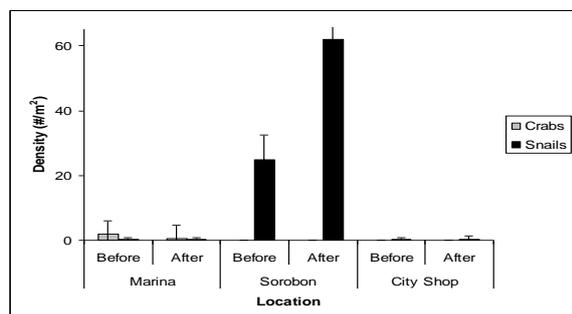


Figure 7. Mean densities (\pm SD) of crabs and snails found in the sediment at each salina. “Before” = original monitoring and “After” = upon completion of the feeding

Discussion

Five bird species were documented at the Marina and City Shop study sites and three were found at the Sorobon study site (Fig. 1). The diets of these shorebirds mainly consist of fish, crustaceans, and insects (Post 2008). Marina has an abundance of crabs for the birds to prey on. Considering the diet of the birds present at the City Shop location, (greater flamingo, great egret, reddish egret, and willet) there could potentially be fish in the deeper depths of the salina. Sorobon, with lower bird species richness, has been observed to have fewer and fluctuating potential prey options in the “inter-tidal” zone. Other possible causes of lower species richness could be due to competition between birds or other organisms, location, salinity level, nesting habitat choice, other food options, or sediment type. The distribution of predatory shorebirds is thought to be directly connected with the density of their main prey but the prey availability may be more important (Finn et al 2008). However, Finn (2008) observed the eastern curlew (long-billed shorebird) chose feeding habitats with less substrate resistance over prey density or biomass, concluding that substrate can be an important factor in habitat selection by large bodied shore-birds. Food can be variable during breeding season and shorebirds have been known to relocate their young to areas with rich resources and/or are protected from predators (Kosztolanyi et al. 2007).

There was a significant difference in composition of sediments among the three study locations. The Marina site had the highest percent composition of large particle sizes $>50\mu m$, the Sorobon site had the highest percent composition of smallest particle sizes $<50 \mu m$, and the City Shop was intermediate to the other sites (Fig. 4). It has been previously documented that crabs and snails prefer certain sediment types for protection and food. *Uca* spp. burrow in to the upper portion of sandy beach zones, staying close to the water/wave line, although sometimes washing onshore (Boshe 1982). The sediments found at the Marina site had a sand-like consistency, therefore, this may explain why higher crab densities were found at this site. The “inter-tidal” zone at each salina may be fully or in part shaped by bottom-up effects, where organisms live in a certain location because of the substrate type, food availability, or production (Gimenez et al. 2009). The sediments at the Sorobon site were very smooth and clay-like, making it a potentially preferred habitat for snails due to food availability (Alfaro et al. 2007). Personal observations during the feeding assays suggested that the sediments at Sorobon are too thick for fiddler crabs to effectively dig borrows; only small indentations were made in the sediment. The composition of City Shop’s sediment is intermediate to the other sites and possibly not

ideal for either snails or crabs to inhabit. In addition, the location of observation at each site may factor into the absence or presence of snails and crabs depending on where the waterline is currently.

In addition to the variability in organisms and sediment composition, the plant type and coverage at each site varied as well. *Sesuvium portulacastrum*, found at Marina ($8.33 \pm 10.4\%$) and City Shop ($2.08 \pm 3.61\%$), is a succulent, ground covering plant. Higher percent cover of *Sesuvium portulacastrum* at the Marina site appeared to correlate with higher fiddler crab densities. The burrowing fiddler crab's activities may aerate the sediments and, thus plant roots (Kristensen 2008). This may increase the growth and or reproductive success of plants over those sites without fiddler crabs. The seagrass seen only at Sorobon could be explained by the fine-grained sediment present compared with course-grained sediment at the Marina site and intermediate grains at the City Shop site.

Over the course of the feeding assays, no snails or plants were consumed at any of the locations. Only two snails survived overall at the Marina site. This may have been a result of desiccation during the month of March when the food assays were running; the water at Sorobon receded ~ 30 meters from the waterline when the plots were initially established, exposing snails to prolonged periods of dry, hot conditions, due to the dry season starting in February and ending in July (Jago et al. 2006). Snails were not typically found at the Marina or City Shop sites, possibly due to a combination of sediment type, food availability, and desiccation due to the receding waterline. The plants were likely not consumed because none of the bird species documented in the "inter-tidal" zone at any of the locations included lush plants in their diet. The fiddler crabs were consumed at all three locations. With highest percent consumption ($35 \pm 22\%$) at the Marina site, followed by Sorobon ($30 \pm 11\%$) and City Shop ($25 \pm 25\%$) (Fig. 6). The tethering may have yielded unnaturally high consumption rates because the tethers can limit mobility of the crabs and could have attracted the attention of the consumers, possibly leading to an elevation in the percent consumption data (Hollebone and Hay 2007). At the Sorobon and City Shop sites, there were ~40-50% of the crabs dying due to desiccation, stress, or any other non-predatory cause (Fig. 6). This may be explained by sediment composition; clay-like sediments may not allow for burrowing activities as discussed previously. The Sorobon and City Shop study sites exhibited dead crabs missing limbs (Fig. 6). These missing limbs may be explained by birds sampling the crabs and the crabs evaded them, a different predator tried to consume the crabs, fighting among

crabs, or autotomy of their limbs, occasionally used during predation attacks (Reaney et al. 2008).

In conclusion, the three salina sites studied show variability in the bird community, sediment type, as well as epi- and infaunal communities. Both, top-down and bottom-up effects have been documented to occur in salt marshes at one location (Johnson et al. 2009). A combination of top-down effects and bottom-up effects may be determining infaunal community structure.

Acknowledgements

I would first like to thank CIEE research station, Bonaire for accepting me into the program and giving me this amazing opportunity. Thanks to Eckerd College and CIEE for the funding. Thank you to Dr. Hollebone for advising me throughout the whole project and the rest of the CIEE staff, Dr. Peachey and Caren Eckrich, and the interns for helpful advise. I would like to thank Amanda deVillers for driving me to all of the Salinas and getting muddy in the process. Thanks to all of my classmates for putting up with the dirt and for the encouragement. Thanks to Yannick de Hoog for endless hours of crab tethering. Thanks to STINAPA and DROB for allowing me to work in the Salinas. Lastly I'd like to thank my family for their ongoing support.

References

- Alfaro, A. C., S. E. Severine, and F. Thomas. 2007. Food habitat partitioning in grazing snails (*Turbo smaragdus*), northern New Zealand. *Estuaries and Coasts* 30:431-440.
- Boshe, J. I., 1982. Predation of fiddler crabs *Uca stenodactyla* (Ocypodidae) by the common shore birds in Pangani Beach, Tanzania. *African Journal of Ecology* 4:237-240.
- Ellis, J. C., W. Chen, B. O'Keefe, M. J. Shulman, and J. D. Witman. 2004. Predation by gulls on crabs in rocky intertidal and shallow subtidal zones of the Gulf of Maine. *Journal of Experimental Marine Biology and Ecology* 324:31-43.
- Erickson, A. A., I. C. Feller, V. J. Paul, L. M. Kwiatkowski, and W. Lee. 2008. Selection of an omnivorous diet by the mangrove tree crab *Aratus pisonii* in laboratory experiments. *Journal of Sea Research* 59:56-69.
- Erwin, R. M. 1996. Dependence of water birds and shorebirds on shallow-water habitats in the mid-Atlantic coastal region: An ecological profile and management recommendations. *Estuaries* 19:213-219.
- Finn, P. G., C. P. Catterall, and P. V. Driscoll. 2008. Prey versus substrate as determinants of Habitat choice in a feeding shorebird. *Estuarine, Coastal and Shelf Science*

- Gimenez, L. 2009. Uncertainty relationships in the estimation of settlement rates of mobile marine organisms. *Marine Ecology Progress Series* 377:103-111.
- Hollebone, A. L. and M. E. Hay. 2007. An invasive crab alters interaction webs in a marine community. *Biological Invasions* 10:347-358.
- Jago, D. S., C. Gerharts, J. Chalk, R. Croes, J. Nolen, F. Simal, K. Rennou, S. Trinidad, J. A. Frans, G. Saragoza, et. al. 2006. Bonaire National Marine Park Management Plan. Part 2:52-89.
- Johnson, D. S., J. W. Fleeger, and L. A. Deegan. 2009. Large-scale manipulations reveal that top-down and bottom-up controls interact to alter habitat utilization by saltmarsh fauna. *Marine Ecology Progress Series* 377:33-41.
- Kosztolanyi, A., T. Szekely, and I. C. Cuthill. 2007. The function of habitat change during brood-rearing in the precocial Kentish plover *Charadrius alexandrinus*. *Acta Ethologica* 10:73-79.
- Kristensen, E. 2008. Mangrove crabs as ecosystem engineers; with emphasis on sediment processes. *Journal of Sea Research* 59:30-43.
- Masakazu, H., N. Takashi, and N. Shigeru. 2005. Effects of avian grazing on the algal community and small invertebrates in the rocky intertidal zone. *Ecological Research* 21:768-775.
- Mendonca, V. M., D. G. Raffaelli, and P. R. Boyle. 2007. Interactions between shorebirds and benthic invertebrates at Culbin Sands Lagoon, NE Scotland: Effects of avian predation on their prey community density and structure. *Scientia Marina* 71:579-591.
- Nakoaka, M. 2005. Plant-animal interactions in seagrass beds: Ongoing and future challenges for understanding population and community dynamics. *Population Ecology* 47:167-177.
- Posey, M. H., T. D. Alphin, L. B. Cahoon, D. G. Lindquist, M. A. Mallin, and M. B. Mevers. 2002. Top-down versus bottom-up limitation in benthic infaunal communities: Direct and indirect effects. *Estuaries* 25:999-1014.
- Post, W. 2008. Exploitation patterns in an assembly of estuarine herons. *Waterbirds* 31:179-192.
- Reaney, L. T., R. Milner, T. Detto, and P. Backwell. 2008. The effects of claw regeneration on territory ownership and mating success in the fiddler crab *Uca mjoebergi*. *Animal Behavior* 75:1473-1478.
- Worm, B. and R. A. Meyers. 2003. Meta-analysis of cod-shrimp interactions reveals top-down control in oceanic food webs. *Ecology* 84:162-173.

Which is more attractive to juvenile fish: availability of food or the complexity of habitat in the mangroves of Bonaire, NA?

Katie Kirschbaum*

Abstract

Habitat selection is critical to the development, growth and reproductive success for most marine animals. Organisms select habitat based on food availability, as in gulls of the North Sea, complexity of structure, as in juvenile fish of seagrass beds, or a combination of both factors as in marine snails of the rocky intertidal zone. Mangrove forests are known to be important habitat and nursery grounds for many endangered and/or economically important species of fish. These habitats are currently under threat by coastal development and overexploitation, therefore, scientifically supported restoration efforts are currently being pursued. The mangroves of Bonaire are threatened by development, causing hypersaline conditions and change in water flow. In this study food availability and composition as well as the structural complexity of the mangrove prop root system were assessed as possible attractants to juvenile fish. Snorkeling observations along permanent transects of the fishes in and amongst the prop roots as well as the algae and invertebrates living on the prop roots were conducted to establish a baseline understanding of the mangrove community (consumers and prey). In order to assess the impacts of consumers on prop root epibiota, consumers were excluded from prop roots using plastic mesh and the regrowth of preferred food species was monitored. The caging experiment showed evidence of the impacts of herbivores in the mangroves as green algae growth increased significantly in their absence and growth of red algae decreased. Artificial mangrove units (AMUs), modeled after prop roots, were also constructed for this study to test the attractiveness of structural complexity to resident fish. Comparisons between the behavior of the fish community of mangrove prop roots and that of AMUs indicated that there is no distinguishable preference between predators and consumers for structurally complex habitat, but that both prefer more complex habitat over simple structure. The data collected concerning preferred food and habitat structural complexity could be used in restoration projects.

Introduction

The selection of appropriate habitat can be critical to the development, growth, and reproductive success of marine organisms. Such selections may be made based on variables such as food availability, complexity of habitat structure or a combination of both factors (Alofs and Polivka 2004, de la Moriniere et al. 2004, Pardo and Johnson 2005). Food availability and diet preference are the main determinants for seabirds, such as gulls, in selecting their preferred habitat. For instance, lesser black-backed gulls feed in the open ocean on fish and crustaceans though mew gulls, herring gulls and black-headed gulls are restricted to the coastal area foraging for bivalves, crustaceans and polychaetes living in the intertidal zone. (Kubetzki and Garthe 2003). In a study on seagrass fish (*Pelates quadrilineatus*, *Syngnathoides biaculeatus*, *Monacanthus chinensis*) and habitat selection, it was found that fish prefer vegetated over unvegetated substrate, furthermore the fish prefer seagrass, a source of food, over *Caulerpa taxiformia*, which provides structure but no other benefit (Burfeind et al. 2009).

Juvenile fish of seagrass beds (e.g. genus *Gobidae*) choose habitat based on 3-dimensional structure; some for shelter, others

for protection from predators (Schultz et al. 2009). Invertebrates, like marine snails, living in the intertidal zone choose habitat based on their own life-cycles and the biological and physical factors of their habitat, including wave action, temperature, food availability, and predation (Pardo and Johnson 2005).

Juvenile mud crabs (*Scylla serrata*) in Australia were found to exhibit active habitat selection when settling from plankton and select structurally complex estuarine habitats of sand and mud with patches of seagrass which can provide both shelter and food (Webley et al. 2009). Snails (*Littorina saxatilis*) along the St. Lawrence River in Quebec are found at highest densities in regions of high food productivity and protection from predators in the intertidal zones, a habitat often characterized by strong gradients in biotic factors such as predation and food availability and abiotic factors such as hydrodynamics; these factors can produce change in life history traits (e.g. size, maturity) (Pardo and Johnson 2005).

Tropical mangrove forests are unique marine habitats that offer many important ecosystem services to the surrounding coastline and the organisms that reside there by acting as buffers against storms, reducing

*kirs0092@umn.ed

erosion and runoff, up-taking carbon, as well as absorbing and transforming nutrients (Nagelkerken et al. 2001). In addition, mangroves are critical habitats to the many species that use the adjacent shallow waters as a nursery; species that are often legally protected because they are endangered or are of commercial importance. (Mumby et al. 2004, Faunce and Serafy 2006, Verweij et al. 2008). For instance, mangroves represent areas of high food availability and low predation risk for juvenile reef fish, such as schoolmaster and mahogany snapper. It has been suggested that these factors contribute to the survivorship and success of juvenile fish that are entrained as plankton by the extensive surface area of mangroves (Laegdsgaard and Johnson 2001, Verweij et al. 2006). Because mangroves are typically located in shallow, sheltered waters and form dense forests with intricate prop root systems, the degree to which food availability or the protective qualities of habitat attracts fish has been difficult to determine (Nagelkerken and Faunce 2008, de la Moriniere et al. 2004). As mangroves are being deforested and overfished, mangrove restoration may become critical to maintaining the health of the reefs (Mumby et al. 2004). Understanding what is attractive to fish in the mangrove habitat may be important in their recruitment to a restored mangrove setting.

On the island of Bonaire, Netherlands Antilles, red mangroves (*Rhizophora mangle*) form dense, fringing forests on the windward side of the island in Sorobon, off the shallow waters of Lac Cai (N 12.09414, W 068.23798). These mangrove trees provide the island with such valuable ecosystem services as reducing wave action, stabilizing sediment, buffer against changes in salinity, and consume and accumulate organic matter and nutrients, acts as a source for small fisheries and is used for recreation. The mangroves of Bonaire have an unusual hydrological pattern of sheet flow and feeder channels, a dieback of red mangroves is thought to be caused by hypersaline conditions caused by damming of these channels (de Meyer and MacRae 2006). These trees have complex prop root structures on the waters edge with algae, sponges and other epibiota (e.g. anemones, bivalves, crabs) growing on the roots.

In Bonaire it is unclear whether it is food availability, structural complexity or a combination of these factors attracting juveniles to this habitat. In this study, I addressed the following: (1) what fish species are utilizing the mangroves as habitat and/or food? (2) what is the composition of organisms

on the mangrove prop roots? (3) how are consumers structuring the community of organisms growing on the prop roots? and (4) how does the complexity of prop root structure influence the fish community present?

Materials and Methods

In order to determine what may attract fish to red mangroves of Sorobon, Bonaire, NA, I conducted (1) observational assessments of the organisms using the mangrove prop root system including those that settle on the prop roots as well as those moving within and amongst the prop roots, (2) experimental caging studies to assess what food options prop roots present to consumers in the system, and (3) experimental, artificial prop root arrays to determine how structural complexity may attract mobile mangrove species.

Observational

I determined the communities of organisms both on and amongst the mangrove prop roots, by documenting the species present and their distributions along replicated (n=5) 30m permanent transects laid out along the contours of the mangrove forest. Observational data collected was used to establish a baseline to determine what food is available in the mangroves and the potential consumers (e.g. herbivores and predators) that rely on it. I conducted two 10 minute midday observations of fish at a distance of 1m away from the edge of the mangroves, allowing time for acclimation. Due to high turbidity and low visibility my observations were limited to species richness of fish in and amongst the prop roots; exact numbers for diversity calculating could not be accounted for. In order to collect enough data on species richness, ten observation points were randomly chosen along each permanent transect and a 1m wide area was monitored from the benthos to the surface. I identified and measured percent cover of organisms (e.g. algae, sponges, anemones) growing on the mangrove prop roots.

Experimental

Once I had established a baseline understanding of the red mangrove prop root community in Bonaire, I initiated experiments to determine which characteristics (availability of food or complex habitat) of the prop root communities attract fish consumers. To assess how prop root communities are structured via preferential grazing, consumers were excluded from access to food items growing on the roots with plastic mesh cages (0.5m long, 10 cm

diameter, 1cm² holes). Three prop roots within 5m of each other were randomly assigned the following treatments: (1) fully caged (from root tip on the benthos to surface of the water), (2) partially caged with an open panel (5 cm) to account for any caging artifacts (e.g. change in water flow, shading, and fish attracted to the structure), and (3) open or an uncaged prop root. Six of these arrays were haphazardly deployed along the mangroves in Sorobon with ≥10m between each set of three roots. After three weeks of monitoring the cages were removed and the resulting cover of organisms was documented. Due to an apparent increase in the volume of organisms present (sponges and algae), samples were collected at three random points along each experimental prop root at each replicate using a 5.5 cm plastic ring placed on the prop root, the sample was taken from the middle. Each sample was returned to the lab in an individual plastic bag, blotted once with a paper towel to remove excess moisture, and then weighed for wet mass (Mettler Toledo XS205). These final wet masses were analyzed using a 2-way ANOVA for species and experimental treatment.

In order to assess how structural complexity influences mobile species represented, an artificial mangrove prop root system was constructed along the edge of the mangroves of Sorobon. Artificial Mangrove Units (AMUs) have been previously used in a variety of structural designs to test the attractiveness of varying complexities (de la Moriniere et al. 2004). For the current study, replicated arrays (n=4) of artificial prop roots were constructed in a simple arrangement (1 prop root) and a more complex arrangement (3 prop roots). A 1m PVC pipe (2.5 cm diameter) was attached upright to a terra cotta tile (30cm²) using a marine epoxy Z*Spar. Holes were drilled into the top of the pipe (2 cm down) and 1m lengths of garden hose were attached using zip ties (simple structure = 1 hose, complex structure = 3 hoses). AMUs were haphazardly placed 1m away from the fringing mangroves, in random assignment of position in pairs at each site. Pairs were placed within 1m of each other, and arrays were spaced > 5m apart. The experiment was run for 10 days and was monitored three times at midday for species richness of fish using the AMUs. Observations were made at 1m from the AMU for 10 min to allow for acclimation. Preliminary observation suggested that fish using the AMUs did not distinguish a difference between simple and complex artificial prop roots, instead data was compared to earlier observations. Species richness of fish using these AMUs was compared with

observational data of fish present in the natural prop roots in order to distinguish any preference for complexity of structure.

Results

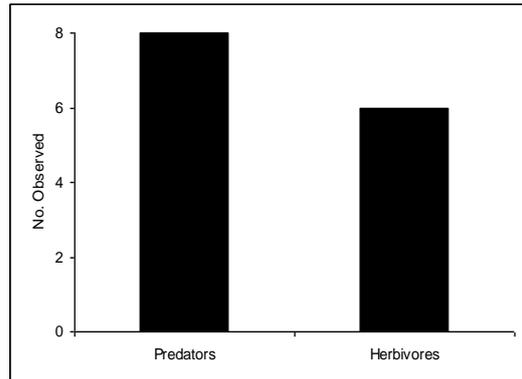


Figure 1. Species richness of the two major categories of fish (herbivores and predators) observed amongst mangrove prop roots at Sorobon.

Observational

Monitoring of the permanent transects in the mangrove prop roots revealed that 8 predatory and 6 herbivorous fish utilize the habitat (Fig. 1). The predatory fishes included the schoolmaster snapper (*Lutjanus apodus*), greater barracuda (*Sphyræna barracuda*), yellowtail snapper (*Ocyurus chrysurus*), gray snapper (*Lutjanus griseus*), French grunt (*Haemulon flavolineatum*), smallmouth grunt (*Haemulon chrysargyreum*), silver jenny (*Eucinostomus gula*) and comb grouper (*Mycteroperca acutirositis*), 8 and the herbivorous fish included the: rainbow parrotfish (*Scarus guacamaia*), striped parrotfish (*Scarus iserti*), bicolor damselfish (*Stegastes partitus*), yellowtail damselfish (*Microspathodon chrysurus*), sergeant major (*Abudefduf saxatilis*) and four-eye butterflyfish (*Chaetodon capistratus*), 6. Personal observation indicates that the abundance of herbivores was greater than that of predators, but turbidity limited my ability to accurately record these numbers.

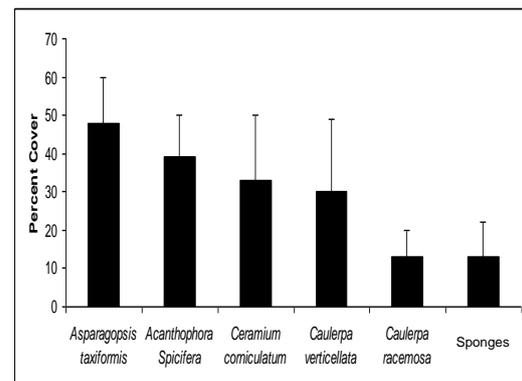


Figure 2. Mean percent algal cover (±SD) observed on mangrove prop roots.

Observation of the prop roots resulted in an initial percent cover measurement, used to determine that three species of red algae (*Acanthophora spicifera*, *Asparagopsis taxiformis*, *Ceramium corniculatum*) dominate the prop root community over the five 30m transects in the presence of consumers, though green algae (*Caulerpa verticellata*, *Caulerpa racemosa*) was seen. *Acanthophora spicifera* had the greatest mean percent cover on the prop roots (48% \pm SD), while *Caulerpa racemosa* had the smallest mean percent cover (8% \pm SD), having only been observed four times over the five transects (Fig. 2).

Experimental

The caging experiment was conducted to determine the composition of organisms growing on the prop roots in the absence of consumers. Percent algal cover on mangrove prop roots between the initial and final observations showed that the partial and caged treatments had effects on algae growth, while open prop roots appeared to be similar. While red algae still dominated the prop root community, percent cover decreased with treatment, allowing for growth of green algae species (Fig. 3).

Treatments followed a similar trend in growth; algae grew in volume, not necessarily in lateral percent cover. There was a decrease in growth of red algae and a slight increase of growth in green algae on roots with a full or partial cage (Fig 4). *Caulerpa racemosa* has a greater mass, though there was an increase in green algae abundance in cages, as supported by the wet mass data, the decrease in red algae as indicated in percent cover is supported by this data as well. A 2-way ANOVA of the wet mass data showed that the difference in mass of algae among caging treatments were statistically significant ($p=0.013$) and the interaction between algae species and treatment was significant ($p=0.015$), indicating that the interaction between species on the prop roots and experimental treatments did have an effect on growth.

The AMU study suggested that there is no difference in preference by predators or herbivores for more or less physical structure of habitat (Fig 5). Of the eight predatory fish observed among natural prop roots, only four (*Lutjanus apodus*, *Sphyraena barracuda*, *Haemulon flavolineatum*, *Eucinostomus gula*) were observed utilizing the AMUs, whereas, five of the six herbivores (*Scarus iserti*,

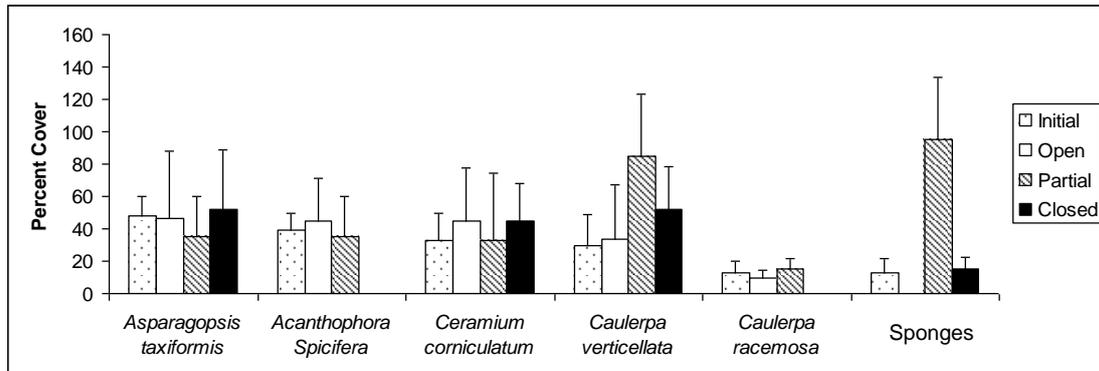


Figure 3. Mean percent algal cover (\pm SD) on prop roots, including mean initial percent cover as well as percent cover observed on open prop roots of the caging study. Initial= original observations of mangrove prop roots, Open= uncaged control treatment, Partial= open cage treatment, accounts for caging artifacts, Closed= fully enclosed cage treatment.

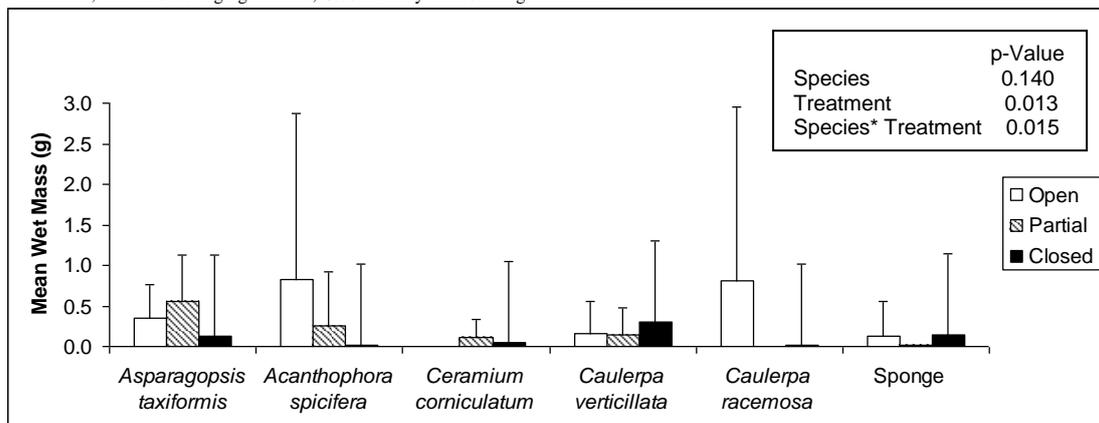


Figure 4. Mean wet mass (\pm SD) among species collected from the prop roots from each experimental caging treatment. Open= uncaged control treatment, Partial= open cage treatment, accounts for caging artifacts, Closed= fully enclosed cage treatment.

Stegastes partitus, *Microspathodon chrysurus*, *Abudefduf saxatilis*, *Chaetodon capistratus*) were documented. Fish observed during this time would through and around the AMUs, others would pause to linger above the substrate, never distinguishing between the pair, as there was no clear preference between the two options.

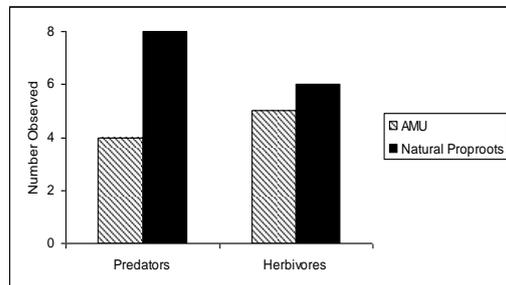


Figure 5. Species richness of the two major categories of fish (herbivores and predators) observed on the AMUs and natural prop roots.

Discussion

Initial monitoring of the red mangrove prop root system of Sorobon, Bonaire, NA was used to establish a baseline understanding of the consumers, the structure of the habitat, and the potential food items in the area. These efforts showed that several types of red and green algae dominated the prop root surface area over sponges, anemones and bivalves. Of the algae, red algae had a higher percent cover (*Asparagopsis taxiformis* 48%, *Acanthophora spicifera* 39%, *Ceramium corniculatum* 20%) of the prop roots than green algae (*Caulerpa verticellata* 30%, *Caulerpa racemosa* 8%). In determining which fish species use the mangroves for habitat and/or food, observations indicated that there were more species of predatory fish than herbivores present; however, the herbivorous fish appeared to be in greater abundance (no data reported due to the effects of water turbidity in acquiring exact counts). The high abundance of herbivores may be explained by the great availability of their food, algae than any other food option.

The results of the caging experiment indicated that the different treatments did have an impact on the growth of algae on the prop roots; this indicates that the availability of food is attracting fish to the mangroves to some degree. By excluding herbivores from consuming algae on the prop roots, *Caulerpa verticellata* wet mass increased in the closed cages versus the open and partial treatments. In turn, prop roots treated with a partial or closed cage showed a decrease in red algae mass and an increase in green algae mass. This indicated that there was a preference for this type of algae not seen until consumers are

excluded, and that herbivores may structure the prop root epibiotacommunity. The mass of the red algae, particularly *Asparagopsis taxiformis*, was still greater than that of the green in the closed cages, but their decrease in wet mass along with the increase in *Caulerpa verticellata* suggests that *Caulerpa* may be more palatable to herbivorous fish. As seen in previous studies comparing the palatability of green algae with red and brown algae, many reef fish, including parrotfish, surgeonfish, and rabbitfish, consume *Caulerpa* (Erickson et al. 2006). Algae in the genus *Asparagopsis* were found to be least preferred in a feeding assay of other red algae, and have been found to be chemically defended against herbivores (Paul et al. 2006, Vergès et al. 2008). Similar results were seen in a consumer exclusion study on crabs living in the mangroves, an increased abundance and species richness in the absence of consumers (Kon et al. 2009). Therefore, removal of consumers of *Caulerpa* could lead to an increase in biomass and possibly the establishment of algal competitive interactions. Further research involving the exclusion of particular consumer species may aid in teasing apart the detailed top-down interactions that determine the make-up of prop root communities.

The documented presence of both herbivorous and predatory fish among the prop roots of red mangroves in Bonaire suggests that this complex structure supports an entire ecological community of organisms. I tested the impact of simple versus complex structure on the composition of fish communities. The species richness observed on the AMUs was does not reflect the species richness first observed on the prop roots, there were more herbivore species (5) than predators (4). Both predators and herbivores were observed on the AMUs indicating that there is no clear preference for complex habitat by either group. A study on colonization of juvenile fish in the mangroves of Curacao also found that there was no preference in nursery fish between natural prop roots and AMUs, and these fish colonized artificial mangroves at the same rate as natural prop roots (Nagelkerken and Faunce 2007). There did not appear to be differences in the number of fish present, there were more on the natural prop roots than the AMUs. The presence of algae on the actual prop roots supported the feeding needs of the fish in a way that the AMUs could not account for. This suggests that it may be a combination both of food availability as well as complex physical structure that attracts juvenile fish to the mangroves, as has been documented in previous studies (Verweij et al. 2006,

Nagelkerken and Faunce 2008). Predatory fish have also been shown to use the complex structure of prop roots for ambush predation rather than protection (Verweij et al. 2006). Communities in which predator-prey interactions are driven by food availability experience bottom up effects, as in whelk predators feeding on intertidal mussels and barnacles, exhibiting a positive correlation between predator density and prey recruitment (Navarrete and Manzur 2008). The presence of predators in the mangroves may also be the result of these bottom-up effects where high food availability for herbivores attracts them and they in turn become prey. Understanding these interactions and the roles organisms play in the mangroves may be used to restore the mangrove ecosystem to its natural state.

Acknowledgements

I would like to thank my advisor Dr. Amanda Hollebone for her guidance and encouragement throughout this whole process, from data analysis to creative solutions in the field. Thanks to Amanda deVillers for driving me out to Sorobon, working with me in the less than ideal conditions of the mangroves and figuring out the data, and to all my classmates for keeping me going. Thank you to CIEE for the resources to make this project possible, and to my parents for making this semester possible.

References

- Alofs, K. M. and K. M. Polivka. 2004. Microhabitat-scale influences of resources and refuge on habitat selection by an estuarine opportunist fish. *Marine Ecology Progress Series* 271:297-306.
- Brooks, R. A. and S. S. Bell. 2005. A multivariate study of mangrove morphology (*Rhizophora mangle*) using both above and below-water plant architecture. *Estuarine Coastal and Shelf Science* 65:440-448.
- Burfeind, D. D., I. R. Tibbetts, and J. W. Udy. (2009). Habitat preference of three common fishes for seagrass, *Caulerpa taxifolia*, and unvegetated substrate in Moreton Bay, Australia. *Environmental Biology of Fishes* 84:317-322.
- de la Moriniere, E. C., H. van der Meij, and G. van der Velde. 2004. What attracts juvenile coral reef fish to mangroves: habitat complexity or shade? *Marine Biology* 144:139-145.
- De Meyer, K. and D. MacRae. 2006. Bonaire National Marine Park Management Plan. Part 1:41-45.
- Erickson, A. A., V. J. Paul, K. L. Van Alstyne and L. M. Kwiatkowski. 2006. Palatability of Macroalgae that Use Different Types of Chemical Defenses. *Journal of Chemical Ecology* 32: 1883-1895.
- Faunce, C. H. and J. E. Serafy. 2006. Mangroves as fish habitat: 50 years of field studies. *Marine Ecology Progress Series* 318:1-18.
- Kon, K., H. Kurojura, and P. Tongnunui. 2009. Mangrove root structures function to shelter benthic macrofauna from predators? *Journal of Experimental Marine Biology and Ecology* 370:1-8.
- Kubetzki, U. and S. Garthe. 2003. Distribution, diet and habitat selection by four sympatrically breeding gull species in the south-eastern North Sea. *Marine Biology* 143:199-207.
- Laegdsgaard, P. and C. R. Johnson. 2001. Why do juvenile fish utilize mangrove habitats? *Journal of Experimental Marine Biology and Ecology* 257:229-253.
- Mumby, P. J., A. J. Edwards, J. E. Arlas-Gonzalez, K. C. Lindeman, P. G. Blackwell, A. Gall, M. I. Gorkczynska, A. R. Harborne, C. L. Pescod, and H. Renken. 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature* 427:533-536.
- Navarrete, S.A. and T. Manzur. 2008. Individual-and population-level responses of a keystone predator to geographic variation in prey. *Ecology* 89:2005-2018.
- Nagelkerken I., S. Kleijnen, T. Klop, R. A. C. J. van den Brand, E. C. Cocheret de la Morinière, and G. van der Velde. 2001. Dependence of Caribbean reef fishes on mangroves and seagrass beds as nursery habitats: a comparison of fish faunas between bays with and without mangroves/seagrass beds. *Marine Ecology Progress Series* 214:225-235.
- Nagelkerken, I. and C. H. Faunce. 2007. Colonisation of artificial mangroves by reef fishes in a marine seascape. *Estuarine and Coastal Shelf Science* 75:417-422.
- Nagelkerken, I. and C. H. Faunce. 2008. What makes mangroves attractive to fish? Use of artificial units to test the influence of water depth, cross-shelf location, and presence of root structure. *Estuarine and Coastal Shelf Science* 79:559-565.
- Paul, N. A., R. de Nys, and P. D. Steinberg. 2006. Seaweed-herbivore interactions at a small scale: direct tests of feeding deterrence by filamentous algae. *Marine Ecology Progress Series* 323:1-9.
- Pardo, L. M. and L. E. Johnson. 2005. Explaining variation in life-history traits:

- growth rate, size, and fecundity in a marine snail across an environmental gradient lacking predators. *Marine Ecology Progress Series* 296:229-239.
- Schultz, S.T., C. Kruschel, and T. Bakran-Petricioli. 2009. Influence of seagrass meadows on predator-prey habitat segregation in an Adriatic lagoon. *Marine Ecology Progress Series* 374:85-99.
- Vergès, A., N. A. Paul, and P.D. Steinberg. 2008. Sex and life-history stage alter herbivore responses to a chemically defended red alga. *Ecology* 89:1334-1343.
- Verweij, M. C., I. Nagelkerken, D. deGraaf, M. Peeters, E. J. Bakker, and G. van der Velde. 2006. Structure, food and shade attract juvenile coral reef fish to mangrove and seagrass habitats: a field experiment. *Marine Ecology Progress Series* 306:257-268.
- Verweij, M. C., I. Nagelkerken, I. Hans, S. M. Ruseler, and P. R. D. Mason. 2008. Seagrass nurseries contribute to coral reef fish populations. *Limnology and Oceanography* 53:1540-1547.
- Webley, J. A. C., R. M. Connolly, and R. A. Young. 2009. Habitat selectivity of megalopae and juvenile mud crabs (*Scylla serrata*): Implications for recruitment mechanism. *Marine Biology* 156:891-899.

**Risky business:
Ecological trade-offs of sub-tidal foraging behavior in parrotfish (*Scaridae*)**

Nathan Landry*

University of Massachusetts Dartmouth

Abstract

Parrotfish promote coral growth by controlling the abundance of algae on coral reefs. Although the importance of parrotfish herbivory on coral reefs has been noted; the feeding behavior of parrotfish is not fully understood. What is known is that territorial parrotfish defend the reef slope, forcing non-territorial parrotfish to move to shallower water to feed. Ecological studies of predator-prey interactions suggest a correlation between risk and foraging behavior. The parrotfish on the reefs in Bonaire demonstrate a risky feeding behavior in the shallow sub-tidal zone that increases the risk of predation by osprey. A chain transect was used to determine the percent cover of algae in the shallow sub-tidal zone and reef flat. The percent cover of algae is greater in the shallow sub-tidal zone, meaning there is more food available in the habitat with higher risk of predation. In the shallow sub-tidal, parrotfish feed on turf algae and *Padina* in the same proportion as they occur on the benthos, meaning parrotfish are not feeding preferentially when in the shallow sub-tidal. To determine if there were diurnal feeding patterns in the shallow sub-tidal, observations were made 3 times per day. Initial phase parrotfish used the shallow sub-tidal zone more than terminal phase parrotfish and yellowtail parrotfish were the most abundant species. The species and phase that were most abundant may be a reflection of parrotfish populations on the reefs of Bonaire or a higher degree of crypsis. Tide levels had an impact on when the parrotfish could feed. Though most feeding occurred during morning and noonday hours, high and transitional tides were only found during these two time frames, which may explain the diurnal feeding behavior.

Introduction

Animals make trade-offs between feeding and predation risk. Risk may not always be accurately determined by the animal; which can result in an over or underestimate of predation risk (Abrams 1993). The presence of a predator can affect the degree of risk that an animal will take (Banks et al. 1999). For example, Banks et al. 1999, found that the distance rabbits move from their holes is directly proportional to the threat of predation. Rabbits with no predator present moved three times farther from their holes as did rabbits with foxes present (Banks et al. 1999). Bottlenose dolphins have been recorded attacking and killing harbour porpoises off the coast of the British Isles. Macleod et al., found that populations of harbour porpoises with the threat of dolphin attacks retain less body fat than those without this predation (2007). Harbour porpoises must balance fat reserves, which protect against starvation, for speed and maneuverability (Macleod et al. 2007). A miscalculation of environmental pressures and cues can cause individuals of a species to take unnecessary precautions or risks that affect an individual's fitness (Abrams 1993).

Parrotfish (Family: *Scaridae*) feed on algae that grow on coral reefs and are an

important part of coral reef systems because they control algal abundance, which can negatively affect coral growth (Rotjan and Lewis 2006, Bellwood et al. 2004). Parrotfish have indeterminate growth and are involved in mating behavior everyday, which demands a lot of energy (Bruggemann et al. 1994). In order to acquire the nutrition needed to grow and reproduce; Stoplight parrotfish (*Sparisoma viride*) prefer to eat algae with high protein (sparse turf on endolithic algae) and energy content (large turfs on endolithic algae) (Bruggemann et al. 1994).

Access to high energy algae can be limited by the territorial behavior of dominant terminal phase *S. viride* on the reef slope (Bruggemann et al. 1994). For example, dominant males defend their foraging areas on the reef slope against conspecifics and other fish species. Smaller, non-territorial parrotfish are forced to feed in the shallow reef environments, such as the reef flat and shallow sub-tidal. If the nutritional value of algae is higher in the shallow sub-tidal than the reef flat, this may lead to a trade off between predation risk and access to food (Bruggemann et al. 1994).

On the island of Bonaire, Netherland Antilles, non-territorial parrotfish have been observed swimming in the shallow sub-tidal zone in order to feed on the algae that grows

*nlandry@massd.edu

along the waters edge (personal observation). This feeding behavior has inherent risk due to predation by osprey. Parrotfish frequenting the shallow sub-tidal are preyed upon by osprey in Bonaire (R. Peachey, personal communication).

Ospreys are diurnal predators that feed mostly on fish (Swenson 1978). Osprey fly 50 to 100 m above the surface of the water and when they spot their prey they dive into the water grabbing the fish with their talons (Robinson 1994). Ospreys are well adapted for catching fish: 1) the feathers around the eye protect the osprey from glare from the sun, and 2) the osprey's eyes are large and positioned frontally, giving the osprey binocular vision, which doubles their acuity compared to prey birds and allows for greater depth perception (Jones et al. 2007).

The purpose of the study is to test the following hypotheses related to the costs and benefits of sub-tidal foraging by parrotfish. H₁: Algae are more abundant in the shallow sub-tidal zone than reef flat, which makes up for the increased risk of predation by birds. H₂: Parrotfish prefer turf algae to macro algae because of the higher caloric value. H₃: Parrotfish feed more actively during the midday compared to morning and dusk due to the sun's position in the sky. Morning light gives a favorable advantage to the osprey allowing it to see its prey better.

Methods and Materials

Study Sites

Observations of parrotfish behavior and measurements of algal distribution were made at two sites on the leeward side of Bonaire: Donkey Beach south of Kralendijk and Sunset Beach, north of Kralendijk. Both sites are visited by osprey and there have been reports of predation on parrotfish by osprey (J. Ligon, R. Peachey; personal communication).

Algal Distribution

Algal percent cover of the reef flat and shallow sub-tidal zone were compared using 150 link chain transects with a link area of 4.5cm². Each zone at both sites was sampled using five random transects consisting of 100 evenly spaced points. The species of algae found during the transects were compared to the parrotfish feeding survey and nutritional values of the algae present in transects was obtained through the primary literature.

Sub-tidal Habitat Use

At each site, a 100 m section of shoreline was marked; using natural and man made

features, enabling randomization of each transect placement and observation areas. Each site was visited once a week, in the morning between 8:00am-10:00am, midday between 12:00pm-2:00pm, and in the afternoon between 4:00pm-6:00pm. A 15m transect of the 100m study site was randomly selected for underwater observations for that day. Weather, surf conditions, and tide level were noted.

Sub-tidal Feeding Behavior

In order to determine the type of algae that the parrotfish are eating, four 30 minute observational periods of parrotfish feeding were conducted. While snorkeling at each site, parrotfish bites were recorded in the shallow sub-tidal zone. In order to ensure the greatest possible accuracy, bites were only recorded when I was within 1m of the feeding parrotfish. The species of algae that were being eaten was recorded, as well as, the number of bites taken from those species.

Statistical tests

Two way ANOVA tests were used to analyze the data of mean number of parrotfish wave⁻¹ using the shallow sub-tidal zone versus time of day, tide level, life phase, and species (Statview 5.0). Excel was used to find the mean percent cover of algae in the shallow sub-tidal and reef flat. Descriptive statistics were used to determine the percent cover of individual algae species and other substrates found in both of these zones.

Results

Algal Distribution

The shallow sub-tidal zone has 78.5 percent algae cover ($\pm 19.5\%$) compared to the reef flat with only 26.1 percent algae cover ($\pm 18.6\%$) (Fig. 1). When the types of algae were separated from the substrates that are not capable of being eaten by parrotfish; turf algae covered 60.1 percent ($\pm 16.4\%$) and *Padina* covered 18.4 percent ($\pm 12.435\%$) of the shallow sub-tidal. They were the only algae found in the shallow sub-tidal zone. *Caulerpa* (2.7%, $\pm 5.3\%$) and cyanobacteria (12.2%, $\pm 20.02\%$) were only found on the reef flat, and the percent cover of sand and coral rubble was higher (72.7%, $\pm 18.4\%$) than in the shallow sub-tidal (21.3%, $\pm 19.7\%$) (Fig. 2).

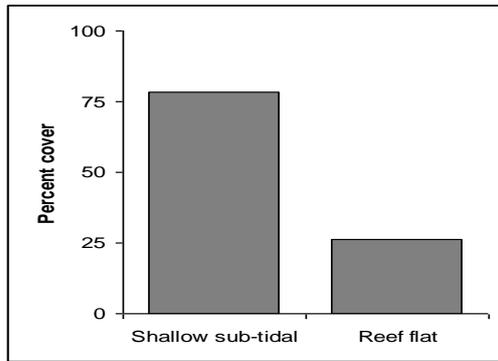


Figure 1: Total percent cover of algae (\pm SD) in the shallow sub-tidal versus the reef flat.

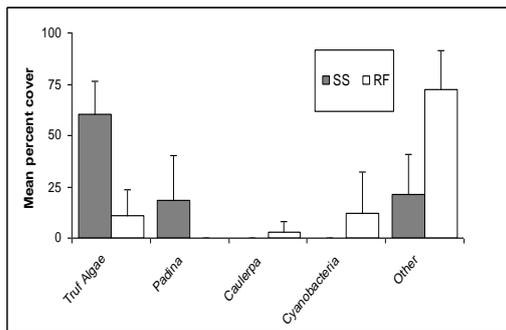


Figure 2: Mean percent cover of algae and other substrate (\pm SD) found in shallow sub-tidal (SS) and reef flat (RF).

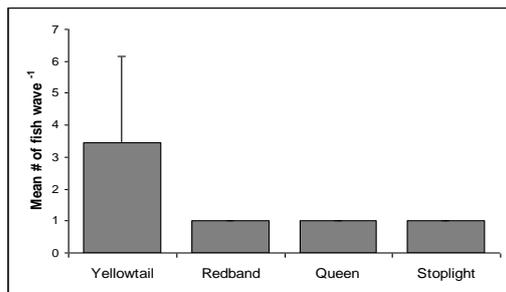


Figure 3: Mean no. of parrotfish wave⁻¹ (\pm SD) for each of the four species observed. Redband, queen, and stoplight parrotfish were only observed once.

Sub-tidal Habitat Use

The yellowtail parrotfish was significantly more abundant ($p=0.0031$, 3.46 individuals' wave⁻¹, \pm 2.697) than the redband, queen, and stoplight parrotfish, which were observed in abundances of one individual wave⁻¹ (Fig. 3). There were significantly more initial phase parrotfish ($p<0.0001$, 4.093 individuals' wave⁻¹, \pm 2.68) than terminal phase parrotfish (1 individual wave⁻¹) feeding in the sub-tidal zone (Fig. 4). Parrotfish were more abundant in the shallow sub-tidal during the noon (3.265 individuals' wave⁻¹, \pm 2.789) and morning (2.5 individuals' wave⁻¹, \pm 2.384) hours rather than in the afternoon (1.667 individuals' wave⁻¹, \pm .577) (Fig. 5).

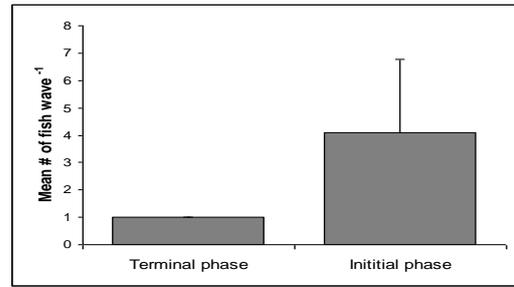


Figure 4: Mean no. of parrotfish wave⁻¹ (\pm SD) for terminal and initial phase individuals.

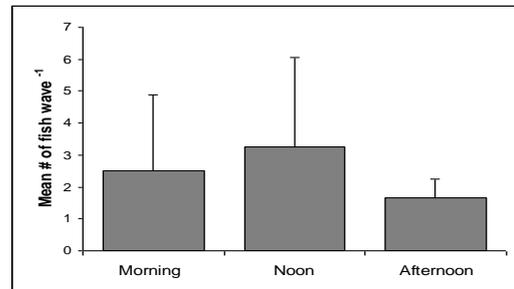


Figure 5: Mean no. of parrotfish wave⁻¹ (\pm SD) for each observation period.

Parrotfish were more abundant in the shallow sub-tidal during high (2.844 individuals' wave⁻¹, \pm 2.637) and transitional tides (2.92 individuals' wave⁻¹, \pm 2.637) rather than low tides (1.667 individuals' wave⁻¹, \pm .577) (Fig. 6).

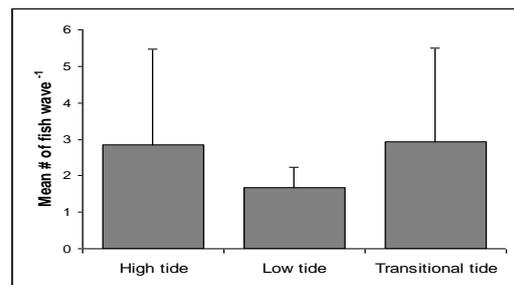


Figure 6: Mean no. of parrotfish wave⁻¹ (\pm SD) for each tide level.

Sub-tidal Feeding Behavior

In the shallow sub-tidal parrotfish are feeding on turf algae and *Padina* in almost the same ratio that it is found distributed on the substrate. *Padina* has a mean percent cover of 18.4% and parrotfish are biting it 17% of the time. Turf algae had a mean percent cover of 60.1% and accounted for 83.5% of the parrotfish bites (Fig. 7).

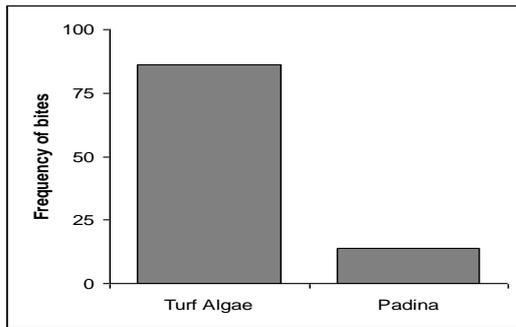


Figure 7: Frequency of bites by parrotfish on two types of algae present in the shallow sub-tidal.

Discussion

The higher percent cover of algae on the shallow sub-tidal compared to the reef flat is probably due to the amount of dead coral substrate that occurs as pavement along the shore. An alga that grows in the shallow sub-tidal has to be able to tolerate periodic exposure to air, strong wave energy and higher intensity of light. Turf algae and *Padina* are the dominant bottom cover in the shallow sub-tidal. Both types of algae grow low to the ground and are anchored securely to the substrate. *Caulerpa* has longer stalks than *Padina* or turf algae and was only found on the reef flat. Cyanobacteria, which do not have the root system, were also found only on the reef flat.

Padina is a Pheophyta, which has low nutrient values across the entire phylum (Paine and Vadas 1969) as opposed to turf algae, which is a mixture of algal phyla and may have a higher nutritional value than *Padina*. However, when parrotfish are feeding in the shallow sub-tidal they are feeding on turf algae and *Padina* in the same ratio as they occur in the habitat. As parrotfish move into the shallow sub-tidal the waves control their movements, not allowing them to choose a specific alga. The trend that parrotfish feed more during high and transitional tides is possibly due to simple logistics. As the tide gets higher, water level over the beds of turf algae and *Padina* increases making it easier for parrotfish to feed and maneuver. To better understand the higher abundance of parrotfish feeding in the morning and midday it is important to know that no high tides or transitional tides occurred in the afternoon. During this study the afternoon tide levels were all low tides. In order to separate the effects of time of day from tidal influences on behavior of parrotfish: observations during afternoon high tides are needed.

Initial phase parrotfish were more abundant in the shallow sub-tidal than terminal phase parrotfish. On the reefs of Bonaire, initial phase parrotfish are probably more abundant and have cryptic colors that blend in with the backgrounds, as well as, patterns that break up their outline (Stevens and Cuthill 2006) better than terminal phase parrotfish. Until underwater observations were conducted, initial phase parrotfish were not known to perform this behavior. Yellowtail parrotfish were found to use the shallow sub-tidal more often than the other species of parrotfish. Again, this may be due to the more cryptic coloring of terminal phase parrotfish compared to Stoplight or Queen parrotfish, which are more brightly colored and are easily seen from above the water.

In initial observations of parrotfish response to a predator, parrotfish reacted to the presence of a scale model osprey being swung over their heads when they were feeding in the shallow sub-tidal. Parrotfish may be aware of the risk of shallow sub-tidal feeding, yet continue to feed there because the shallow sub-tidal has three times more algae (78.5% cover) than the reef flat (26.1% cover).

In conclusion, there is more algae in terms of percent cover in the shallow sub-tidal, parrotfish fed on turf algae and *Padina* in the same proportion as it occurred on the substrate of the shallow sub-tidal, and although parrotfish were more abundant in the shallow sub-tidal in the morning and midday it may be due to co-occurrence of high tides during the sampling period rather than diurnal feeding patterns.

The type of algae in the shallow sub-tidal is not the most nutritious, but non-territorial parrotfish risk predation to feed there because the resources are readily available. There was no significant difference between feeding during different times of the day, but parrotfish may be able to reduce the risk of predation slightly by feeding at high tide, when there is more water covering the shallow sub-tidal, facilitating maneuverability. In conclusion, parrotfish may be making a trade off between predation risk and feeding in the shallow sub-tidal where algae is plentiful.

Acknowledgements

I would like to thank my advisor, Dr. Rita Peachey for her guidance and the effort she put in to making this project a reality. Thank you to the entire CIEE faculty, Dr. Amanda Holleb and Caren Eckrich, for their ideas and encouragement and to all of CIEE for giving me the tools and opportunity to

accurately and properly carry out my research. Without the support of this institution, none of this would have been possible. To all of my friends: Alissa, Katie, Julie, Michelle, and Marylou for their support and ideas which helped to shape this project. Thank you.

References

- Abrams, P.A. 1994. Should prey overestimate the risk of predation? *The American Naturalist* 144:317-328.
- Banks, Peter B., Hume, I.D. and O. Crowe. 1999. Behavioral, morphological and dietary response of rabbits to predation risk from foxes. *Oikos* 85:247-256.
- Bellwood, D.R., Highes, T.P., Folke, C., and M. Nystrom. 2004. Confronting the coral reef crisis. *Nature*. 429:827-833.
- Bruggemann, J.H., van Oppen, M.J.H. and A.M. Breeman. 1994. Foraging by the stoplight parrotfish *Sparisoma viride*. I. Food selection in different, socially determined habitats. *Marine Ecology Progress Series* 106:41-55.
- Jones, M.P., Pierce Jr., K.E. and D. Ward. 2007. Avian vision: A review of form and function with special consideration to birds of prey. *Journal of Exotic Pet Medicine* 16:68-87.
- Macleod, R., Macleod, C.D., Learmonth, J.A., Jepson, P.D., Reid R.J., Deaville, R., and G.J. Pierce. 2007. Mass-dependent predation risk and lethal dolphin-porpoise interactions. *Proceedings of the Royal Society of Biological Sciences* 274:2587-2593.
- Paine, R.T. and R.L. Vadas. 1969. Calorific values of benthic algae and their postulated relation to invertebrate food preference. *Marine Biology* 4:79-86.
- Robinson, S.K. 1994. Habitat and foraging ecology of raptors in Amazonian Peru. *Biotropica*. 26:443-458.
- Rotjan, R.D. and S.M. Lewis. 2006. Parrotfish abundance and selective corallivory on a Belizean coral reef. *The Journal of Experimental Marine Biology and Ecology*. 335:292-301.
- Stevens, M. and I.C. Cuthill. 2006. Disruptive coloration, crypsis and edge detection in early visual processing. *Proceedings of the Royal Society of Biological Sciences*. 273:2141-2147.
- Swenson, J.E. 1978. Prey and foraging behavior of ospreys on Yellowstone lake, Wyoming. *Journal of Wildlife Management*. 42:87-90.

Comparison of Epibionts between Green (*Chelonia mydas*) and Hawksbill (*Eretmochelys imbricata*) Sea Turtles in Bonaire, NA

Marylou Hildebrand*

Abstract

Many pelagic organisms, including sea turtles, host unique communities of epibionts on the surfaces of their bodies. Although sea turtle epibiota have been studied in other areas of the world, very little research has been conducted on the epibionts found on sea turtles inhabiting the water around Bonaire, Netherland Antilles. In this study, epibiont samples were obtained from 33 sea turtles found in Bonaire. Epibionts included green and red algae, polychaete worms, skin barnacles, and turtle barnacles. Barnacle abundance and epibiont biodiversity was determined for each size class (Small, Medium, Large juveniles) of the two most common species of sea turtles found on Bonaire (*Eretmochelys imbricata* and *Chelonia mydas*). There was no significant difference in number of barnacles between *E. imbricata* and *C. mydas*. However, there was a significant increase in the number of barnacles with increasing size class in both *E. imbricata* and *C. mydas*. Epibiont biodiversity was significantly higher on *E. imbricata* but did not increase with size class for either species. Such findings indicate that the distinct life histories of *C. mydas* and *E. imbricata* may lead to varying degrees of epibiont accumulation.

Introduction

When finding an appropriate place to live, there are many species that utilize other organisms as habitat. Like moss on trees, these relationships are often commensal and long-term (Nogata and Kiyotaka 2005). Epibionts are organisms that spend at least part of their life attached to other organisms and can range from microscopic bacteria to large whale barnacles, which can grow up to several centimeters in length (Crisp and Stubbings 1957). In the marine environment, epibionts can include barnacles, algae, crabs, coral, anemones, and polychaetes (Goodman et al. 2007). Certain species of barnacles have been found to be species-specific, settling only on one particular host species (Nogata and Kiyotaka 2005). For example, the barnacle *Coronula diadema* only settles on the skin of cetaceans (Nogata and Kiyotaka 2005). Humpback whales, manatees, and several species of sea turtles are known barnacle hosts (Cintrón-De Jesús 2001). Sea turtles are host to the turtle barnacles (*Chelonibia testudinaria*), which are exclusive to sea turtles and are found growing on their skin or shells (Frick et al. 2004). Sea turtles have also been known to host communities of algae, small invertebrates, and other sessile organisms (Goodman et al. 2007). The epibionts that grow on the shells and skin of the turtles can indicate the animal's movements, ecology, and typical range (Schaerer 2003).

The four most common species of sea turtle in Bonaire include hawksbill (*E. imbricata*), green (*C. mydas*), loggerhead (*Caretta caretta*), and leatherback (*Dermochelys coriacea*) sea turtles. Nesting season ranges from late May until December each year. From January through April the primary turtles that frequent the island are foraging juvenile *E. imbricata* and *C. mydas*, which differs from the turtle population during nesting,

which includes large adults (M. Nava, personal communication).

C. mydas have smooth scutes on their shells with little or no grooves, offering a less suitable habitat for epibiota than the overlapping scutes on the shells of *E. imbricata* (Gulko and Eckert 2004). Accordingly, the first hypothesis of this study is that epibiont biodiversity will vary between *C. mydas* and *E. imbricata*. The second hypothesis is that epibiont diversity will increase with the size and, therefore, age of the turtles. Larger turtles have greater surface area for epibionts and epibionts may accumulate over time as turtles grow. The third hypothesis is that the number of barnacles will vary between *E. imbricata* and *C. mydas*, due to the differences in shell structure. Finally, the fourth hypothesis is that the number of barnacles, like biodiversity, will increase with size class. By addressing these hypotheses, this study provides further insight into the life history of sea turtles.

Materials & Methods

The island of Bonaire, Netherland Antilles is an oceanic island encircled by fringing reefs located in the southern Caribbean. Mature sea turtles nest in Bonaire from May through December and juvenile sea turtles forage in the shallow waters of Bonaire and Klein Bonaire year round (G. Egbreghts, personal communication).

From February through April, 2009, sea turtles were collected with the assistance of Sea Turtle Conservation Bonaire (STCB), using two different methods. Surveys were conducted by snorkeling or SCUBA, with 2 to 4 people swimming parallel to the coast followed by a boat.

Second, in Lac Bay, turtles were caught using a gill net, 100 meters long by 3 meters high. The net was deployed for a period of one hour. The net

*mkhildeb@ucsd.edu

was monitored by a minimum of three snorkelers, and turtles that swam into the net were immediately removed and brought aboard an attending boat. Upon conclusion of the one hour net deployment period, the net was retrieved, turtles were processed and immediately released near the site of capture. GPS coordinates of each site where turtles were captured were recorded.

The turtles were measured, photographed, and tagged. Photographs of each turtle's dorsal and ventral sides were taken. Using a flat-tipped dive knife and a dissection kit, epibionts were removed from the turtle's shell and skin (Fig. 1). Algae was scraped from the top and bottom of overlapping scutes. Barnacles and other organisms were removed using the dive knife or by hand. Epibionts were placed into screw-top vials filled with sea water for transport to the laboratory. Samples were preserved in 95% ethyl alcohol and identified with a dissection microscope to the lowest possible taxon (Schaerer 2003).

Epibiont biodiversity was determined by the sum of barnacle types present (skin or other),



Figure 1. Collecting epibionts from a hawksbill sea turtle (*E. imbricata*) in Bonaire, Netherland Antilles on February 18, 2009 at Klein Bonaire.

collected from each turtle. Epibiont biodiversity of *C. mydas* and *E. imbricata* was compared using an un-paired t-test ($\alpha = 0.05$). In addition, turtles were classified as small (25-35cm), medium (36-50cm), and large (>51cm) to determine whether biodiversity increases with size for either species. A two-factor analysis of variance (ANOVA, $\alpha = 0.05$) was used to analyze the epibiont biodiversity of *C. mydas* and *E. imbricata* in relation to turtle size class (small, medium, and large). Fisher's PLSD (protected least significant difference) was used to detect differences in biodiversity within the factors (size class and species of turtle).

An unpaired t-test ($\alpha = 0.05$) was used to compare the number of barnacles per turtle between *C. mydas* and *E. imbricata* and a two-

factor ANOVA was used to analyze the number of barnacles per turtle and size class of the two species ($\alpha = 0.05$). Fisher's PLSD (protected least significant difference) was used to detect differences in number of barnacles per turtle within the factors (size class and species of turtle). All statistical tests were run in StatView 5.0 on a PC.

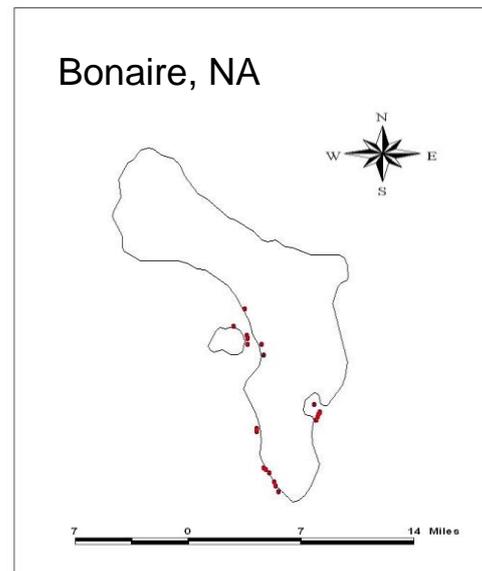


Figure 2. Map of Bonaire, Netherland Antilles showing capture sites of the 33 sea turtles collected between January and May, 2009.

Results

During the seven week collection period, 16 *C. mydas* and 17 *E. imbricata* were sampled from various locations around Bonaire (Fig. 2). The epibionts collected include 304 barnacles, 3 polychaetes, green algae, red algae, crustose coralline algae, and sandy microhabitats within *Ceramium* algal turfs. Sandy microhabitats were only found on *E. imbricata*. The turtle barnacle, *Chelonibia testudinaria*, two species of skin barnacles, *Platylepas coriacea* and *Platylepas decorata*, and the gooseneck barnacle, *Lepas hilli* were identified. *Platylepas coriacea* has not been reported before on *E. imbricata* or *C. mydas* (M. Frick, personal communication).

The biodiversity of epibionts on *E. imbricata* (2.529 ± 0.943) was significantly greater than the biodiversity of *C. mydas* (1.625 ± 0.806) (Fig. 3; unpaired t-test; $p=0.006$). However, biodiversity does not increase with size class in either species (Table 1) (Fig. 4).

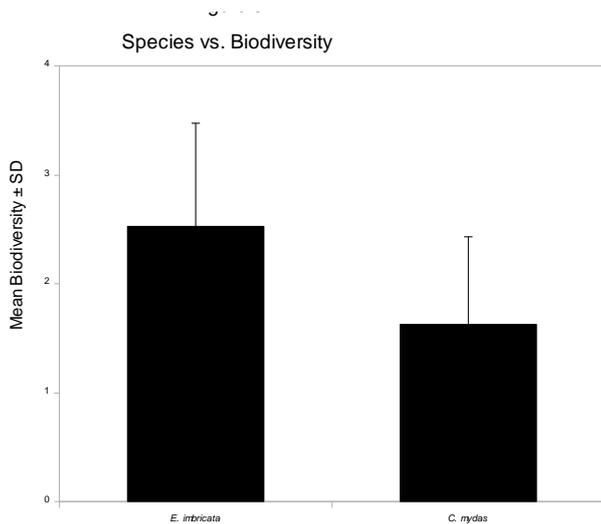


Figure 3. Mean biodiversity ± SD of the hawksbill turtle (*E. imbricata*) and green turtle (*C. mydas*). (Unpaired t-test; $p=0.006$).

There was not a significant difference in the number of barnacles on *E. imbricata* (10.647 ± 10.600) when compared to *C. mydas* (7.688 ± 7.726) (Fig. 5; unpaired t-test; $p=0.369$). However, both species had an increase in the number of barnacles as the size of the turtles increased. The small size class had significantly fewer barnacles than the large size class (Table 2, Fig. 6; Fisher's PLSD; $p=0.013$). The medium size class was not significantly different from the small or large size class (Table 2, Fig. 6; Fisher's PLSD; $p=0.185$).

Table 1. a) Two-way ANOVA table comparing the biodiversity of the hawksbill (*E. imbricata*) and green sea turtle (*C. mydas*) by size class and b) the results of Fisher's PLSD post hoc test on the means of the species and c) the results of Fisher's PLSD post hoc test on the means of the size classes.

a) ANOVA Table for Total Biodiversity

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Species	1.000	5.785	5.785	7.033	0.0132	7.033	0.730
Size	2.000	0.494	0.247	0.300	0.7429	0.601	0.092
Species * Size	2.000	1.204	0.602	0.732	0.4902	1.464	0.157
Residual	27.000	22.210	0.823				

b) Fisher's PLSD for Total Biodiversity
Effect: Species
Significance Level: 5%

	Mean Diff.	Crit. Diff.	P-Value
<i>E. imbricata</i> , <i>C. mydas</i>	0.904	0.648	0.008

c) Fisher's PLSD for Total Biodiversity
Effect: Size
Significance Level: 5%

	Mean Diff.	Crit. Diff.	P-Value
S, M	0.253	0.750	0.4942
S, L	-0.068	0.865	0.8727
M, L	-0.321	0.825	0.4309

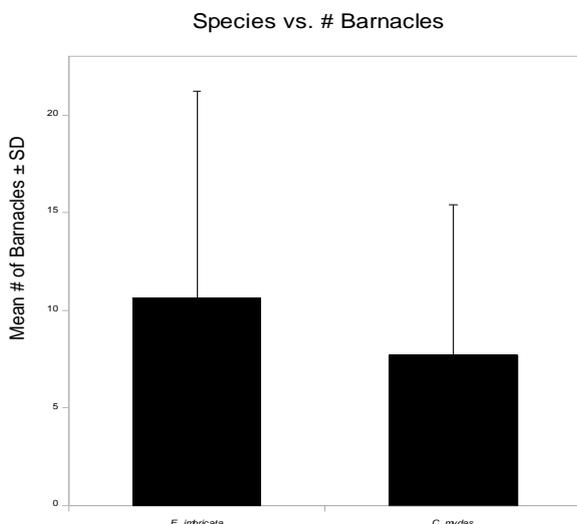


Figure 4. Mean biodiversity ± SD for each size class of the hawksbill (*E. imbricata*) and green turtles (*C. mydas*) collected between January and May, 2009 in Bonaire, Netherlands Antilles; S = small (20-35cm), M=medium (36-50cm), L= large (>51cm).

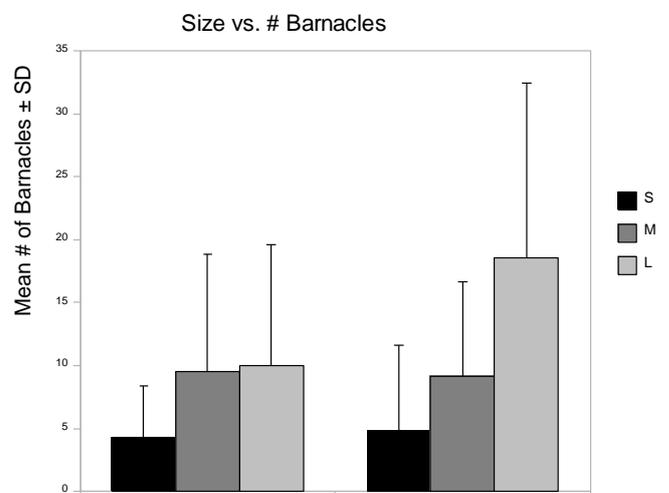


Figure 5. Mean number of barnacles ± SD of the hawksbill turtle (*E. imbricata*) and green turtle (*C. mydas*). (Unpaired t-test, $p=0.369$).

Table 2. a) Two-way ANOVA table comparing the number of barnacles turtle⁻¹ of the hawksbill (*E. imbricata*) and green sea turtle (*C. mydas*) by size class and b) the results of Fisher's PLSD post hoc test on the means of the species and c) the results of Fisher's PLSD post hoc test on the means of the size classes.

a) ANOVA Table for Total # Barnacles

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Species	1.000	62.930	62.930	0.816	0.3743	0.816	0.135
Size	2.000	426.470	213.235	2.765	0.0808	5.531	0.490
Species * Size	2.000	108.718	54.359	0.705	0.5030	1.410	0.152
Residual	27.000	2081.905	77.108				

b) Fisher's PLSD for Total # Barnacles
Effect: Species
Significance Level: 5%

	Mean Diff.	Crit. Diff.	P-Value
<i>E. imbricata</i> , <i>C. mydas</i>	2.960	6.276	0.3418

c) Fisher's PLSD for Total # Barnacles
Effect: Size
Significance Level: 5%

	Mean Diff.	Crit. Diff.	P-Value
S, M	-4.812	7.259	0.1851
S, L	-10.830	8.372	0.0132
M, L	0.000	7.985	0.1337

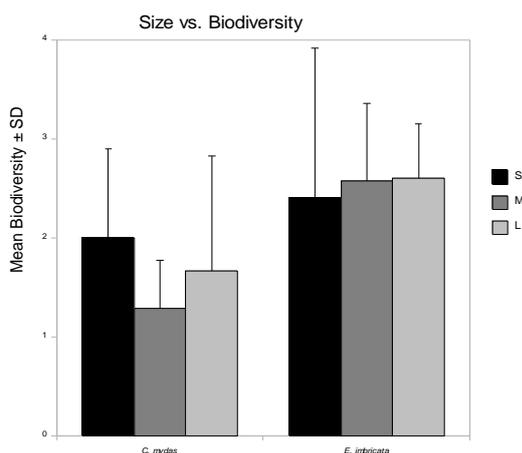


Figure 6. Mean number of barnacles ± SD for each size class of the hawksbill (*E. imbricata*) and green turtles (*C. mydas*) collected between January and May, 2009 in Bonaire, Netherlands Antilles; S = small (20-35cm), M=medium (36-50cm), L= large (>51cm).

Discussion

The hypothesis that biodiversity of epibionts on the hawksbill sea turtle, *E. imbricata*, would be greater than the biodiversity of epibionts on the green sea turtle, *C. mydas*, was supported by this research. The craggy carapace of *E. imbricata* may provide additional microhabitat that may increase epibiont diversity. The hypothesis that biodiversity will increase with size class, on the other hand, was not supported through this research. Biodiversity in this study was based on broad taxonomic categories. By identifying the epibionts to species, estimates of epibiont diversity would increase and, therefore, better represent the true biodiversity of epibionts on sea turtles in Bonaire. Additional taxonomic expertise would be necessary for realizing the goal of determining accurate epibiont biodiversity on sea turtles.

The hypothesis that the number of barnacles on *E. imbricata* would be greater than the number of barnacles on *C. mydas* was not supported by this study. This hypothesis was based on the assumption that the jagged carapace of *E. imbricata* accumulates more epibionts than the smooth carapace of *C. mydas*. However, the majority of barnacles found were skin barnacles that are not influenced by carapace structure. Further, the hypothesis that the number of barnacles will increase with size class for *E. imbricata* and *C. mydas* was supported by this study. This may be due to a variety of factors. First, the surface area on turtles' carapace and skin available for epibiont settlement increases as they grow. Larger turtles offer more space for epibiont settlement, resulting in decreased competition among epibionts and increased epibiont abundance. Smaller turtles, on the other hand, offer less space for epibiont settlement, resulting in increased competition and decreased abundance. The observed increase in barnacle abundance in larger turtles may also be explained by the accumulation of epibionts over time. Specifically, larger and therefore older turtles have simply had more time to accumulate epibionts than smaller, younger turtles.

Turtle barnacles (*Chelonibia testudinaria*) and skin barnacles (*Platylepas spp.*) were found on the turtles in Bonaire as well as in Puerto Rico (Schaerer 2003). In Puerto Rico, *C. testudinaria* was the dominant species of turtle barnacle but very few were found during this study (Schaerer 2003). Schaerer (2003) defines turtles that are <65cm as juveniles and notes that *Chelonibia spp.* were rarely found on turtles from this size class. All but one of the turtles collected during this study were <65cm, making the vast majority of sampled turtles juveniles. Such abundance of juvenile turtles in Bonaire during the sampling period is most likely due to the fact that there are no sea turtle nesting activities taking place between January and May. Therefore, foraging juvenile turtles are most prevalent. Perhaps sampling through the nesting season would change the

relative numbers due to the presence of adult turtles in the population.

The study of sea turtle epibionts is a relatively new field of ecology. By increasing turtle sample size as well as identifying epibionts to higher taxonomic levels, continued research will boost confidence in results and possibly reveal other relationships. In order to determine the effects of bodily surface area on the number of epibionts; the area of skin and carapace could be determined and densities of epibionts could be compared. Through investigating sea turtle ecology and epibiont-host relationships, perhaps the nature of the relationship will be better understood. Are epibionts adding drag to the host? At what point do epibionts have a negative effect on turtles? Research that can answer these questions may be used by sea turtle managers to help recognize potential problems or threats to future populations of sea turtles.

Acknowledgements

There are many people I would like to thank for their assistance with my project. First off, Dr. Rita Peachey for her invaluable help and advice with the planning, analyzing, and editing of my research paper. Thank you to Anna Malek for her diligent editing and Amanda deVillers for her map making skills. I'd also like to thank Caren Eckrich and Amanda Hollebhone for their additional assistance as well as the rest of the CIEE staff for their support. A huge thank you to the staff and volunteers of STCB, without whom I would not have been able to find or catch any turtles to study. Especially Mabel Nava and Dr. Robert van Dam for their help with my research, and 'Funchi' Egbreghts, Moogie, and Siep Busink for making Wednesday turtle surveys (and cookies!) my favorite part of the week. Special thanks to Micheal Frick of the Caretta Research Project for his expertise in turtle barnacle identification. Thank you to my family for giving me the opportunity to study in Bonaire. Finally, countless thanks to my research team for their constant encouragement and support, and for putting up with smelly barnacle dissections on the dining room table.

References

- Cintrón-De Jesús, J. 2001. Barnacles associated with marine vertebrates in Puerto Rico and Florida. *Unpublished work* 1-36.
- Crisp, D. J. and H. G. Stubbings. 1957. The orientation of barnacles to water currents. *The Journal of Animal Ecology* 26:179-196.
- Egbreghts, Gielmon 'Funchi'. Field Specialist. Sea Turtle Conservation Bonaire - P.O. Box 492, Kralendijk, Bonaire, NA . Phone: +599 717 2225. E-mail: info@bonaireturtles.org

- Frick, Michael. G. Caretta Research Project - PO Box 9841, Savannah, GA 31412-0041. Phone: 912.447.8655. E-mail: caretta05@aol.com.
- Frick, M. G., Williams, K., and D. Veljacic. 2004. New records and observations of epibionts from Loggerhead sea turtles *Caretta caretta*. *Southeastern Naturalist* 3(4):613-620.
- Goodman, M. A., Goshe, L. R., Braun-McNeill, J., and L. Avens. 2007. Epibiont Collection from Loggerhead Sea Turtles in the Estuarine Waters of North Carolina, USA. *National Marine Fisheries Service*.
- Gulko, D.A. and K.L. Eckert. 2004. Sea turtles: an ecological guide. *Mutual Publishing* 1:1-128.
- Nava, Mabel. Manager. Sea Turtle Conservation Bonaire - P.O. Box 492, Kralendijk, Bonaire, NA .Phone: +599 717 2225. E-mail: info@bonaireturtles.org
- Nogata, Y. and M. Kiyotaka. 2005. Larval development and settlement of a whale barnacle. *Biology Letters* 2:92-93.
- Schaerer, M. T. 2003. A survey of the epibiota of *Eretmochelys imbricata* (Testudines: Cheloniidae) of Mona Island, Puerto Rico. *Revista de Biología Tropical* 4:87-90.

