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Guana Island
Marine Biology Research
and
Related Activities
Program Proposal

June 27th - July 31

Proposal date: June 1, 1994

Submitted to:

The Falconwood Corporation
and Guana Island Wildlife Sanctuary

Submitted by:

Lianna Jarecki
HLS Community College

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Henry and Gloria Jarecki
Guana Island
10 Timber Trail
Rye, NY 10580

30 May, 1994

Dear Henry and Gloria,

Many people think the Caribbean is a place to relax in a laid-back, nothing-moves-too-fast atmosphere. My experience here has been the opposite. I have been teaching more courses than would be expected of any college-level instructor in the US, and , on top of that load, I have been developing new course curricula, running an lecture series, and volunteering for various National Parks Trust activities. In the midst of this overload, I constantly chide myself at not yet having written this proposal. Apparently now the starting date is close enough to heighten my concern about planning marine science month beyond that for completing my various other projects. This is not to say that I have been ignoring Guana. My foremost loyalty is to Guana, and, in nearly everything I do, I feel as though I am representing GIWS. When Mr. Wheatley hired me, he said that he hoped to provide a link between education at the college and research on Guana. This goal has been met in many ways, providing a link not only with the college but also with the National Parks Trust, the Conservation and Fisheries Department, the J.R. O'Neal Botanic Garden, and the general community. Recently, I took students, faculty, and an interested youth on a biological field trip to Guana. Just last week, Andrew Guthrie and I transplanted seedlings of the Sabal Palm, a rare plant found nowhere in the BVI but Guana, and took them to the botanic garden.

As the semester winds down, I am prepared to turn my full attention and time to Guana Islands Wildlife Sanctuary. So, here, finally, is the long-awaited report and proposal for marine science month, 1994.

Marine research is equipment and labor intensive, requiring at least two divers and a lot of time for every research project, yet marine science month participants have proven quite productive over just two field seasons. Although our group includes only a few principle investigators, we already have two research papers--one published and one submitted for publication. Copies of both are included here. Additionally, as you may remember from last year, Stephen Spotte has published some photographs of Guana's fish in his book on keeping marine aquariums (Guana has a copy).

As my life turns more towards the teaching aspect of academics, so do my projects, and this year I plan to spend much of my time teaching marine ecology and coordinating the experts we have available to extend their intellectual resources for the benefit of this community. I have organised an intensive course in coral reef management; I have a $60,000 grant pending from USAID for a five-week intensive course in natural resource management (if I can get it together in the short time available); and I plan to include an upper-level biology student as a formal intern of our research month. The various projects and programs I propose are described in the following pages, along with research reports and proposals from each of the principle investigators participating this year. Skip is intending to send along four scientists from his group for a week or so, and I asked him to arrange this with the Guana Island office directly, as it would impinge more on the hotel and booking schedule than on my activities.

As always, your interest and support of science, conservation, education, and the BVI community through Guana Island Wildlife Sanctuary is greatly appreciated by all who have the unique opportunity to be involved in this very special program.

Love,

Liana

LOGISTICS

Boats:

Marine Science Month: full use of the whaler plus 10 days use of Sovereign I,. This is the same as last year. Graham and Dave are both experienced and competent to use the whaler, but as agreed upon previously, I will drive the Soveriegn when we use it for diving.

Coral Reef Monitoring Course: Transportation for ten to fifteen students to and from Guana for three half-day field sessions, with specific times to be arranged. Once on Guana, we will need boat transportation to marine sites around Guana (Muskmelon and White Bays, and one trip to Lee Bay, Great Camanoe.

Trucks/transportation on Guana:

Marine researchers will need access to trucks for transporting equipment up and down the hill and for carrying scuba tanks between the generator house and the dock. Most of these activities can be accomplished before 7:40 a.m. and after 4:30 p.m. so as not to interfere with regular hotel business, but I would like to have free access to one vehicle during the hours specified.

Sea Table:

The right side of the sea table was leaking last summer, and I sent a memo asking to have it repaired (I tried to repair it then but was unsuccessful). However, it has not yet been fixed, and I would like to have it ready for use during the reef course starting on June 27th.

Scuba tanks and compressor:

All scuba tanks need to be visually inspected and certified by a dive shop prior to the initiation of marine science month activities. The air compressor should be checked out and maintained as Mario sees fit.

BUDGET

Marine Science Month Research

Research supplies: mylar, pvc, tools, hardware, spare parts for compressor, rebar, epoxy, film, developer, photography equipment, pins, paper, pens.	$1,200
Dive gear: To replace old equipment and provide a backup set of diving equipment. Bouyancy compensator, regulator, console, mask, fins and snorkel.	$1,500
Aquaria for sea table: 3 ten gallon aquaria and 3 five gallon.	$300
Safety equipment: oxygen tank fill, first aid kit restock items, spare parts for save-a-dive kit:	$200
Contingency fund: repairs, emergency air fills, transportation, etc.	$800
Communications: telephone, fax, postage, shipping, etc.	$400
Stipend for coordinator: full time (40 hrs per week) @ $12.50/hr from June 26th until July 31st	$3,500
Stipend for full-time intern 27 June - 31 July: five weeks (40 hrs/week) @ $5.00/hr	$1,000
TOTAL:	**$8,900**

Coral Reef Management Course

Airfare — To be covered by student tuition

- Graham Forrester
- Dave Carlon
- Elizabeth Kintzing

Logistics: Five Days field work
- use of Sovereign (3 half days)
- One full day will be spent on the NPT boat
- Transportation for students and instructors between Guana and QE bridge daily

- Supplies for monitoring station
  - underwater epoxy
  - marker pins
  - floats
  - line
  - pvc and joints for quadrat sampling

$600

- Wet lab (sea table) and collecting equipment
  - buckets
  - hoses and T-fittings
  - aquaria

$300

TOTAL: $900

Museum Display Renovation

Formalin and alcohol	$200
Collecting jars and mounting materials	$150
Photo printing and enlargements	$850
Film and developer	$300
Photo backing board	$150
Poster board	$ 50
Spray Mount and tacking glue	$ 70
Wall mount velcro	$ 90
Picture frames	$150
Stipend, part time June 9th - June 26th (50 hours)	$625
TOTAL:	**$2,635**

Bill for Marine Science Month 1994 program development and organisation

January - June, 1994

telephone/fax and email		$450
office supplies (paper, printer ribbon, etc.) and photocopying		$60
postage/shipping		$150
time @ $12.50/hr for 60 hours		$750
	TOTAL	**$1,410**

GRAND TOTAL: $13,845

Project Proposal: Lianna Jarecki
Guana Island Marine Science Month Project Director

I. Education

A. Internships

In the 1993 season, two teenage students, Kishan Cupid and Rashita Maynard, from Tortola, spent a week with the marine science program. During the week, they learned to snorkel and learned quite a bit about local marine and terrestrial creatures and their ecology. They learned to collect, mount, and identify insects, and they assisted Christina Leahy with kestrel behavior observations. They enjoyed the experience and left with a new awareness and appreciation for biological diversity in their own environment.

Ian Greenspan spent a full two weeks with us, and he helped mostly with terrestrial research. However, he was quite interested in becoming more involved with marine biology and was planning to get scuba certified before the 1994 season.

Internships such as these provide an opportunity for community outreach. Louis Potter, from Town and Country Planning, has a potential young intern who I have agreed to take for a week this season if she is interested, which is not yet clear. However, interns with little experience with the marine environment and with Biology in general are of little assistance to the progress of research programs and, in fact, take time away from these studies. It would, of course, be more beneficial for us, and also for the student, to have (an) intern(s) with a solid educational background and familiarity with the marine environment. As I am now in a position to locate such an intern, I have selected one of the top biology students at the college to assist us as a formal, paid intern for the duration of marine science month activities.

Darryl Sookram is a student in the Advanced-level Biology two-year program. His interests are specifically in marine ecology, and he is an experienced skin diver. I have made arrangements with Liz Kintzing, our dive safety officer, to train him as a certified open water scuba diver. Darryl will be enrolled in the coral reef management course to be offered at the end of June, and he is one of the students selected to be sponsored by the Rotary Club. During the month of July, he will be expected to learn to field identify corals and other invertebrates, as well as the more common reef fish; he will take data from the permanent transects around Guana; he will maintain the sea table aquariums; and he will assist in filling tanks, maintaining equipment, etc.

B. Courses

I have developed a week-long, intensive coral reef management course to be taught at the college and on Guana Island from June 27th until July 2nd. Principle investigators Graham Forrester, Dave Carlon, and diving expert and safety officer Liz Kintzing will be team-teaching the course along with myself and Julie Overing, from the Conservation and Fisheries Department. This course will use college classroom and laboratory facilities and Guana's research facilities and boats. GIWS has agreed to offer logistical support including boat transportation and some equipment. Those investigators who will be teaching this course will have their air fare to the BVI reimbursed through funds gathered from tuition. BVI Rotary has offered to sponsor three students tuition, and there has been quite a bit of interest in enrollment in this course. A course outline is included in appendix A.

Additionally, I have secured a grant from OUS/USAID to run a five-week intensive Natural Resource Management Program, taught by a variety of experts, including Guana's own Skip Lazell. This course will consist of five modules: Introduction to Natural Resources Management, taught by Lloyd Gardner from Jamaica; Resource Planning and Development, taught by Ron Black from Hocking College in Ohio; Watershed Management, taught by Gary Ray from St John (this is who Dr. Liao is presently working with), Coral Reef Management, taught by Lianna Jarecki; and Wildlife Management, taught by Skip Lazell and Wenhua Lu (Skip's wife).

USAID will send eight regional students from the Caribbean and the BVI will match that with eight or more students, to a total of about sixteen students. The object of the course is to provide hands on training in natural resource management to students interested and working in related fields. Employees from National Parks Trust and the Planning Department are interested in receiving such training. Another objective of the course is to develop a management plan for Sage Mountain National Park and to install a reef monitoring site and study plan at the Monkey Point moorings. Research facilities on Guana will be needed for a couple days during the coral reef management module of this course (8 - 13 August).

A copy of the natural resources management program proposal can be found in appendix B. This proposal describes the course and schedule in more detail.

II. Research

A. Salt Pond Ecology Project

In March, the Falconwood Corporation granted $5,000 to initiate a comprehensive, two-year study of Virgin Island salt ponds. This project will be launched this July. The entire project will require about $60,000 to complete, and funds are presently being sought from a number of US funding agencies. The proposed research and its justification are described in the following paragraphs.

Hypersaline ponds represent a critical and unique wetland ecosystem, upon which a number of endangered species, including the Caribbean flamingo, depend. However, relatively little is known of the fauna and flora associated with Caribbean hypersaline ponds.

The Caribbean flamingo, *Pheonicopterus ruber ruber*, lives solely in hypersaline ponds and feed by filtering planktonic animals from the water. It is now endangered throughout its range and was completely eradicated from the Virgin Islands by the mid-1900's. However, a few wandering flamingos, presumably from the Dominican Republic population, still occasionally visit St. Croix and St Thomas ponds to feed. In an effort to re-establish a permanent flamingo population in the Virgin Islands, twenty flamingos were introduced to Anegada Island in 1992 by the Guana Island Wildlife Sanctuary in cooperation with The Conservation Agency and the Bermuda Zoo and Aquarium. In conjunction with this program, I have been sampling the planktonic fauna and chemical characteristics of Virgin Islands hypersaline ponds since 1988.

My preliminary data (which were presented and published at the Symposium for Public and Private Cooperation in National Parks Development on Tortola in 1991; see appendix C) reveal dramatic and previously undocumented seasonal cycles in a wide diversity of planktonic organisms associated with seasonal salinity and rainfall. Because plankton form the base of the salt pond food chain, bird populations at the ponds are probably dependent on these cycles of plankton and salinity.

Nearly every Virgin Island, even those smaller than 1,000 acres, has one or more hypersaline ponds. At least three shore bird species, including the endangered Bahama pintail duck, use these ponds as their sole nesting habitat. The ponds are regularly hunted by the fishing bat, which requires still water to locate prey. Many shorebirds rely on hypersaline ponds for food and shelter, and some seabirds, including the magnificent frigate bird, occasionally feed there.

To be effective, hypersaline pond conservation efforts will require extensive information on rainfall, chemical characteristics of the water, planktonic fauna, bird species present and their feeding requirements. I propose to conduct a comprehensive, two-year ecological study of ten ponds on Anegada, Guana, St. John, St. Thomas, and Tortola. Measurements of rainfall and daily weather patterns, water depth, salinity, dissolved nutrient concentrations, dissolved oxygen levels, and alkalinity will be taken monthly at each pond. Plankton will be sampled and identified; shore vegetation will be identified and mapped; and bird species will be inventoried and their behavior (e.g. nesting, feeding) will be observed. Additionally, ten to fifteen other ponds will be sampled bi-yearly in the same manner. The data collected will be published in the appropriate scientific journals.

Hypersaline ponds are unique and ecologically valuable wetland habitats which support a diversity of terrestrial animals. They should be protected and managed. This study will provide information critical for the successful re-establishment of the Caribbean flamingo in the Virgin Islands and will provide the necessary data for identifying environmental threats to hypersaline pond ecosystems, for targeting critical sites for protection and for developing management plans for them.

B. Coral Reef monitoring

Through the integration of the research projects of Graham Forrester, Dave Carlon, and myself, ten permanent transects around Guana Island are monitored on an annual basis. On each of these thirty-meter transects, all corals, sponges, and fish are identified. Measurements of species diversity, species richness, and percent cover for members of these groups are calculated. The combining of expertise provides the ability to study Guana's reefs at a level of detail beyond that of any reef study in the Virgin Islands. The data collected annually from Guana's reefs allow us to compare abundance of particular species in different reef areas; they show associations between species, such as certain corals, sponges, and fish; and they will indicate any long-term changes in reef structure or species composition.

As in previous years, I plan to collect data on sponge species present along the ten transects around Guana. These transects are marked with permanent rebar stakes cemented in the reef thirty meters apart. A tape measure is stretched between the two markers and presence or absence of sponge is noted every ten centimeters down the transect line. When a sponge is encountered, it is identified (as specifically as possible) and recorded, These methods will be repeated for corals.

Because sponges are notoriously difficult to identify in the field and little is known about species composition of Virgin Island sponge communities, I will continue efforts to establish a dried sponge reference collection. For each species collected, the specimen is photographed *in situ*, a piece of the sponge is removed (so as not to kill the entire organism), preserved in formalin and then dried. Spicule preparations are made from siliceous demosponges. Each sponge is identified to species, when possible, and those difficult to identify will be taken (eventually) to the Harbor Branch Oceanographic Institute for comparison with their Caribbean sponge collection.

III. Museum

I developed a small natural history museum on Guana in 1991. After three years, the collection has deteriorated significantly. I propose to renovate the collection starting in June. This will require having some of the photographs reprinted and mounted, reprinting and mounting the explanation signs, cleaning the display cases, replacing many of the specimens, replacing labels, re-organising the library collection, and adding some new marine photographs. The photograph printing will have to be done in the States, but the remaining work can be finished on Guana, given appropriate materials. I will need assistance with re-doing the displays, and plan to incorporate this work into the duties of the marine month assistants (both Darryl and Ian) and perhaps other volunteers (e.g. Dawne). I will also need to spend several days outside of marine science month on Guana with an assistant. As usual, I will work these details out with the management, and I can stay on my boat if the rooms are full. However, expenses incurred on Guana while working on the museum or during marine science month should be billed to GIWS.

GUANA ISLAND MARINE SCIENCE MONTH PROPOSAL AND REPORT

Population regulation in coral reef fishes: a long term study

Part 1: Long term monitoring

Introduction and methods

This part of the project is a continuation of the monitoring study initiated in 1992. Its aim is to provide a long term analysis of patterns in the abundance of reef fishes and how they relate to characteristics of the reef habitat. The proposal for July 1994 is to continue censuses initiated during 1992. The censuses during July 1994 would be done at the sites established in 1992 (see Figure 1).

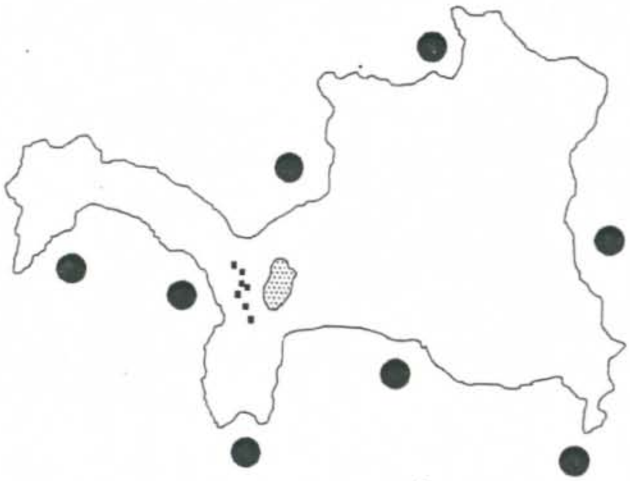

Figure 1. Map of study sites around Guana Island

The methodology would be the same as in previous years (see previous proposals). The censuses will be done during the middle 2 weeks of July; prior experience suggests that this is sufficient time to complete them.

Preliminary results of monitoring from 1992-3

Data from the first two years of monitoring show that 1993 was generally a better year for recruitment of juvenile fishes than 1992. Adult densities were generally similar between years. Future surveys will be used to test whether year to year variation in recruitment of larval fishes influences temporal changes in the density of adult fish.

Results from 1992 and 1993 indicate strong relationships between habitat characteristics and the density of some common fishes. A good example is the three spot damselfish (see Figure 2). The adult density of this species is highly correlated with the cover of live coral on the reef (this feature explains 85% of the variation in fish density). Juveniles show a weaker, but still significant relationship with live corals. Densities of some other species, most wrasses for example, show little relationship to habitat features. Continuation of the surveys will allow us to test whether these two groups of species respond differently to changes in the environment that alter reef features, e.g. hurricanes that destroy live coral.

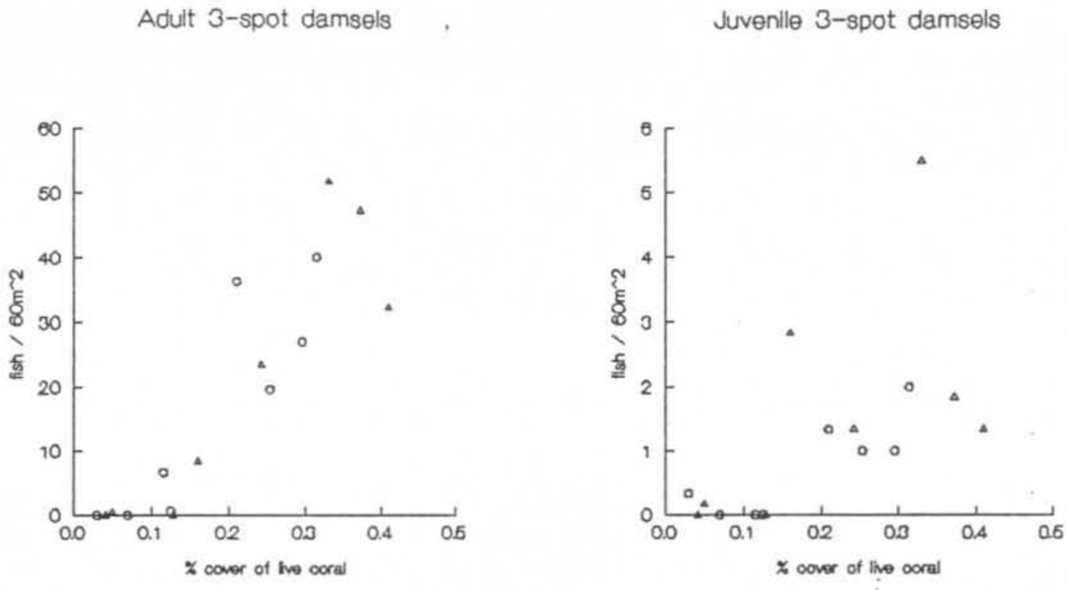

Figure 2. Relationships between the density of 3-spot damsels and the percent cover of live coral. Each point represents the average count from three transects at each site. Triangles indicate counts from 1992 and circles 1993.

Part 2: Detailed population studies of three species

Introduction

As an extension of the monitoring project, I propose to initiate more detailed studies of the population dynamics of the three species listed below.

Study species	**Scientific name**
Bridled goby	*Coryphopterus glaucofraenum*
Colon goby	*Coryphopterus dicrus*
Goldspot goby	*Gnatholepis thompsoni*

These species were chosen as common, representative, members of the fish community occupying thereefs around Guana Island. In addition, basic ecological information is available on these species from my ongoing behavioural studies (see 1992 and 1993 proposals). The long term goal is to obtain estimates of mortality, growth, and reproduction of the three species. Crucial to making estimates of these population processes is the ability to recognize individual fishes in their natural habitat, and follow their fates over time. The three study species have very little skin pigmentation and so are translucent. A preliminary experiment (see 1992 report) has indicated that this makes it possible to inject coloured inks under the skin of these species to produce small marks that are visible to divers. These marks can be used to recognize different individual fishes. The success of this experiment suggests that it may be possible to use a new, more powerful, technique to mark these fishes. The technique involves injecting tiny (1*2 mm) pieces of plastic film under the fish's skin (see Figure 3). The film has a 3 digit number printed on it which is visible to an observer if the skin and tissues are unpigmented. Using different coloured film thus allows thousands of fish to be given a unique tag and be recognized as individuals. The tags, called Visual Implant tags, are manufactured by Northwest Marine Technology Inc. They have been successfully used on many species and, because the tag material is biologically inert, do not have adverse effects on the fishes.

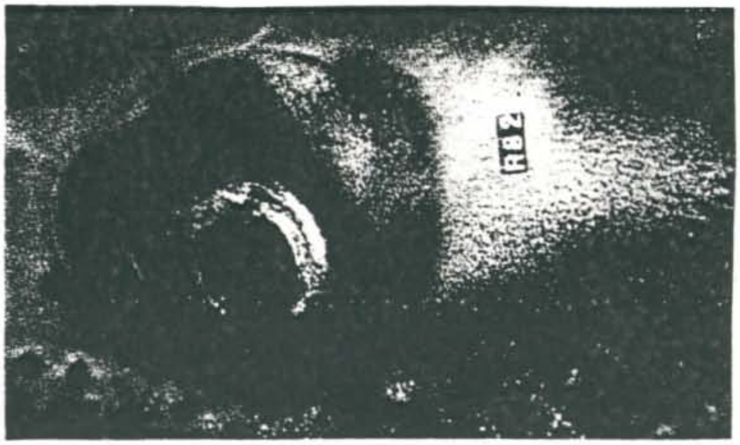

Figure 3. A visual implant tag injected behind the eye of a salmon.

Aims

The goal for 1994 is to mark approximately 240 individuals of the study species with visual implant tags, and to follow the fate of these individually marked fishes in their natural habitat.

Methods

Six 2*2 m study areas will be established on isolated patch reefs during the first week of July. All individuals of the study species within the study areas will be captured by divers using anaesthetic and hand nets. Each fish will be measured and injected with a visual implant tag while still anaesthetized. It will then be released unharmed at its point of capture. We will tag approximately 240 fish from the study plots (based on censuses during 1993).

To provide useful estimates of growth and survival the tags must (1) be retained in the fishes' tissue for long periods, and (2) not have adverse effects on the fishes' growth or behaviour. To evaluate the success of tagging I propose to monitor the fate of the tagged fishes three times:

(1) During the final week of July 1994.

(2) During October 1994.

(3) During July 1995.

On each occasion divers will make thorough searches of the study plots and surrounding areas. We will note the location, tag number, and condition of each marked goby. The first monitoring (July 1994) is to check for tag rejection and any obvious ill affects from the tags. During the second monitoring (October 1994) we will recapture all tagged fishes seen to measure their growth between July and October. This will be the main test of the effectiveness of the tags because the interval is long enough for the fish to grow significantly, but not so long that many of them will have died. By July 1995 many of the gobies marked during July 1994 will probably have died (most goby species for which information is available live only 3-5 years), but we hope to recapture enough marked individuals to reliably estimate growth rates.

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February 28, 1994

Lianna Jarecki
HLS Community College
Box 3079
Road Town, Tortola
British Virgin Islands

Dear Lianna,

I have enclosed a report on last summers research on Guana, and a paper just out in the Journal of Experimental Marine Biology and Ecology. Some of the data for this paper was collected during the first Marine Science Month, way back in 1992.

As for plans this Summer, I have two primary objectives: 1) to collect the racks and settlement plates from last year, and 2) to set up a growth and survivorship experiment with the coral *Favia fragum*. I plan on shipping the settlement plates from last summers work to the University of New Hampshire for analysis. At the University I will inspect plates for settled corals with dissecting microscopes and image analysis software. Will I need a permit to ship these "samples" of Island? If so I can get in touch with Julie Overing about a permit. Concerning the second objective, I'm interested in comparing coral growth and survivorship at different depths. I plan to transplant small *Favia* colonies from shallow water to three depths: 3, 10, and 20 m, at White Bay. These colonies will be photographed *in situ* in order to determine size and left in the field for one year. Next year I will photograph colonies again and determine survivorship and change in size from the digitized slides. A similar experiment is already under-way in St. Croix. Results from these experiments will allow me to compare the effects of depth on survivorship and growth at two sites that vary in reef morphology.

This work is part of on-going research on Guana and St. Croix to determine the causes of vertical zonation in Caribbean reef corals. I am particularly interested in the ecological processes which effect distributions of early life-history stages of corals. After I have completed the analysis of the settlement plate data from Guana, I plan to write up the results for publication.

Oh yes, hats off to you for organizing a great month to do marine biology on Guana. The logistics ran very smoothly and we (Liz and I) were able to get a tremendous amount of work done. The compressor did cause a few problems, but machinery does not always cooperate when you need it. All and all, I think that things went very well.

Talk to you soon,

Dave Carlo

Title: The importance of larval processes in vertical patterns of reef coral distribution

Participants

Project leader: Dave Carlon, Department of Zoology, University of New Hampshire
Diving Assistant: Liz Kintzing, Marine Program, University of New Hampshire

Background and Objectives:

Reef building corals are often distributed in vertical zones at many locations throughout the Caribbean. These patterns can be quite stable over geological time as well as from one location to another. Little is presently known about the ecological processes which lead to these patterns. This project seeks to understand how processes that occur early in the life-history of reef corals determine patterns of adult vertical structure on the reef. Two questions are being addressed: 1) Does larval settlement vary with depth on the reef? and 2) How do larval patterns of distribution relate to juvenile and adult distributions? This study will contribute to a fundamental understanding of how reef communities are organized, and may provide insight into the recovery of Caribbean coral reefs after large natural and manmade disturbances.

Progress to date:

Work this Summer concentrated on quantifying the vertical distribution of adult and juvenile corals, and setting up an experiment to quantify coral settlement with depth.

Two sites that vary in reef topography were chosen for this study. The first site was the Guana Head located on the Southwest side of the Island. Here the reef starts at approximately 6 m depth and slopes gradually outward to a depth of 10 m. At a distance of 50 m from the shore the reef drops across a vertical wall to a sandy bottom at 22-25 m. This wall supports vigorous hard coral, soft coral, and encrusting invertebrate growth. The second site was located near Long Point along the Northern side of Muskmelon Bay. The reef extends seaward from granitic boulders along a gradual slope to a depth of approximately 22 m. As depth near Long Point increases, coral cover breaks up into single large heads separated by sand. At Muskmelon Bay reef topography changes from a gradual slope to a steep wall moving from Long Point to the Northeast corner of the Bay.

Adult density was estimated with line transects. A 30 m line was extended across the reef parallel to the shore. Care was taken to ensure the line followed the contours of the reef. At each 2.5 cm interval species of reef coral was noted. Soft corals, sponges, and algae were also counted along each transect. Adults were counted at three depths at each site: 6, 15, and 24 m. A total of three transects were counted at each depth. Adult density for each species is expressed as the percentage of points occupied out of the total points counted per transect. Individual transects provide replicate measures of adult abundance at each site and depth.

Juvenile coral abundance was determined with square quadrats. In this study I define juvenile corals as those colonies smaller than 40 mm diameter. The smallest coral colonies observed were approximately 4 mm in diameter. Previous research has estimated coral growth rates of 3 - 15 mm year^{-1} (linear extension). It is therefore likely that juveniles range from a few months to 6-7 years in age, depending on species. In order to determine juvenile density, I identified and counted all coral juveniles within ten, 1 m^2 quadrats which were randomly positioned along each line transect. A total of 30 quadrats were counted at each depth, making 90 total for each site.

To quantify larval settlement and recruitment with depth we initiated a settlement plate experiment at the two sites. At the same depths where adults and juveniles were counted, galvanized steel mesh racks with ceramic tiles were attached to the reef. Each rack consisted of 4 pairs of tiles bolted to the top and bottom of a 0.75 m square piece of mesh. Racks where attached to the reef in groups of four at 6, 15, and 24 m. There were two of these vertical arrays of racks per site. This experiment will be left in place for one year. Racks and plates will be retrieved during the Summer of 1994 and inspected for coral settlers.

Results from transect and quadrat data

Corals, sponges, and algae

The vertical distributions of hard corals, sponges, and algae differed between the two sites. At the Guana Head, live coral cover was maximal at the intermediate depth where the vertical drop in the wall was greatest (Figure 1A). In comparison, coral cover declined with depth at Muskmelon Bay (Figure 1B). Total sponge cover showed a similar pattern with depth as the corals at Guana Head: maximal cover was measured at 15 m depth (Figure 1A). This similar response of hard corals and sponges to depth at Guana Head probably reflects the diversity of habitats available on the steeper portions of the reef. The wall provides both cryptic and exposed habitats, supporting massive, encrusting, and branching coral forms. Encrusting and upright sponges were also common along the wall. Branched algae (*Dictyota spp.*) were more abundant at Guana Head compared to Muskmelon Bay, and decreased in abundance at the intermediate depth compared to the shallow and deep depths at Guana Head. Algal cover tended to increase with depth at the Muskmelon Bay.

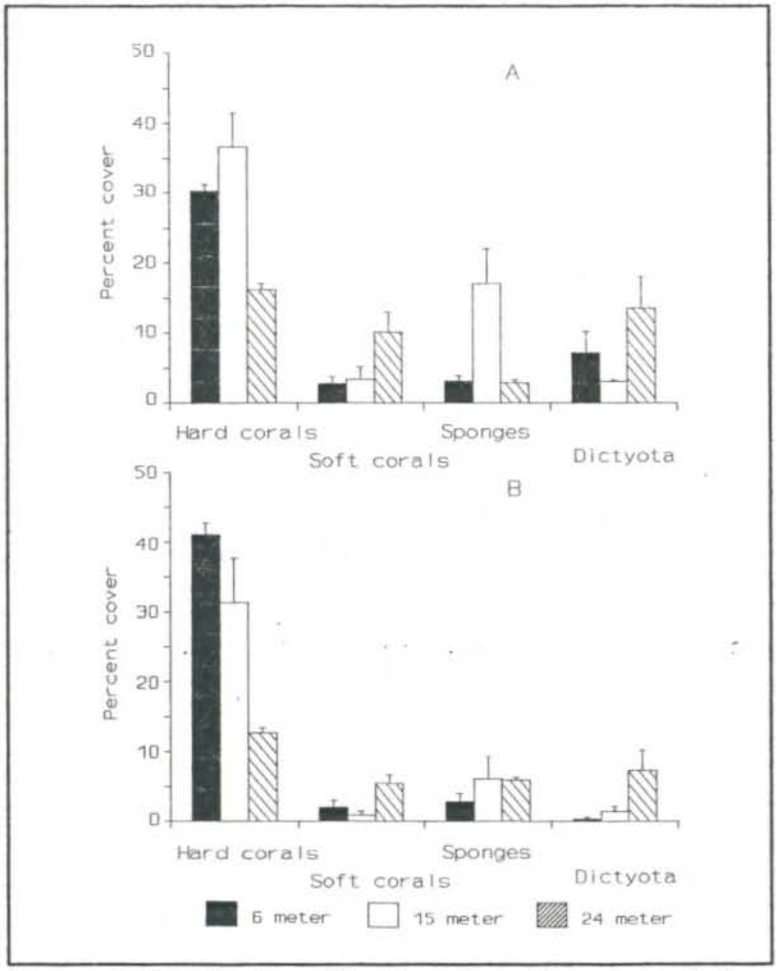

Figure 1 Distribution of hard corals, soft corals, and algae at two sites and three depths on Guana Island: A) Guana Head, B) Muskmelon Bay

The distribution of soft corals (primarily Gorgonians) with depth was much more consistent among the two sites compared to the corals, sponges, and algae (Figure 1A and 1B). At both sites, soft coral cover increased with depth, reaching a maximum at 24 m depth.

Table 1. Mean abundance and standard error (in parenthesis) of reef corals and hydrozoans at two sites on Guana Island. Adult statistics were calculated from nine 30 meter line transects. Juvenile statistics were calculated from 90 meter^{-1} quadrats.

	Adult percent cover		Juvenile abundance (m^{-2})	
Species	Guana Head	Musk. Bay	Guana Head	Musk. Bay
Massive corals				
Montastrea annularis	3.52 (0.63)	4.92 (0.99)	0.42 (0.17)	0.36 (0.11)
Montastrea cavernosa	5.82 (1.06)	8.78 (1.62)	0.43 (0.08)	0.58 (0.08)
Meandrina meandrites	0.25 (0.12)	1.48 (0.38)	0.19 (0.07)	0.89 (0.03)
Colpophyllia natans	1.37 (0.63)	1.55 (0.56)	0.09 (0.03)	0.09 (0.05)
Diploria strigosa	0.55 (0.28)	0.87 (0.26)	0	0.18 (0.04)
Diploria labrynthiforis	0.26 (0.13)	1.29 (0.55)	0.04 (0.03)	0.14 (0.04)
Siderastrea siderea	4.26 (0.63)	2.13 (0.50)	0.84 (0.21)	0.92 (0.19)
Dendrogyra cylindrus	0.19 (0.19)	0	0.07 (0.02)	0.08 (0.03)
Head corals				
Siderastrea radians	0	0.29 (0.18)	0.16 (0.10)	0.29 (0.15)
Dichocoenia stokesii	0.11 (0.07)	0.04 (0.02)	0.07 (0.02)	0.08 (0.03)
Branching and foliaceous corals				
Acropora palmata	0	0.28 (0.24)	0.01 (0.01)	0
Acropora cervicornis	0.43 (0.22)	0	0.11 (0.07)	0.06 (0.04)
Agaricia agaricites	2.65 (0.73)	1.79 (0.59)	6.20 (1.97)	1.62 (0.42)
Agaricia fragilis	0.62 (0.18)	0.09 (0.06)	0.56 (0.24)	0.07 (0.03)
Leptoseris cucullata	0.45 (0.26)	0.28 (0.09)	0.39 (0.11)	0.03 (0.02)
Porites porites	1.33 (0.67)	0.26 (0.13)	0.92 (0.44)	0.27 (0.10)
Porites asteroides	1.28 (0.39)	1.29 (0.55)	1.50 (0.40)	2.09 (0.38)
Porites colonensis	0.63 (0.18)	0.35 (0.12)	0.42 (0.12)	0.09 (0.04)
Madracis mirabilus	0.51 (0.34)	0.04 (0.04)	0.13 (0.11)	0.02 (0.02)
Madracis decactis	1.64 (0.89)	0	0.16 (0.09)	0.17 (0.13)
Mycetophyllia aliciae	0.07 (0.07)	0.23 (0.12)	0	0
Mycetophyllia ferox	0	0.04 (0.04)	0	0
Large polyped corals				
Scolymia spp.	0.23 (0.09)	0.19 (0.09)	0.39 (0.15)	0.30 (0.10)
Mussa angulosa	0.36 (0.11)	0.53 (0.15)	0.02 (0.02)	0.01 (0.01)
Eusimilia fastigiata	0.31 (0.12)	0.17 (0.15)	0.06 (0.02)	0.21 (0.05)
Fire corals				
Millepora alcicornis	0.49 (0.23)	1.23 (0.61)	0.03 (0.02)	0.02 (0.02)
Millepora complanata	0.03 (0.03)	0	0.14 (0.08)	0.04 (0.04)
Millepora squarrosa	0.25 (0.14)	0.07 (0.07)	0.07 (0.07)	0

Hard Corals

I have identified over 40 species of hard coral during my two summers on Guana Island. It is likely that more species will be documented with more diving visits to the Guana. At present, coral diversity on Guana compares favorably to other regions in the Caribbean (Glynn, 1973). Currently, the richest described Caribbean coral fauna is that of Jamaica. Wells (1973) has identified over 62 species from depths as deep as 150 m. Considering that Guana Island lacks reef coral habitat deeper than 30 m, hard coral diversity is high on Guana. A list of all identified coral species to date will be included in next years report.

Twenty five species of hard coral and three species of Fire coral (Hydrozoa) where sampled with line transects (Table 1). The massive corals *Montastrea annularis*, *M. cavernosa*, and *Siderastrea siderea* made up the majority of live coral cover at both Guana Head and Muskmelon Bay. Other species that exceeded 1% cover included the Lettuce coral *Agaricia agaricites*, the Yellow sulphur coral *Porites asteroides*, and the Finger coral *Porites porites*. Species that dominate shallow water on other reefs are conspicuously absent at Guana. Most notably the Elkhorn (*Acropora palmata*) and Staghorn (*Acropora cervicornis*) corals. However these corals may have been quite dense on the island in the past. Remnants of Elkhorn reefs are visible in shallow water on the North and South sides of the Island.

Juveniles of all the adult species were observed in quadrats with the exception of two *Mycetophyllia spp.* and the Fire coral *Millepora squarrosa* (Table 1). Small corals of these species are difficult to separate from congeners may have been included as juveniles of similar species. The highest densities of juveniles were recorded for *Agaricia agaricites* (1.62-6.20 colonies m^{-2}) and *Porites asteroides* (1.50-2.09 colonies m^{-2}). Very few juveniles were observed for the dominant massives (e.g. *Montastrea, Siderastrea* [<1.0 colonies m^{-2}]). The high juvenile abundance of smaller, foliaceous forms and low abundance of massive species has also been reported in Curacao (Bak and Engel, 1979) and St. Croix (Rogers et al. 1984).

Patterns of adult and juvenile abundance were similar in some species but markedly different in others. In the majority of massive forms patterns of juvenile abundance did not reflect adult abundance (Figure 2). This pattern is illustrated by the species *Montastrea cavernosa* and *Siderastrea siderea*. In these species, the relative abundance of adult colonies with depth does not reflect the relative abundance of juveniles at the same depths. For example, *Montastrea cavernosa* had similar abundance as juveniles across the three depths for both sites (Figure 2C and 2D). However, the adult pattern changes markedly depending on the site. At Guana Head adult abundance peaks at the intermediate depth (Figure 2A), whereas at Muskmelon abundance drops with depth (Figure 2B).

In contrast to the massive species, smaller encrusting and foliaceous forms often had similar distributions of juveniles and adults over the three depths sampled (Figure 3). The two species with the highest juvenile abundance (*Agaricia agaricites* and *Porites asteroides*) reached greatest adult density at the two shallow depths (6 and 15 m) regardless of site (Figure 3A and 3B). Juvenile abundance for these two species (Figure 3C and 3D) reflected the adult pattern: there were greater numbers of juveniles in quadrats at 6 and 15 m depth than the deeper, 24 m site. Thus it appears that ecological processes that establish small corals of foliaceous species may be important in that they also largely control adult distributions. This idea will be tested with data collected from the settlement experiment

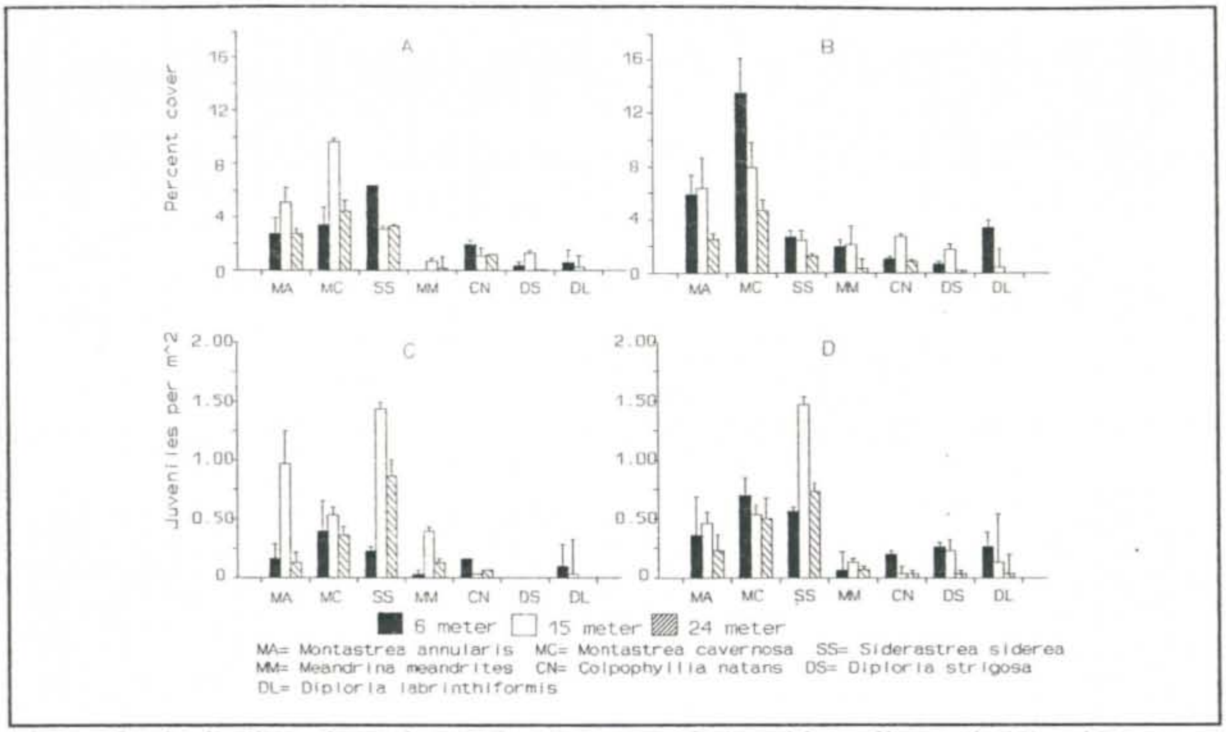

Figure 2 Distribution of massive adult corals (A and B) and juvenile corals (C and D) at two sites on Guana Island. Left Panels (A and C) are from Guana Head. Right Panels (B and D) are from Muskmelon Bay.

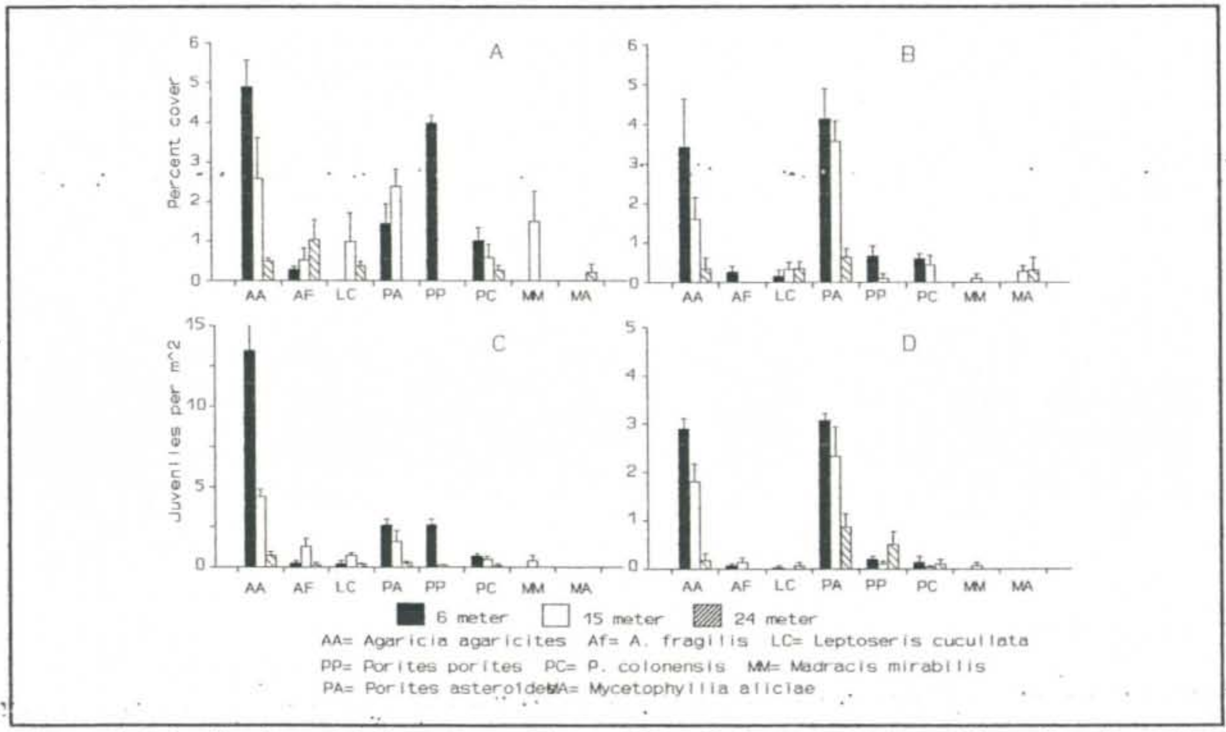

Figure 3 Distribution of foliaceous and branching adult (A and B) and juvenile (C and D) corals at two sites. Left panels (A and C) are from Guana Head. Right panels (B and D) are from Muskmelon Bay.

which will characterize vertical distributions of the early benthic phase of corals: that of the newly settled larvae.

Future work on Guana

During the Summer of 1994 I will retrieve the settlement experiment initiated last year. I also plan to begin a series of experiments that compare coral growth rates at different depths. This research will provide insight into the physiological and ecological processes that structure coral reefs, and will be of predictive value in determining the consequences of reef destruction throughout the Caribbean.

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THE
UNIVERSITY OF
CONNECTICUT

Marine Sciences Institute
Avery Point
Groton, Connecticut 06340

22 February 1992

Ms. Lianna Jarecki
HLS Community College
Box 3097
Road Town, TORTOLA
British Virgin Islands

Dear Lianna

Enclosed is a proposal for work at Guana Island this July. I hope you find it acceptable. Please contact me if additional information is required.

Also enclosed is a draft description of our work at Guana Island in 1991. As I mentioned yesterday, we made more than 1000 sections of male *Neopontonides chacei* (all <5 mm) to examine the state of gonadal maturation. This aspect isn't included in the manuscript yet, but will be added shortly.

Thank you.

Yours truly

Stephen Spotte

Encll Proposal, draft manuscript

SSlss

GUANA ISLAND PROPOSAL 1994

Collections

(1) The spotted cleaning shrimp, *Periclimenes yucatanicus*, is an obligate associate of sea anemones in the West Indies. Its principal host is the anemone *Condylactis gigantea*. The morphology of *P. yucatanicus* appears to vary regionally. An objective this summer is to make a collection of *P. yucatanicus* for comparison with specimens I have collected at other locations. The ultimate objective is to perform a cluster analysis of morphologic characters by region, overlay the results onto a pattern of oceanic surface currents, and determine if regional differences are predictable. I need access to a turtle grass bed where the sea anemone *Condylactis gigantea* is abundant. If the nearest suitable habitat is off Tortola, I shall need a boat for one or two days.

(2) *Periclimenes rathbunae* is a small, translucent shrimp found in association with the sea anemone *Stichodactyla helianthus* in shallow, high-energy zones. Some authorities believe that *P. rathbunae* actually comprises two species. In 1991 we found several specimens of *P. rathbunae* in White Bay, but more are needed. I shall attempt to collect them at the same location.

(3) In 1991, colleague Patricia M. Bubucis and I made extensive collections of caridean shrimps from octocorallians in White Bay (see draft manuscript enclosed). We recovered 9 shrimp species, several of which could not be identified. The *Latreutes* were juveniles of an apparently undescribed species. I intend to spend a half-dozen dives or so resampling the area in the hope of finding some adults.

(4) Undescribed caridean shrimps are occasionally found in association with colonial hydroids and antipatharians (black corals). My colleagues and recently described *Periclimenes antipathophilus*, which lives on black corals. I plan to spend a dive or two searching for hydroids and black corals to sample. Maybe we can find a deep reef off Tortola or somewhere else nearby.

(5) An undescribed mysid lives in association with two sea anemones of the genera *Bartholomea* and *Heteractis*. I shall try to collect some specimens for for future description.

Experiments

The experiments below can be conducted by Lucia and me wearing SCUBA gear and recording data on acetate slates. After a preliminary dive to survey the scene, I shall undertake two of the three experiments. All can be conducted off the beach, thereby reducing our need for a boat except when collecting.

(1) Coloration of adult trumpetfish (*Aulostomus maculatus*) associated with foraging behavior.

There is some evidence that in the trumpetfish coloration is related to foraging behavior, particularly when in the presence of other foraging associates. However, this interesting possibility has not been tested quantitatively.

(2) Time-series analysis of fish cleaning behavior.

Do the clients at a cleaning station arrive randomly or in clusters? Questions of this genre are asked by traffic engineers projecting highway usage and by architects designing entrances and exits of public buildings.

(3) Association behavior of sand gobies.

Several species of "sand gobies" are prevalent in the rubble areas off the beach. I can measure the extent to which they are positively or negatively associated by swimming ghost transects.

Stephen Spotte, Ph.D.
Marine Sciences Institute
THE UNIVERSITY OF CONNECTICUT
Noank CT 06340

22 February 1994

April 26, 1994

Christina L. Leahy, M.A.L.S.
2049 Main Street
Glastonbury, Connecticut
U.S.A. 06033
Telephone No.: 203-657-2409
FAX No.: 203-228-4755

1994 B.V.I. Project Proposal - Sponsored by GIWS:

Over the last two years I have spent approximately two to three weeks each year on Guana Island, studying the killy hawk, recording observations and behavioral data. This work is funded by the Guana Island Wildlife Sanctuary (GIWS). The killy hawk, or killy-killy's scientific name is Falco sparverius caribaearum, or American kestrel, and is a variety (subspecies) recognized from Puerto Rico and the Virgin Islands to Grenada. The killy hawk is not highly migratory, and its life history is not well known. Through this research, I hope to determine the killy hawk population size in the B.V.I., to be able to recognize and document any fluctuations in the resident population, and better understand the role the species plays in the island environment. Information about habitat requirements as well as population dynamics is important for the development of conservation plans affecting this species. In order to accomplish these goals, I ask for the written permission of the Government of the British Virgin Islands, to trap and band the killy hawk (kestrel) in the B.V.I. I hope to observe killy hawk on Guana Island, Beef Island, Tortola, Virgin Gorda, The Camanoes, Anegada, Peter Island, and islands with similar habitat to Peter Island. The greatest number of killy hawks that I counted on a single island was on Peter Island (July 1993). An estimated six to ten individual birds were either sighted or heard calling on Peter Island during one days observation period, which suggests that two families were observed. In North America there is a large variation in territory size (i.e., 1 to 10 pairs per 100 acres) probably dependent on food and nest site availability, two important factors to be studied in the B.V.I. I do not plan to work in bird sanctuaries and at no time will a bird's life or health be jeopardized by our work.

The major goals of the project are outlined as follows:

1. Capture killy hawk utilizing a well documented and safe bird trapping procedure called bal-chatri traps. The traps are monitored at all times while in use, and all birds are released as soon as possible (approximate handling time 15 minutes). All individuals performing the actual trapping and handling of the birds are considered experts in the procedures to be followed, with many accumulated hours (years) of practice. References were provided to the Permanent Secretary last year and donated to the B.V.I. College library, describing this invaluable method of trapping and its safety to both bird and prey item used as bait.

2. Place a color coded band on the left tarsus (leg) of each killy hawk captured. We will utilize various colored bands to represent the island an individual bird is trapped on, i.e., one color per island. Each color band will be coded with a unique number for further individual field identification. Color coded banding enables us to gain information on individual behaviors, which is necessary to evaluate local raptor (bird of prey) populations and to develop an understanding of the life history of the local populations residing in the B.V.I. Information gathered and researched would include territory size and home range, habitat requirements and habitat utilization. Understanding the life history of the killy hawk will give us insight into the role that the hawk plays in the island ecosystem, the environmental niche that they occupy on the islands, and to determine the importance of their presence in the B.V.I.

This information will help determine environmental factors important to the preservation of the B.V.I. killy hawk population. Banding birds is a tried and true method for studying the life histories of birds of prey. The banding procedure is considered safe for B.V.I. killy hawks for a number of reasons. Most importantly, banding will not visually make the birds more vulnerable to predators, as they have no known natural predators in the B.V.I. Additionally, the banding procedure will not cause birds any pain, nor will the bands cause any health risks to individuals banded. References provided to the Permanent Secretary describe the utilization of color coded banding in various species of birds.

3. This study will be run in cooperation with Dr. David Bird, Director of Avian Science and Conservation at the Macdonald Raptor Research Center, McGill University in Quebec, Canada. Dr. Bird is a well known kestrel (killy hawk) expert with many years spent researching this species, and he has published numerous papers on this particular bird species (falcon family). We would also like to place an additional aluminum band of the Canadian Fish and Wildlife Service, each with a unique number and information regarding the recovery of such bands, on the right tarsus of each bird trapped. In cooperation with the U.S. Fish and Wildlife Service, the information from recoveries of birds banded with Canadian Fish and Wildlife Service bands goes into an extensive data base in Washington D.C., which compiles data on survival rates, migration and dispersal patterns, and fidelity to wintering areas for individual bird species. This data base is an important resource in raptor research. The bird references and books provided to the Permanent Secretary document the importance of banding in studying and researching the life history of a bird species.

4. In addition to banding the killy hawk, while capturing and handling the birds, various parameters will be measured and obtained on individuals, and will include wing (chord) length, beak (mandible) length, whole body length and body weight. Other data to be recorded will include the sex of the individual bird, the approximate age (fledgling versus adult), presence of ectoparasites (parasites living externally), plumage appearance (feather damage, molting stage), and general health of the bird. Some of the measurements obtained may help determine and verify the subspecies of killy hawk captured and banded in the B.V.I., since some subspecies differences are determined by certain body measurements. Captured birds will be released immediately upon increased stress levels as determined by the bird's behaviors.

Research results once summarized will be provided to the Ministry of Natural Resources upon completion of this project.

I look forward to your response, sincerely yours,

Christina L. Leahy

Christina L. Leahy, M.A.L.S.

Appendix A

Coral Reef Management Course

27 June - 2 July

Coordinator: Lianna Jarecki

General Objective

This week-long intensive course in Caribbean coral reef management will provide students with theoretical and practical understanding of tropical shallow-water marine systems. Topics discussed will include: ecology of coral reefs, mangroves, and sea grass, environmental threats and protection, monitoring systems for documenting and anticipating habitat changes, and management plan development for coral reefs. Extensive field and laboratory sessions will familiarise students with specific habitats and will provide hands-on training in coral reef management. Local examples of habitat destruction as well as protection and management will be used to illustrate topics.

Schedule and Location

Each day will be divided into morning lectures and afternoon field and laboratory work. Most lectures will be given at H.L. Stoutt Community College, while laboratory exercises and field work will be conducted at the Guana Island research facilities. A monitoring site will be established at the Monkey Point mooring area off Guana Island.

Instruction:

Lianna Jarecki, Biology instructor and marine biologist at H.L.S.C.C., will coordinate this course. Instruction will be given by Ms. Jarecki, Dr. Graham Forrester (fish ecologist at the University of California, Santa Barbara), Mr. Dave Carlon (tropical invertebrate biologist from the University of New Hampshire), and Ms. Julie Overing (marine biologist at the Conservation and Fisheries Department, BVI). Safety and technical support will be provided by Ms. Liz Kintzing (PADI Instructor and emergency medical technician).

Course Outline

Caribbean Coral Reef Management

A. Ecology of Caribbean shallow marine systems

1. Interdependent systems: mangrove, seagrass, and reefs

2. Mangroves and associated wildlife
    a. lagoons
    b. salt ponds
    c. land use and erosion
    d. coastal development, pollution and dredging
    e. seabirds and wading birds

3. Seagrass and associated wildlife
    a. algae and vascular plants
    b. ecological succession in lagoons
    c. important commercial and/or threatend species e.g. green turtles and conch
    d. environmental threats to seagrass communities

4. Coral reefs
    a. reef types: fringing reefs, barrier reefs, patch reefs and atolls.
    b. reef zonation: reef crest, spur and groove, and reef slope.
    c. dominant coral reef species, including corals, gorgonians, sponges, echinoderms, crustaceans, and fish
    d. patchiness and species associations: microhabitat preferences
    e. cosmopolitan species
    f. environmental protection
        for species or for habitats?
    g. threats to coral reefs
        land-based development
        anchoring
        dredging
        pollution
        predator depletion
        natural threats

B. Ecological Monitoring

1. Species identifications
    a. Red, White, and Black mangrove
    b. Eel grass, Turtle grass, and Manatee grass
    c. Calcareous green algae
    d. Dominant reef invertebrates
    e. Dominant reef fish
    g. Commercially important reef organisms

2. Methods for monitoring:
    a. mangroves
    b. salt ponds (water chemistry, plankton cycles, breeding birds)
    c. sea grass (growth rate, density, species composition)
    d. coral reefs (permanent transects, quadrat sampling, photographic sampling)
    e. sampling measurements: percent live cover, species composition, species richness, species associations.

C. Installing and taking data from a permanent coral reef monitoring site at mooring installations

FIELD WORK; SCUBA certification is required to participate in this exercise.
Uncertified participants can observe from the surface by snorkeling.

D. Habitat protection and species conservation

1. Developing regional management plans
2. Anchoring restrictions
3. Mooring systems
4. Fisheries protected areas
5. Pollution control (waste disposal; desalination operations)
6. Ecosystem conservation vs. protecting single species
7. Legal considerations and community cooperation
    a. fisheries
    b. tourism
    c. individual initiatives (e.g. Guana Island)

E. Community Education

1. Understanding ecology
2. Awareness of environmental destruction
    a. globally
    b. locally
3. Providing opportunities for action and cooperation
    a. public participation in research and monitoring
    b. beach clean-ups
    c. mandatory donations/ habitat use fees.
4. Encouraging ecologically sustainable industries
    a. sailing, snorkelling, diving
    b. sustainable fishing
    c. impact considerations

Appendix B

Natural Resource Management

Program Proposal

H. Lavity Stoutt Community College
Paraquita Bay, Tortola
British Virgin Islands

Submitted to: OUS/USAID
Development Training Project
University of the West Indies

Introduction and Justification

With growing emphasis on environmental conservation worldwide, small islands--which generally harbour unique environments and unusual organisms--are in special need of people with expertise in protecting and managing natural areas. Most Caribbean islands are small and, therefore, space-limited. Rapid population expansion consumes land and threatens the unique creatures and habitats of these islands. With this rise in population comes growth in technology and industry, which leads to severe pollution problems; most small islands do not have the land mass or the economic strength to accommodate these changes. Thus, environmental education and specific training in natural resource management is particularly important in the small island developing states (SIDS) of the Caribbean.

A need for such training has been stressed by government and non-government groups within the British Virgin Islands, particularly by the National Parks Trust, which acquires and maintains parks and protected areas (both terrestrial and marine) in this region. An outline for a five-week intensive course in natural resource management has been designed by the H Lavity Stoutt Community College. The aim of this course is to offer training from international experts to students throughout the Caribbean as well as to fill the needs for resource management training in the BVI.

The program will be taught by professional educators and researchers with expertise in specific aspects of natural resource management. It will comprise five modules: Introduction to Natural Resource Management, Resource Planning and Development, Watershed Management, Coral Reef Management, and Wildlife Management. Instructors will include Lianna Jarecki, of H Lavity Stoutt Community College, Lloyd Gardner, of Omni Services, Jamaica, Dr. Gary Ray, of the Virgin Islands National Park, St. John, Dr. James Lazell and Dr. Wenhua Lu, of The Conservation Agency, USA, and Ron Black, of Hocking College, USA.

The course stresses both terrestrial and marine environments and will produce management plans for natural areas in the BVI. The study program will include actual on-sight projects for completion during a five week duration.

Social and economic benefits

The beneficial outcomes of this program will include the following:

1. Increase environmental awareness locally;
2. Provide specific training in natural resource management for individuals presently working in this area;
3. Assure that this training is of the highest quality and relevance by inviting international experts in specific fields of resource management as well as utilizing local experts in the Virgin Islands to serve as instructors;
4. Extend the benefits of such training to the whole Caribbean by offering this course as a regional program for all Caribbean SIDS
5. Develop and initiate specific management and monitoring programs for terrestrial and marine areas targeted by the National Parks Trust as being in urgent need of management plans (e.g. a management plan for Sage Mountain National Park and coral reef monitoring stations around mooring installations in marine protected areas);
6. The specific projects suggested by the National Parks Trust will encourage ecotourism, which should create jobs for the graduates of this program;;
7. Provide a forum for interaction between students and instructors of resource management from many Caribbean Islands and from the United States. Such interactions will provide a more global understanding of environmental management than a less international program would.

Course Schedule and Descriptions

This intensive course will run for five weeks, with lecture, laboratory, and field instruction continuing full-time throughout the duration of the course. Each week will consist of one course module, taught by an professional educators with specific expertise in the discipline and in the Caribbean environment.

The first module is an introductory course in natural resource management with emphasis on the ecology, economic benefits, and development/management of a variety of terrestrial and marine resources. This module is followed by practical exercises in resource planning and development, which will include the creation of a master plan for Sage Mountain National Park, Tortola. Students will then study forest ecology and watershed management with emphasis on practical conservation techniques. The following week's module will train students in marine ecology and techniques of coral reef management. One objective of this course is to plan and install a coral reef monitoring station. The final module will cover terrestrial wildlife management and will train students in conservation techniques for identifying and protecting biotically rich habitats and protecting endangered species.

Introduction to Natural Resource Management **18-23 July**

Instructor: Lloyd Gardner, MSc
Environmental Consultant, Omni Services
Kingston, Jamaica

This course will offer an introduction to the theories and techniques of natural resource management. Natural history and ecology of the Caribbean will be taught with respect to the practical use of natural resources in society. It is expected that students will come away with a solid base of theoretical knowledge to build on in the next sections of the course. Field and laboratory work will provide hands-on experience with various types of natural resources and techniques for management.

Resource Planning and Development **25-30 July**

Instructor: Ron Black, MSc
Instructor in Natural Resource Management
Hocking College
Ohio, USA

This course involves the process of master planning for natural/cultural resource management areas. Areas of study include land acquisition boundaries, resource inventories, planning of accessways, day use facilities, concessions, interpretive systems and resource maintenance and management strategies. The lab portion of this course consists of planning exercises in the field at a resource management area. Completion of a master plan for the assigned area is required.

Watershed Management **2-6 August**

Instructor: Gary Ray, PhD
Conservation Biologist
Virgin Islands National Park
St. John, USVI

This course will cover theoretical and practical aspects of watershed management. Topics discussed will include forest ecology, impacts of land use on water conservation, economic benefits of forest resources, soil erosion and water conservation techniques, biological threats to natural forests, and reforestation methods for natural protected areas. The module will include classroom instruction and laboratory analysis, but will emphasize field work. Students will work in a variety of habitat types and will be involved with soil and water conservation programs through interaction with the BVI Agriculture Department.

Coral Reef Management **8-13 August**

Instructor: Lianna Jarecki, MSc
Biology Instructor
H. Lavity Stoutt Community College
Tortola, BVI

Lectures will cover the topics of tropical marine ecology and conservation. Economic interests and use of marine resources, including fisheries and the charter boat industry, will be discussed. Field and laboratory exercises will train students in species and habitat identification, assessing environmental quality, planning mooring systems, and identifying key habitats for parks and fisheries protected areas. Students will be required to take part in the planning and installation of a reef monitoring station at a National Parks Trust moorings site. Students will assess species diversity, percent live cover, and relative abundance at this site, and these measurements will be continued in the future by the Conservation and Fisheries Department. Julie Overing, marine biologist at the BVI Conservation and Fisheries Department, will be supervising the installation of a coral reef monitoring site and will assist in training students to use underwater research equipment and collect ecological data.

Wildlife Management **14-19 August**

Instructors: James Lazell, PhD and
Wenhua Lu, PhD
The Conservation Agency
Rhode Island, USA

This module will cover practical and theoretical topics of wildlife management. Lecturing shall focus on species diversity, population dynamics of key species, life histories, and habitat requirements. Field work will emphasize the interrelationship of animals and their habitats in a variety of ecosystems, minimum area requirements for protection of populations and habitats, reintroductions and protection of endangered species, and the economic value of wildlife protection, particularly with respect to tourism. A variety of islands will be visited to study the behavior and habitats of some of the endangered fauna of the BVI, including the Caribbean flamingo, the Anegada Rock Iguana, and the Bridled Quail Dove.

Appendix C

J. Exp. Mar. Biol. Ecol., 173 (1993) 247–263

OPPORTUNITY!

Dave Carlon

JEMBE 02041

Larval dispersal distance as an explanation for adult spatial pattern in two Caribbean reef corals*

David B. Carlon and Richard Randolph Olson

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Abstract: Larval dispersal distance is a parameter which can account for differences in adult spatial distribution between closely-related marine invertebrates. To examine its importance in relation to Caribbean reef corals, we observed the larval swimming and settlement behavior of two Caribbean coral species; one of which (*Favia fragum* [Esper]) has a highly aggregated adult distribution, the other of which (*Agaricia agaricites* [Linnaeus]) is less aggregated. Larvae of the highly aggregated species, when followed in situ by divers, settled rapidly (less than 10 min) and showed little discrimination among different types of substrata. Larvae of the less aggregated species swam longer and showed clear discrimination between types of substrata. Our data suggest a correspondence between larval swimming/settlement behavior and adult distribution. Such a relationship between larval behavior and adult distribution could be important in understanding the linkage between life history and adult spatial patterns in sessile marine invertebrates.

Key words: Behavior: Caribbean; Coral; Dispersal; Larvae; Settlement

INTRODUCTION

Many sessile marine invertebrates have aggregated patterns of spatial distribution. These include corals (Lewis, 1970; Grassle, 1973; Maragos, 1974; Dana, 1976; Gerodette, 1981), barnacles (Wethey, 1984, 1986), polychaetes (Rosenberg, 1974; Eckman, 1979), and ascidians (Young et al., 1988). In sessile organisms that produce demersal or planktonic larvae, aggregated adult distributions may result from pre-settlement processes or from differential post-settlement mortality. While processes which affect post-settlement survivorship are undoubtedly important in producing patterns of adult distribution on a number of spatial scales (e.g. Connell, 1985), the importance of pre-settlement processes in creating adult patterns remain largely unknown.

The distribution of settled larvae on the sea floor is related to physical processes which transport larvae near the benthos (Butman, 1987) and to larval behavior during dispersal and settlement. Since the majority of invertebrate larvae are weak swim-

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mers compared to the currents they are carried in (Chia et al., 1984), currents will largely determine the rate and direction of horizontal advection. However, larval behavior which influences vertical position in the water column may determine both the scale of dispersal and the area over which larvae search for potential settlement sites. For example, after release from the parent colony, larvae may swim for short periods before descending to the benthos (Olson, 1985; Davis & Butler, 1989; Stoner, 1990). This brief planktonic period often results in short distance dispersal: on the order of a few cm to meters. After initial contact with the benthos larvae may reject unfavorable settlement sites and return to free-stream currents (Davis, 1987; Mullineaux & Butman, 1991). This behavior may increase the potential of contacting preferable substrata.

There are three ways in which larval behavior can create aggregated adult spatial patterns:

(1) *Gregarious settlement*: larvae settle preferentially near conspecifics.
(2) *Selection of microhabitats:* larvae select microhabitats that are distributed in an aggregated fashion.
(3) *Limited dispersal:* larvae typically disperse and settle short distances from the parent.

The first two mechanisms involve active habitat selection by larvae (e.g. Meadows & Campbell, 1972). These have been invoked to explain patterns of recruitment in bryozoans (Keough & Downes, 1982), corals (Sebens, 1983; Morse et al., 1988), barnacles (Raimondi, 1988, 1990), abalone (Morse & Morse, 1984; Shepherd & Turner 1985), polychaetes (Jensen & Morse, 1984), and sand dollars (Highsmith, 1982a). The third hypothesis, limited larval dispersal, may also produce aggregated patterns of adult distribution but convincing evidence for it is provided by only a few groups of organisms, such as bryozoans (Keough & Chernoff, 1987), ascidians (Olson, 1985; Grosberg, 1987; Davis & Butler, 1989; Stoner, 1990) and solitary corals (Gerodette, 1981).

Whether adult aggregation is due to limited dispersal or behavior at settlement has important consequences for the population dynamics and evolution of benthic marine invertebrates. For example, limited dispersal may result in populations that are effectively closed to outside recruitment and are highly susceptible to local extinction (Keough & Chernoff, 1987; Davis & Butler, 1989). Additionally, limited dispersal in clonal marine invertebrates such as sponges, hydroids, bryozoans, ascidians, and corals results in patches of highly related individuals which increases the probability of fusion between colonies (Jackson, 1985; Grosberg, 1987). Fusion events may be advantageous for these organisms in that they increase overall colony size, which can increase colony survivorship.

This paper compares larval behavior during dispersal and settlement of two Caribbean reef corals: *F. fragum* (Esper) and *A. agaricites* (sensu van Morsel, 1983). The behavior of the larvae is then related to the spatial distribution of adult colonies.

Specifically, larval swimming times, larval preference for natural substrata, and the degree of aggregation of adult colonies, are compared between these two species.

In situ techniques are used to observe coral larvae in the field. Over the past decade a number of investigators have documented larval dispersal through direct observations of swimming larvae. This technique is limited to organisms with relatively large larvae, such as ascidians (van Duyl et al., 1981; Olson, 1983, 1985; Young, 1986; Davis, 1987; Olson & MacPherson, 1987; Stoner, 1990), and corals (Resing & Best, 1988). Data from these observations provide useful assessments of how much vertical and horizontal movement larvae typically accomplish.

METHODS

STUDY LOCATION AND SPECIES

Research was conducted at two locations in the Caribbean. Larval swimming observations and settlement experiments took place at the Discovery Bay Marine Laboratory, Jamaica, West Indies (77° 24′ W; 18° 28′ N). Data on spatial pattern were collected at Guana Island, British Virgin Islands (64° 35′ W; 18° 30′ N). It was not logistically possible to collect data on larval swimming and settlement behaviors and data on adult spatial pattern in the same location. However, the spatial pattern of adults we quantified at Guana Island were similar to spatial pattern of adults we observed at other locations in the Caribbean. These include Discovery Bay, Jamaica: the San Blas Islands, Panama; and the Florida Keys. At these locations adults of *F. fragum* were typically found in small clumps (1 m diameter), whereas *A. agaricites* tend to occur in much larger patches. Additionally, Lewis (1970) documented aggregated distributions of *F. fragum* and *A. agaricites* using quadrat data in Barbados. Since we have no a priori reason to believe that there are large differences in larval behavior among locations, we feel our experimental results from Discovery Bay, Jamaica, are applicable to other parts of the Caribbean, including Guana Island.

The two study locations differed primarily in the vertical distribution of corals. The southwest side of Guana Island is surrounded by a fringing reef which extends ≈ 1 km from the shore. The fore-reef slopes gradually to ≈ 10 m, at which point the reef drops off sharply to a sandy bottom at 20–25 m. Hard and soft corals are most abundant between 3 and 20 m depth and species composition is similar to Jamaica (D. Carlon, unpubl. data). At Discovery Bay, Jamaica, vigorous coral growth extends well beyond 30 m (Hughes & Jackson, 1985). General accounts of reef community structure and zonation in Jamaica are given in Goreau (1959), Goreau & Wells (1967), Kinzie (1973), and Liddell & Ohlhorst (1987). Community structure at Jamaica has changed considerably after Hurricane Allen of 1980 (Woodley et al., 1981). Most notably, populations of many foliaceous and branching corals (i.e. *Agaricia, Porites, Acropora*) have been reduced to much lower densities in shallow water (< 30 m, Hughes, 1989).

Favia fragum and *A. agaricites* are common members of Caribbean reefs (Glynn, 1973). *Favia fragum* forms small (<8 cm diameter) hemispherical colonies and is most abundant in shallow (<3 m) back- and fore-reef habitats (Goreau, 1959; D. Carlon, pers. obs.). *Agaricia agaricites* has a wide depth distribution (Goreau & Wells, 1967). It typically forms mound-like colonies in shallow water but is more plate-like with increasing depth (Hughes & Jackson, 1985). Van Morsel (1983) documented two reproductive patterns among the five formae of *A. agaricites* described by Wells (1973), and proposed a new species *A. humilis*. In this paper we adopt van Morsel's taxonomy and include four formae in *A. agaricites*: forma *agaricites* (Linneaus), forma *caranata* Wells, forma *danai* Milne Edward & Haime, and forma *purpurea* (Lesueur). Both species brood planula larvae: *F. fragum* releases larvae on a lunar cycle throughout the year (Szmant-Foelich et al., 1985; Soong, 1990), whereas *A. agaricites* releases larvae in the spring and summer with no apparent lunar periodicity (van Morsel, 1983). *Favia fragum* and *A. agaricites* present a particularly good opportunity to make comparative observations of larval behavior in situ as both species brood large (>1 mm) planula larvae which can be observed directly by divers.

SPATIAL PATTERN

We used two methods to quantify the spatial pattern of *F. fragum* and *A. agaricites* at Guana Island. In order to determine if adult colonies of these two corals were distributed in a uniform, random, or clumped fashion, we counted the number of coral colonies in 27 1-m^2 quadrats that were randomly positioned within a 600 m^2 area of fore-reef slope (4.5–10 m depth) located 1 km south of White Bay. The variance to mean ratio was calculated from these quadrat data and the statistic

$$I = (s^2/\overline{X})\,(n-1)$$

was compared to a χ^2 distribution with $(n-1)$ degrees of freedom. Values of I that exceed the critical χ^2 value indicate an aggregated distribution (Andrew & Mapstone, 1987).

We also used a nearest-neighbor method to compare the degree of aggregation between *F. fragum* and *A. agaricites*. Hines' index of pattern (Hines & Hines, 1979; described in Krebs [1989]) was calculated from nearest-neighbor distances specified by the T-square sampling procedure (Besag & Gleaves, 1973). Briefly, a random point was located within the same area where quadrat data were collected. From this point two distances were measured: (1) the distance to the nearest coral colony (x_i), and (2) the distance from the nearest coral colony to its nearest neighbor (z_i), given that the neighbor creates an angle $>90°$ between itself, the colony nearest to the random point, and the random point. This was repeated 40 times for each species. Hines' index is sensitive to differences in the magnitude and variability of x_i and z_i. In general, large values of Hines index indicate aggregated distributions, whereas low values indicate uniform distributions. Critical values of this index are given in Hines & Hines (1979).

LARVAL SWIMMING OBSERVATIONS

Larvae of both coral species were obtained by bringing adult colonies into the laboratory and placing them in beakers of seawater overnight. The following morning larvae were removed and placed in 10 ml syringes for transport to the field.

Locations for larval swimming observations were established on the fore reef at 15 m depth, and the back reef at 5 m depth. Each observation began with a diver ejecting a larva from a syringe at ≈0.5 m above the benthos. The larva was tracked visually from a distance of at least 0.5 m. While this distance may deter fish predators, there was no noticeable hydrodynamic effect on the swimming larva. At the end of the observation, notes were made on the total swimming time and the fate of the larva.

In situ observations were made in the morning (9:00 am to 12:00 pm) over a 2-wk week period during June of 1992. During this period, wind speeds were <20 knots and there was no noticeable variation in current velocity among days at the back and fore-reef sites.

LARVAL SETTLEMENT EXPERIMENTS

Experiments designed to test the effect of different substrata on settlement and metamorphosis were conducted in the field and laboratory. Larvae for all experiments were obtained in the same manner as for the larval swimming observations and all larvae used in experiments were released the previous night, i.e. they were less than 24 h old at the beginning of all experiments.

In order to determine if *A. agaricites* larvae preferentially settle and metamorphose on particular substrata, larvae were offered the following natural substrata in the field:

(1) bare coral rubble (dead *Acropora cervicornis* with no visible filamentous or coralline algae)
(2) coral rubble with a thin coating (1–3 mm) of filamentous algae (*Enteromorpha spp.*)
(3) coral rubble encrusted with the coralline algae *Spongites sp.2* (R. Steneck pers. comm.)
(4) coral rubble encrusted with the coralline algae *Paragoniolithon typica* (sensu Adey and Vassar, 1975).

A single substratum (≈2 cm diameter × 8 cm long) was placed in a cylindrical clear plastic chamber (16 cm diameter × 7 cm high) with nitex windows (100 μmesh). Three of these chambers (each with the same substratum), were then secured to a square plastic rack (0.61 × 0.54 m), and racks were randomly positioned within a 50 m^2 area on the fore-reef slope at 10 m depth and secured to the bottom. A total of eight racks was deployed, with six replicates of each experimental substratum divided among two different racks. Ten *A. agaricites* larvae were then injected into each chamber with a syringe, making a total of 240 larvae for the experiment. After 24 h, racks and chambers were retrieved from the reef and transferred to the laboratory for examination. Experimental substrata were examined under a dissecting microscope and the number of settled, metamorphosed individuals was counted. Settlement and metamorphosis was scored if the septal ridges of the newly settled polyp were visible. Preference was determined as the number of larvae that settled and metamorphosed on the substratum divided by the total number of swimming or settled larvae found within the chamber. This experiment was analyzed as a one-way nested analysis of variance (ANOVA) with racks nested within substratum treatment.

A similar field experiment was conducted to determine if *F. fragum* larvae preferred to settle and metamorphose on substrata collected from the shallow or deep reef. In this experiment *F. fragum* larvae were offered one of two different substrata:

(1) coral rubble collected from the back reef at 2 m depth
(2) coral rubble collected from the fore-reef slope at 10 m depth.

Rubble fragments used in this experiment were randomly collected at each depth and no effort was made to use rubble encrusted with a particular epibiont. A total of six racks was randomly positioned in the same area as the previous experiment, with nine replicates of each experimental substratum divided among three racks. Ten *F. fragum* per chamber were used, making a total of 180 larvae for this experiment. This experiment was analyzed as a one-way nested ANOVA, with racks nested within substratum treatment.

Examination of the substrata used in the previous experiment designed to test preference by *F. fragum* larvae for coral rubble collected from two different depths suggested that these larvae settled indiscriminately with respect to substrata type: metamorphosed larvae were found on bare rubble, filamentous algae, and coralline algae. In order to determine if larvae distinguished between these substrata, a laboratory experiment was conducted where larvae were presented with one of three types of substrata:

(1) bare coral rubble
(2) coral rubble with a coating of filamentous algae
(3) coral rubble encrusted with coralline algae (*Spongites sp.2*).

A single piece of rubble was placed in a 200 ml glass vial filled with unfiltered seawater. Each substrate was replicated three times for a total of nine separate experimental vials. Five *F. fragum* larvae were then added to each vial. After 24 h the substrata were examined under a dissecting microscope, and metamorphosis was scored as in the field experiments. A total of 45 larvae were used in this experiment, and the data were analyzed as a one-way ANOVA.

RESULTS

SPATIAL PATTERN

Quadrat data indicated that both *F. fragum* and *A. agaricites* have an aggregated pattern of distribution at the scale of 1 m^2 (*F. fragum*: $I = 140.3$, $df = 26$, $p < 0.05$; *A. agaricites*: $I = 250.9$, $df = 26$, $p < 0.05$). Comparison of the observed quadrat counts with those expected if coral colonies were randomly distributed across the fore-reef slope reveals that in both species there were significantly greater number of quadrats with colony densities much less than, or much greater than, the population mean in each species (Fig. 1).

Nearest-neighbor data indicated that the tendency towards aggregation is greater in *F. fragum* than in *A. agaricites*. Hines index of pattern gave a statistical result similar to the quadrat data in that it indicated significantly aggregated distributions for both species with a $p < 0.005$. However, the actual value of this index was greater for

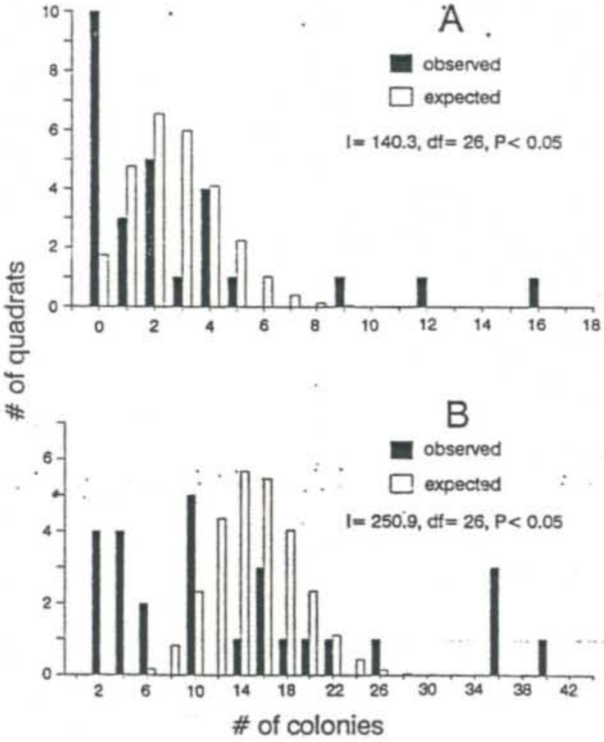

Fig. 1. Frequency distribution of the number of 1-m^2 quadrats with different numbers of adult colonies at Guana Island: (A) *F. fragum*, and (B) *A. agaricites*. Expected frequencies (light bars) were calculated by assuming Poisson distribution.

F. fragum (1.84) than for *A. agaricites* (1.65). Comparison of means and standard deviations of point-organism distances (X) and organism-neighbor distances (Z) for each species suggest the scale of aggregation in *F. fragum* is smaller than *A. agaricites* Table I). Point-organism distances are larger and have a greater variability than the organism-neighbor distances in *F. fragum*. In comparison, point-organism and organism-neighbor distances of *A. agaricites* are similar in mean and standard deviation.

LARVAL SWIMMING OBSERVATIONS

A total of 44 *F. fragum* larvae and five *A. agaricites* larvae were followed in situ. The small sample size of the latter group was due to the long total swimming time in *A. agaricites* larvae (none attached during the observation period) and unpredictable larval release by adult colonies which resulted in a shortage of larvae for field observations.

The vertical pattern of swimming was very consistent for *F. fragum* larvae. Virtually all larvae when released, began swimming upwards for a short period (1–3 min), then reversed their direction. Total larval swimming time for *F. fragum* larvae that eventually attached to the benthos was ≈4 min (Fig. 2), and there was little variation in total swimming time between larvae released in the back- and fore-reef habitats.

There was no consistent vertical pattern of swimming for *A. agaricites* larvae. However, none of these larvae attached during the observation period (Table II), and all larvae released on the fore-reef slope swam for at least 17 min. *A. agaricites* larvae released at the back reef also swam for an extended period of time, but both were eaten by damsel fish.

We use the word "attachment" instead of "settlement" because no larvae were observed to begin metamorphosis. When a larva contacted a surface, it attached itself through adherence of its mucus, and began moving around the surface using its cilia. In no cases did any larvae swim back up into the water column after their first, initial contact.

Although we had intended to follow the fate of larvae after attachment, this proved unfeasible. After a larva had attached, we monitored it approximately once every 5 min.

TABLE I

Hines' index of pattern, mean point-organism distances (X), and mean organism-neighbor distances (Z) as defined by T-square sampling for two species of reef coral. Standard deviations are given in parentheses ($n = 40$ for all measures).

Species	Statistic		
	Hines' index	X (m)	Z (m)
F. fragum	1.84	0.63 (0.47)	0.40 (0.37)
A. agaricites	1.65	0.24 (0.19)	0.23 (0.16)

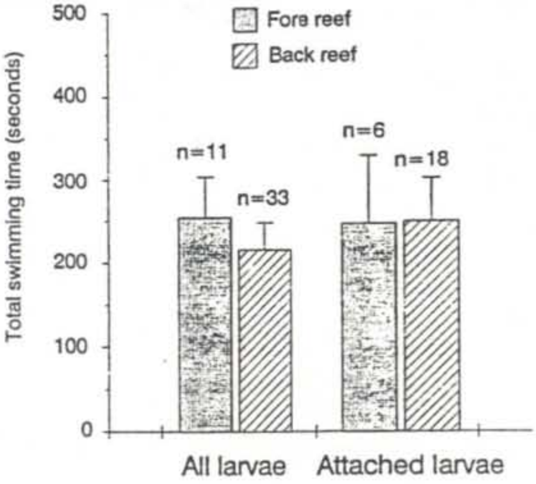

Fig. 2. In situ swimming times for *F. fragum* larvae that were lost, eaten, or attached (All larvae) and for those larvae that attached (Attached larvae) during the observation period at two different reef habitats at Discovery Bay, Jamaica. Vertical bars are 1 SD.

but eventually all larvae were lost within half an hour of attachment because they crawled away from their initial site.

Larvae of *F. fragum* showed no obvious preference for different surfaces in their attachment. More than half of the larvae (15 of 24) attached to algae such as *Halimeda*, *Padina*, and *Penicillus*. However, in most cases, the final contact of a larva with a surface occurred as it was "tumbling" in circles in the small-scale, near-bottom turbulence above the benthos. Thus the actual contact with a surface appeared to be more of a random process in the midst of turbulence than an active swimming movement by the larva.

TABLE II

Swimming times and fate of *A. agaricites* larvae released in two different habitats at Discovery Bay, Jamaica. Fates: N = no sign of settlement; E = eaten by damselfish.

Trial	Habitat	Swimming time (min)	Fate
1	Fore-reef	24:00	N
2	Fore-reef	17:00	N
3	Fore-reef	21:00	N
4	Back-reef	3:37	E
5	Back-reef	7:45	E

SETTLEMENT EXPERIMENTS

Experiments designed to test larval preference for natural substrata indicated that *A. agaricites* larvae are more specific in their settlement requirements for natural substrata than *F. fragum* larvae. *A. agaricites* larvae settled and metamorphosed in greatest numbers on the coralline algae *Paragoniolithon typica* followed by the coralline algae *Spongites sp.2* (Fig. 3). Very little settlement and metamorphosis occurred on bare rubble (mean = 1.67%, SD = 4.08) and no settlement occurred on fragments coated with filamentous algae. Analysis of variance revealed a significant effect of experimental substrata on *A. agaricites* settlement and metamorphosis ($F = 20.52$, df = 3,4, $p < 0.01$). however, comparisons of the means with an SNK test indicated no significant difference between treatments at the 0.05 level due to large variation in settlement and metamorphosis among replicates of substratum treatments. In comparison, *F. fragum* larvae were equally likely to settle and metamorphose on coral fragments collected from the shallow and deep reef (Fig. 4, ANOVA, $F = 2.77$, df = 1,4, $p > 0.10$). Moreover, *F. fragum* larvae settled with equal propensity on bare rubble, filamentous algae, and coralline algae in laboratory trials (Fig. 5, ANOVA, $F = 0.27$, df = 2,6, $P > 0.75$). These experiments suggest that *A. agaricites* larvae rely on specific cues related to coralline algae for settlement and metamorphosis, whereas *F. fragum* will settle and metamorphose with equal probability on bare coral rubble, coralline algae, and rubble coated with filamentous algae.

A greater proportion of *F. fragum* larvae settled and metamorphosed during the 24-h period of the field experiments than *A. agaricites* larvae. Eighty three percent ($n = 140$)

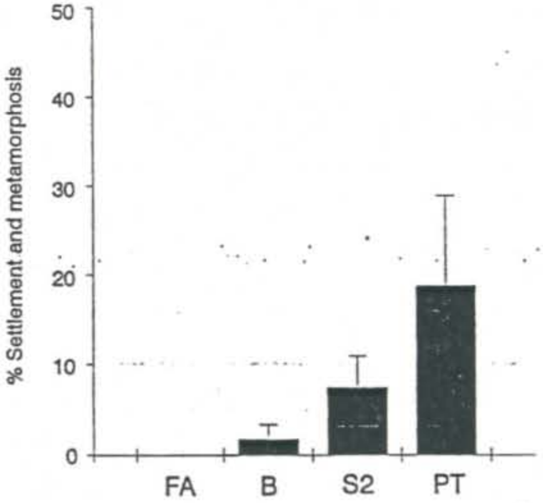

Fig. 3. Percent settlement and metamorphosis of *A. agaricites* larvae on four different substrata: FA = filamentous algae; B = bare coral rubble; S2 = coralline alga *Spongites spp.2*; PT = coralline alga *Paragoniolithon typica*. Vertical bars are 1 SD error, $n = 6$ for all substrata.

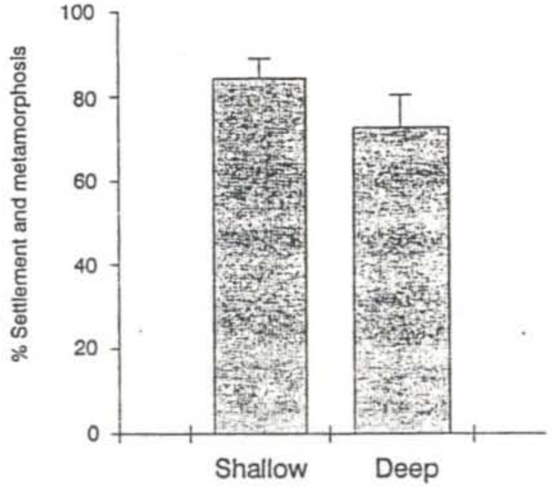

Fig. 4. Percent settlement and metamorphosis of *F. fragum* larvae on coral rubble collected from two different depths; shallow (<3 m) and deep (>10 m). Vertical bars are 1 SE, $n = 9$ for all substrata.

of *F. fragum* larvae settled and metamorphosed in experimental chambers overnight, whereas 23% ($n = 219$) of *A. agaricites* larvae settled and metamorphosed during this period.

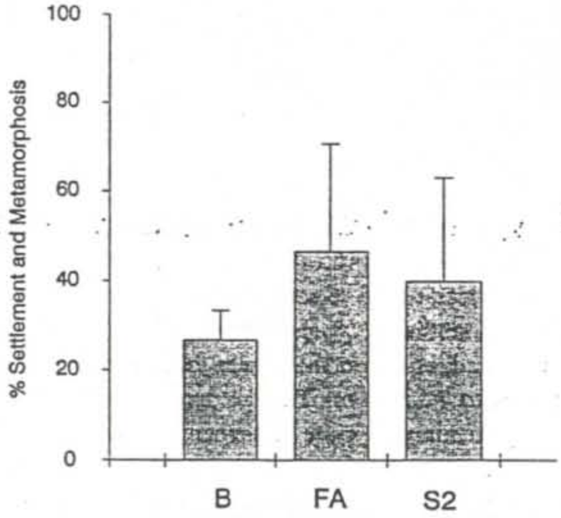

Fig. 5. Percent settlement and metamorphosis of *F. fragum* larvae on three different substrata: B = bare coral rubble; FA = filamentous algae; S2 = coralline alga *Spongites spp. 2*. Vertical bars are 1 SE, $n = 3$ for all substrata.

DISCUSSION

Aggregated patterns of spatial distribution have been reported for corals on both Pacific (Grassle, 1973; Maragos, 1974) and Caribbean (Lewis, 1970; Dana, 1976) reefs. Although a number of authors have suggested that the planula larvae of tropical corals may disperse over short distances (Duerden, 1902; Stephenson, 1931; Dana, 1976), no study has documented dispersal in the field. Our results provide strong evidence that the patchy distribution of *F. fragum* results from limited larval dispersal as well as its ability to settle on a variety of surfaces. *A. agaricites* also occurs in aggregations, however, limited dispersal is unlikely to explain this pattern as *A. agaricites* larvae were observed to swim for much longer periods and showed no sign of settlement.

The number of in situ observations for *A. agaricites* was small ($n = 5$), however, results from the settlement experiments conducted in the field support the longer swim times (compared to *F. fragum*) observed in these larvae. In the field settlement experiment, less than 1/3 (23%) of the *A. agaricites* larvae had settled during 24 h. In comparison, more than 3/4 (83%) of the *F. fragum* larvae settled during the same time period in a similar field experiment. This result does not appear to be related to lack of suitable environmental conditions for settlement of *A. agaricites* larvae: both field experiments were conducted on the fore-reef slope where adult colonies are common, and coralline algae were included in settlement chambers. Coralline algae have previously been shown to induce metamorphosis in *A. agaricites* forma *danai* (Morse et al., 1988). The potential for dispersal in *A. agaricites* larvae may be similar to that of the closely related *A. agaricites humilis* Verrill. Laboratory experiments have demonstrated that this species is capable of delaying metamorphosis for periods of up to 1 week (Morse et al., 1988). In situ observations of *A. agaricites humilis* (D. Carlon, unpubl. data) also suggest increased dispersal potential: these larvae often swam for periods > 10 min with no signs of descent.

The general settlement behavior of *F. fragum* and the specific settlement behavior of *A. agaricites* larvae may further contribute to small and large scale dispersal in these two species. The less-selective settlement behavior of *F. fragum* larvae increases the probability that larvae settle near the initial point of contact with the benthos. If there is a positive relationship between larval swimming time and dispersal distance, as in ascidians (Davis & Butler, 1989) and other coral species (D. Carlon, unpubl. data), then the combination of less-selective settlement and a short swimming time would distribute the majority of settling *F. fragum* larvae within a few meters of the parent colony. On the other hand, *A. agaricites* larvae had much more specific settlement requirements compared to *F. fragum*. This settlement behavior would increase the probability of rejecting an inappropriate settlement site and would therefore tend to increase total swimming time. The combination of preferential settlement behavior and the tendency of *A. agaricites* larvae to disperse over longer distances (as indicated by the swimming times) makes it highly unlikely that the aggregated distribution of adult colonies is the result of larvae settling short distances from parents. It is much more probable that *A. agaricites* larvae settle in locations distant from the parental habitat.

Previous research on the settlement behaviors of *F. fragum* and *A. agaricites* larvae support the differences in settlement behavior found here. Lewis (1974a) found *F. fragum* larvae would settle on a variety of unnatural (glass surfaces) and natural (sand, coral fragments, and conspecifics) substrata. More larvae settled in bowls with coral fragments and conspecifics compared to larvae in bowls without these substrata, however, comparisons among natural substrata (e.g. sand, coral fragments, and conspecifics) were not made. Morse et al. (1988) found greater numbers of *A. agaricites* (forma *danai*) larvae to settle and metamorphose on coral fragments encrusted with coralline algae compared to coral fragments with microalgal and bacterial films, boiled coral fragments, and polystyrene surfaces.

Moreover, these workers found the field distribution of two other closely related *Agaricia* species: *A. tenuifolia* and *A. agaricites humilis* to reflect larval preferences for coralline algae. If the settlement preferences of *A. agaricites* larvae are also important in the distribution of recruits, then these behaviors may explain the aggregated pattern of adults found here. A patchy spatial distribution of coralline algae and preferential larval settlement on this substratum would lead to aggregated patterns of adults (e.g. mechanism 2 in the Introduction). However, differential post-settlement mortality of juvenile corals on different natural substrata, cannot be eliminated as an alternative explanation for this pattern without careful field experiments (Keough & Downes, 1982).

The aggregated spatial distribution of *A. agaricites* may also be related to asexual processes. A number of coral species with branching or plating morphologies are capable of asexual reproduction through fission of adult colonies (Highsmith, 1982b). In Jamaica, Hughes & Jackson (1985) estimated the probability of a fission event averaged from 0.020 to 0.051 per year for *A. agarcites* (forma *purpurea*) colonies at two different sites. Fission of larger colonies would lead to aggregates of smaller individuals, depending on levels of disturbance and survivorship of daughter colonies produced by fission. Nonetheless, patches of *A. agaricites* colonies at Guana Island and Jamaica often contain many small (< 1 cm diameter), evenly-shaped colonies that appear to be sexual recruits. It is therefore likely that both asexual and sexual processes contribute to aggregates of *A. agaricites*.

The vertical distribution of *F. fragum*, being limited to shallow reef habitats, is not explained by larval behavior during dispersal or settlement. Larvae of this species swam for a short period and did not directionally disperse up the reef slope after release as in the colonial ascidian *Diplosoma similis* (Stoner, 1990, 1992). Moreover, results from the settlement experiment conducted in the field demonstrated that *F. fragum* larvae: (1) readily settle in deep reef habitat, i.e. they do not delay metamorphosis in this environment, and (2) do not discriminate between substrata collected from the shallow and deep reef, even though adults of *F. fragum* are rarely found in deep (>7 m) reef habitats (Goreau, 1959; Szmant-Foelich, 1985; J. Porter, pers. comm.). Although larval dispersal occurs over a small scale in this species (several meters), the non-directional swimming behavior and general settlement requirements of *F. fragum* larvae would eventually lead to colonization of deep reef habitats. This potential for *F. fragum* to colonize deep-reef habitats suggests that differences in post-settlement mortality between shallow and deep-reef habitats must play an important role in the vertical zonation of *F. fragum* in shallow back- and fore-reef habitat. Post-settlement mortality in *F. fragum* may be due to poor competitive ability in regions of the reef where competition for space can be intense (Jackson, 1991), or perhaps to physiological intolerance to light regimes characteristic of deeper reef environments. Lewis (1974b) has shown that *F. fragum* juveniles have highly reduced growth when raised without light. however, the effects of reduced light regimes characteristic of the deep reef on the growth and survivorship of these corals in the field remain unknown.

This study has revealed that larval behavior during dispersal and settlement can result in different scales of dispersal between two reef corals. At present it is unclear how general these results are for other species of Caribbean and Pacific reef corals. The planula larvae of *A. agaricites* and *F. fragum*, as in many species of corals that have brooding development, are physically similar in appearance (Harrison & Wallace, 1990). However, the consequences of this mode of larval development for adult spatial pattern and population dynamics cannot be generalized to other coral species without careful study of larval behavior.

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The Mid-summer Community of Caridean Shrimps Associated with the Slimy Sea Plume (*Pseudopterogorgia americana*) at Guana Island, British Virgin Islands*

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Abstract:

Key words:

INTRODUCTION

The gorgonians (octocorallians) of south Florida (USA) and the West Indies are conspicuous features of the shallow, inshore benthos. Descriptions of their biology and ecology have included abiotic factors that affect distribution and mortality (Garzón-Ferreira and Zea, 1992; Kinzie, 1973; Wheaton, 1987; Yoshioka and Yoshioka 1989a, 1989b), taxonomy (Bayer, 1991), community structure (Dahlgren, 1989), competitive interactions (Alino et al., 1992; Sebens

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and Miles, 1988), adaptive evolution at the molecular level (Gerhart, 1984; Kingsley et al., 1990; Sammarco and Coll, 1992), and predator-prey interactions at the species level (Ciereszko and Schneider, 1987; Ruesink and Harvell, 1990).

Not discussed in these and other reports is the fact that gorgonian colonies are themselves complex communities harboring dynamic and largely hidden populations of resident organisms, notably mysids and caridean shrimps. The mysids have barely been studied; present knowledge of what we shall call "gorgonian shrimps" is restricted to taxonomic studies in which the gorgonians have been mentioned only as sources of holotypes or paratypes. This specialized literature continues to evolve as previously undetected species of gorgonian shrimps emerge and older ones are redescribed (e.g., Criales, 1992; Heard, 1986; Heard and Spotte, 1991, 1994).

Gorgonian shrimps are small (carapace length ordinarily <6 mm), but hundreds of individuals of several species can occupy single colonies. Our report is the first to describe any aspect of their community organization. The importance of these shrimps in the ecology of gorgonian communities is a fertile subject for future investigation.

METHODS

SAMPLE COLLECTION

We sampled only colonies of *Pseudopterogorgia americana*, the slimy sea plume. Gorgonians are notoriously difficult to identify in the field, but *P. americana* can be identified easily, is numerous throughout the West Indies, and inhabits a wide range of depths. Collections were made between 21 and 26 July 1992 in White Bay at Guana Island, British Virgin Islands, within ~200 m of a point of land known as Iguana Head. **Coordinates of the site are ____.** At this location the bottom slopes steeply from shore, terminating at 22 m in a level expanse of sand. The site has little wave action, although strong subsurface currents are sometimes encountered. Gorgonians grow in profusion along the slope, and *P. americana* is especially abundant. Sample collection was completed in 6 d partly because of time constraints, but also because time trend effects are lessened by compressing the sampling period (Woolf 1968, p. 127).

We follow convention in treating individual gorgonians as sampling units and restricting use of the term samples to collections from all sampling units obtained during a single dive (Ludwig and Reynolds 1988, Waters and Erman 1990). We selected gorgonian colonies haphazardly by diving to the predetermined depth (see below), swimming perpendicular to the forereef slope, and sampling the first colony of *P. americana* encountered. Colonies were rejected only if encrusted with *Millipora* or other hard organisms that might have punctured the sample bags.

A numbered plastic bag (45.7 x 91 cm, **8 mil thickness**) was placed over the gorgonian, cinched at the base of the colony, and shaken vigorously to dislodge any shrimps (**Fig. 1**). The bag was then pulled away while still cinched tightly, and the mouth was sealed with a rubber band. Afterward, a yellow plastic trash-bag tie was fastened to the base of the colony to prevent repeat sampling. Bags were used only once. Shrimps were recovered by pouring the contents of the bags through a 355-µm sieve. Shrimps were pooled by sampling unit, fixed for several days in 10% formalin-seawater, and preserved in 70% ethanol. The collection procedure introduces minimal sampling bias, as assessed in a previous study (Spotte and Bubucis, unpublished data). In this earlier work, shrimps from 16 *P. americana* colonies were collected by the method described (range = 0 to 29). Immediately afterward, the entire colonies were collected in separate bags and examined for any remaining shrimps. None could be found.

Random numbers corresponding to sampling depths between 3 and 22 m were generated before every dive with a hand calculator in an effort to avoid bias introduced by replicate sampling at arbitrarily selected depth ranges. Excess random numbers were generated in case a bag broke. We arranged the numbers in descending order (i.e., deepest to shallowest) to facilitate planning of the dives. Sampling sequence within samples was therefore nonrandom. Depths in feet were recorded underwater from one of our depth gauges (Spotte's) and converted to metres before data analysis. After completion of field work, calibration of the depth gauge was checked in a pressure chamber against known simulated depths using a gauge accurate to within 0.025%. The test was conducted three times at 1.5-m intervals (rate of ascent and descent = 0.3 m/s) within a simulated depth range of 0 to 45.7 m. Differences between paired values were not significant, as determined by linear regression analysis: $n = 126$, $t_{n-2} = -3.834$, multiple $R = 0.9996$, $p < 0.001$. Depth adjustments in the data therefore were not required.

DATA COLLECTION

Shrimps were identified from dichotomous keys of Chace (1972) and Heard (1986). Morphologic and reproductive data recorded were size (measured as carapace length, CL), sex, number of dorsal and ventral rostral teeth (RTD and RTV), whether females were ovigerous or nonovigerous, whether ova were eyed or uneyed, and, where appropriate, number and type of appendix masculina spines (apical and lateral) of males. The males of some species (e.g., *Hippolyte nicholsoni*) do not have lateral spines. In one species that does (*Neopontonides chacei*), the distal lateral spines appear to change into apical spines. The designations apical and lateral are therefore arbitrary, and we chose to express results for both *H. nicholsoni* and *N. chacei* (the two most numerous species) as total appendix masculine spines. Some of the smaller shrimps had rounded nubs where an appendix masculina spine should be. We recorded them as males with zero spines. As defined here, carapace length is the distance between the tip of the rostrum and posterior dorsal margin of the carapace (Heard & Spotte, 1991). Nonovigerous specimens were sexed by placing one of the second pleopods in a wet mount and examining it with light microscopy for an appendix masculina. The sex of some immature specimens could not be determined and their sex was recorded as unknown. For *N. chacei*, chelae of pereopods 2 were recorded as symmetrical or asymmetrical because of discrepancies in available taxonomic keys (see Discussion).

Because *N. chacei* was the predominant species recovered at Guana Island, a series of males (***n*** = ___) was sectioned to determine whether appendix masculina spination correlates positively with the presence or absence of active sperm in the testes.

DAMAGED AND FRAGMENTED SPECIMENS

Some specimens removed from the sieve were badly damaged; others were fragmented. Fragments were recovered either as heads (with carapace) or abdomens. We recorded these as individual shrimps for the following reason. If a sampling unit contained several heads and abdomens of the same species we could not know whether the fragments belonged together (and if so, which fragments) or matched parts of other individuals perhaps lost during sample collection. In any case, the numbers of detached heads and abdomens were occasionally unequal. True *n* is therefore unknown.

Fragmented specimens yielded incomplete information. A detached head with carapace could be measured and the rostral teeth counted, but sex was indeterminate; a detached abdomen allowed the specimen to be sexed but not measured. Rostrums without tips yielded indeterminate rostral tooth counts and precluded carapace measurement. When both second pleopods were missing from a damaged or fragmented specimen and the shrimp was not ovigerous, sex could not be assessed from external characters.

DATA ANALYSIS

Data were analyzed first for ecological patterns. We assessed depth distributions by species, by numbers of species, and by numbers of shrimps. Possible size (as CL) and sex effects on depth distribution were analyzed for the two predominant species. We examined the data for species associations by depth, species diversity (number of species per gorgonian), species abundance (numbers of each species per gorgonian), and population intensity (total numbers of shrimps per gorgonian). "Population intensity" is an estimate of a population expressed as the number of organisms per habitat unit (i.e., sampling unit), as distinguished from "population density," which is the number of organisms per area or volume of the sampling unit (Waters and Erman 1990).

We then assessed biological attributes of the two predominant species based on morphologic and reproductive data. We tested for sex effects on size and on numbers of RTD, measured the extent of sexual dichotomy, assessed the relationship between size and numbers of appendix masculina spines (or whether females were ovigerous), and estimated minimum size for possession of one appendix masculina spine or the presence of ova. Absent characters from damaged and fragmented specimens were treated statistically as missing data. Shrimps of indeterminate sex and size were omitted from data analyses involving these factors.

Only the pressure gauge variables were distributed normally. Transformation did not relieve heteroscedasticity in the other variables, and they were assessed by nonparametric methods.

RESULTS

Over 6 d we collected 9 samples comprising 51 gorgonians, recovering 1418 specimens (including fragments) of 9 species (**Table 1**). Of the total number, 1364 (96%) were whole, undamaged shrimps yielding complete data. *Neopontonides chacei* and *Hippolyte nicholsoni* were present in the greatest numbers. Species diversity (number of species per gorgonian) ranged from 1 to 5 ($X = 2.4$). Species abundance results are summarized in **Table 2**. A distribution fit of the population (total numbers of shrimps per gorgonian) was binomial: range = 0-156 with 17 categories ($n = 51$), $p = 0.1778$. Population intensity results computed casewise in the same analysis: $X = 0.54$ (±0.64 SD), median = 0.31, mode = 0.31; X (mean sum) = 27.8(±32.8 SD). The size of the standard deviation, which exceeds the mean, is further evidence of a binomial distribution (e.g., Ludwig and Reynolds, 1988).

Mean depth distributions by species are summarized in **Table 1**. The predominant species, *N. chacei* and *H. nicholsoni*, occupy different mean depths. A casewise scatterplot of the numbers of *N. chacei* per gorgonian against depth yielded a horizontal regression line, suggesting little variation. The negative regression line in a similar plot of *H. nicholsoni* data **(Fig. 2)** indicates that the numbers of *H. nicholsoni* per gorgonian diminish with depth.

We converted raw depth data into four octaves of arbitrarily selected ranges. The greatest mean number of species occurred between 13.0 and 17.2 m **(Fig. 3)**, although the greatest mean number of shrimps was found between 8.7 and 12.9 m **(Fig. 4)**. Depth distributions of *N. chacei* and *H. nicholsoni* by size (i.e., by CL) were tested independently with Spearman's rank correlation test. The slope of the curve in both analyses was slightly negative. For *N. chacei* $n = 960$, $\rho = -0.0721$, $t_{(n-2)} = -2.2363$, $p = 0.0256$; for *H. nicholsoni* $n = 371$, $\rho = -0.1503$, $t_{(n-2)} = -2.9205$, $p = 0.0037$. Depth distributions of *N. chacei* and *H. nicholsoni* by sex were tested independently with Mann-Whitney *U*-tests; the relationship was not significant for either species. For *N. chacei* (males, females) $U = 110255$, $n = 493$ (M) and 460 (F), and $p = 0.4603$. For *H. nicholsoni* (unknown, males, females in multiple paired comparisons) $U = 2.3912.5\text{-}11561.5$; $n = 48$ (unknown), 124 (M), and 189 (F); and $p = 0.1305\text{-}0.8416$. Significance was seen in several between-species comparisons by depth **(Table 3)**, and the most highly significant comparisons (i.e., $p < 0.001$) include *H. nicholsoni* as a pair member.

Sexual dichotomy in *N. chacei* and *H. nicholsoni* was assessed using Mann-Whitney *U*-tests with CL as the dependent variable. Significance was detected only for *H. nicholsoni* (data for specimens of unknown sex excluded), with females significantly larger than males (mean CL = 1.84 mm v. 1.26 mm); $U = 3333.0$, $n = 122$ (M) and 181 (F), and $p = 0.0000$. For *N. chacei*: $U = 111229.0$, $n = 489$ (M) and 458 (F), and $p = 0.8581$.

Hippyolyte nicholsoni rarely has RTD. The effect of sex on RTD in *N. chacei*. was not significant, and males and females are equally likely to have the same number (Mann-Whitney *U*-test): $n = 489$ (M) and 458 (F), $U = 11129$, and $p = 0.8581$.

Appendix masculina spination plotted against CL is depicted in **Fig. 5**. Correlation between these variables was assessed using

Spearman's rank correlation test and found to be strong for *N. chacei* (n = 499, ρ = 0.83, $t_{(n-2)}$ = 33.2414, p = 0.0000) but weak for *H. nicholsoni* (n = 147, ρ = 0.45, $t_{(n-2)}$ = 6.0276, p = 0.0000). Male *N. chacei* can acquire a single spine at 1.25 mm CL (X = 1.8 mm, range = 1.0-2.8 mm). Mean number of spines was 3.8 (range 0 to 9, n = 493). Male *H. nicholsoni* can acquire a single spine at 0.9 mm CL (X = 1.3 mm, range = 0.7-1.8 mm). Mean number of spines was 2.9 (range = 0-6, n = 122).

Figures 6 and **7** summarize relative egg-bearing status of the two predominant species. Female *N. chacei* can become ovigerous at 1.9 mm CL (X = 2.4 mm, range = 1.9-2.8 mm, n = 109). For female *H. nicholsoni*, minimum CL at ovigery is 1.2 mm (X = 2.3 mm, range = 1.2-2.9 mm, n = 71). Statistical distributions of uneyed and uneyed were not different for either species, as tested with Spearman's rank correlation: For *N. chacei* n = 109, ρ = 0.05, $t_{(n-2)}$ = 0.5207, p = 0.6037; for H. nicholsoni n = 71, ρ = 0.03, $t_{(n-2)}$ = 0.2897, p = 0.7729.

In his species description of *Neopontonides chacei*, Heard (1986) reported that the chelae of pereopods 2 are symmetrical (see Discussion). In our material, 11% (101 Of 903 specimens) had asymmetrical chelae. We recorded this data in dichotomous form (specimens missing a chela were excluded) and constructed a fourfold contingency table to test the null hypothesis of independence between sex and chelae symmetry. The null hypothesis was rejected (n = 893, χ^2 = 78.5089, p = 0.0000; ϕ^2 = 0.088). At Guana Island, female *N. chacei* are more likely than males to have asymmetrical chelae (**Fig. 8**).

DISCUSSION

Individual colonies of *Pseudopterogorgia americana* harbored up to 156 caridean shrimps of as many as 5 species. *Neopontonides chacei* and *Hippolyte nicholsoni*, the predominant species, occupy distinctly different mean depths. The depth distribution of *H. nicholsoni* shows the stronger trend with numbers of shrimps per gorgonian declining as depth increases. Most species occurred near the shallow end of the depth range sampled. Not surprisingly, the depth at which the greatest mean number of shrimps occurred (**Fig. 4**) bracketed the mean depth occupied by *N. chacei*, which outnumbered all other species. Depth distributions of *N. chacei* and *H. nicholsoni* were independent of size or sex. Significant difference in between-species associations as a function of depth were apparent mainly when *H. nicholsoni* was included as a pair member, further reinforcing the limited vertical range of *H. nicholsoni*. Significant sexual dichotomy was apparent in H. nicholsoni, with females significantly larger than males. comparatively more *H. nicholsoni* than *N. chacei* were ovigerous, which raises the possibility of differences in seasonal fecundity. This could be assessed only by sampling at other seasons.

We were unable to calculate population densities because we knew neither the area nor volume of the individual gorgonians. *Pseudopterogorgia americana* grows in protean forms. Branches are often partly or completely dead, and overall shape ranges from gnarled and stunted to fully upright and bushy. As in other cnidarians, the percentage of polyps expanded and contracted, and the degree of expansion and contraction, substantially affect both the surface area and volume of a colony. Newly collected colonies retract their polyps and shed mucus copiously. The result of this trauma is colony deformation within minutes. The common name "slimy sea plume" has not been bestowed loosely: separating commensal shrimps from mucus retained in the sample bags became the most tedious aspect of our collection procedure. The prospect of obtaining useful information on the area or volume of collected colonies is bleak. Any future method of determining population densities of gorgonian shrimps should probably be applied in the field under conditions of minimal disturbance. Our sampling technique appears to stress *P. americana* colonies severely, but does not kill them (Spotte and Bubucis, unpublished data). Full recovery, however, might take weeks or months. The alternative is to devise collection procedures that are less stressful to the host.

Our results are weakened by the uncertain taxonomic status of the shrimps recovered. Of the 9 species recovered, only *H. nicholsoni*, *P. antillensis*, and *Trachycaris rugosa* could be identified with confidence using morphologic characters and existing keys. *Neopontonides chacei* was described by Heard (1986) based on 31 specimens from St. Lucia (West Indies), Antigua (British West Indies), Carrie Bow Cay (Belize), and the Florida Keys (USA). Some had been collected from *Pseudopterogorgia americana.* He listed the principal diagnostic characters as (1) rostrum with 0-4 dorsal teeth but no RTV, (2) chelae of pereopods 2 symmetrical, and (3) merus of pereopods 3-5 lacking a well developed tubercle or keel-like swelling on the distal flexor margin. These distinguished *N. chacei* from *N. beaufortensis* and *N. dentiger*, the only described members of the genus. Heard considered *N. chacei* to be most closely related to *N. beaufortensis*, differing in the symmetry of its pereopod 2 chelae, in the comparative slenderness of its pereopods 3-5, in the absence of a tubercle on the merus of pereopods 3-5, in the shape of the rostrum and eyelobe, and in the setation and spination of pleopods 1 and 2 and the propodus of pereopod 5.

The Guana Island specimens agree with Heard's diagnosis in having 0-4 dorsal rostral teeth (three specimens have a single RTV). However, many of the Guana Island shrimp have asymmetrical pereopod 2 chelae; still others have a prominent keel on the distal flexor margin of the merus of pereopods 3-5. These last two characters are diagnostic of *N. beaufortensis.* Heard (1986) was aware of overlapping characters and suggested that all specimens of *N. beaufortensis* in reference collections be compared with *N. chacei.*

We have not compared our Guana Island shrimp with the *N. chacei* type material. However, after examining several *N. beaufortensis* supplied by R. W. Heard we believe our shrimp to be either *N. chacei* or an undescribed species of *Neopontonides*. *Neopontonides dentiger* is restricted to the northeastern Pacific (Cantera et al., 1987; Ríos, 1986; Wicksten, 1983) and therefore allopatric. Deviation from diagnostic species characters might not be unusual in a large a series of specimens such as ours; alternatively, regional variation should not be discounted. Heard (1986) mentioned examining several shrimp collected from species of gorgonians other than *P. americana* and finding them similar to *N. beaufortensis* in some characters but distinct in others. He concluded that "These forms may represent new taxa or they may be ecophenotypic variants of *N. beaufortensis.*"

Criales (1992) recently clarified the taxonomic status of *T. rugosa* (= *T. restrictus*). She was able to examine only nine males in existing reference collections. Two had been collected by hand at 25 m off Isla de Aguja (Colombia) and the remaining seven by suction sampler between 33 and 68 m off South Carolina (USA). Females available for examination were far more numerous and came from depths of 8 to 20 m. Known substrata from which both sexes had been collected included coral, coral sand, and calcareous algae. Criales speculated that male *T. rugosa* are more cryptic than females and live at greater depths.

Both Guana Island specimens in our collections are small males (CL = 2.5 mm) and were obtained from the same gorgonian at 13.7 m. Males examined by Criales (1992) were larger (CL = 3.03-5.65 mm). Our data extend the habitable depth of male *T. rugosa* into the known range of females but add little to knowledge of substratum occupancy. Although we were careful to sample only gorgonian colonies, small bits of substratum might have entered the sample bags inadvertently. We believe that if *T. rugosa* is an associate of *Pseudopterogorgia americana*, the relationship is facultative.

The specimens of *Latreutes* are juveniles of an apparently undescribed species (R. W. Heard, personal communication). The specimens of *Tozeuma* also are small, but appear closest to *T. cornutum*. Any small shrimp of the genus *Periclimenes* collected from the western North Atlantic requires careful examination. This applies especially to those of the "iridescens" complex (Heard and Spotte, 1991; Spotte et al., 1994), an indeterminant number of species that conform with *P. iridescens* in Chace's dichotomous key (Chace, 1972). Most of the *Periclimenes* spp. we collected from *P. americana* colonies at Guana Island were small, rendering their identity even more uncertain.

ACKNOWLEDGEMENTS

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FIGURE LEGENDS

Fig. 1 Part of the collecting method sequence. A plastic bag was placed over the gorgonian, cinched at the mouth, and shaken vigorously to dislodge any shrimps. FIGURE WILL BE A HALF-TONE, WHICH IS BEING PROCESSED NOW (14 February 1994)

Fig. 2 Scatterplot of the numbers of *Hippolyte nicholsoni* per gorgonian computed casewise against depth. Curve fit is linear, confidence intervals are 95%, and n = 51.

Fig. 3 Box and whisker plot of the number of species of gorgonian shrimps (range = 1-5) against four artibrarily selected depth ranges. Total n = 51.

Fig. 4 Box and whisker plot of the number of shrimps (all species combined) against four arbitrarily selected depth ranges. Total n = 51.

Fig. 5 Standard deviation plots of carapace length against total numbers of appendix masculina spines for *Neopontonides chacei* (top) and *Hippolyte nicholsoni* (bottom).

Fig. 6 Box and whisker plot of the numbers of female *Neopontonides chacei* with n shown above the whiskers.

Fig. 7 Box and whisker plot of the numbers of female *Hippolyte nicholsoni* with n shown above the whiskers.

Fig. 8 Box and whisker plot of the relative incidence of pereopod 2 symmetry against sex for *Neopontonides chacei* with n shown above the whiskers. Scale of the ordinate: 0 = symmetrical, 1 = asymmetrical.

Table 1 Partial frequency table and mean depth of shrimps recovered from the gorgonian *Pseudopterogorgia americana*. *Trachycaris rugosa* = *T. restrictus* (Criales, 1992).

Species	Frequency	Percent	Mean depth, m
Neopontonides cf. *chacei*	967.	68.19	12.6
Periclimenes cf. *patae*	36.	2.54	11.9
Latreutes sp.	13.	0.92	14.5
Periclimenes sp.	2.	0.14	21.3
Hippolyte nicholsoni	383.	27.01	8.2
Pseudocoutierea antillensis	9.	0.63	13.6
Periclimenes cf. *pauper*	2.	0.14	10.0
Tozeuma cf. *cornutum*	4.	0.28	10.2
Trachycaris rugosa	2.	0.14	13.7

Table 2. Species abundance (numbers of each species per SU). Mean and median values have been computed casewise (n = 1418). Means are also expressed as mean sums (numbers of each species per SU where n = 51).

Species	Mean, casewise	Median, casewise	Mean, sum
Neopontonides cf. *chacei*	0.3756	0.1765	19.1569
Periclimenes cf. *patae*	0.0138	0.0000	0.7059
Latreutes sp.	0.0038	0.0000	0.1961
Periclimenes sp.	0.0026	0.0000	0.1333
Hippolyte nicholsoni	0.1438	0.0784	7.3333
Pseudocoutierea antillensis	0.0031	0.0000	0.1569
Periclimenes cf. *pauper*	0.0008	0.0000	0.0392
Tozeuma cf. *cornutum*	0.0015	0.0000	0.0784
Trachycaris rugosa	0.0008	0.0000	0.0392

Table 3 Paired comparisons (Mann-Whitney U-test) of between-species distribution by depth. Levels of significance: n.s. = not significant, * = <0.05, ** = <0.01, *** = <0.001.

Species	1	2	3	4	5	6	7	8	9
Neopontonides cf. *chacei*		n. s.	**	n. s.	***	n. s.	*	n. s.	n. s.
Periclimenes cf. *patae*			**	n. s.	***	n. s.	*	n. s.	n. s.
Latreutes sp.				*	***	n. s.	*	**	***
Periclimenes sp.					n. s.	n. s.	n. s.	n. s.	n. s.
Hippolyte nicholsoni						**	*	n. s.	*
Pseudocoutierea antillensis							*	n. s.	n. s.
Periclimenes cf. *pauper*								n. s.	n. s.
Tozeuma cf. *cornutum*									n. s.
Trachycaris rugosa									

HALF-TONE MADE FROM A 35-mm COLOR TRANSPARENCY SHOWING THE COLLECTING METHOD *IN SITU*.

Mailed to the photo lab on 13 February 1994

Fig. 2

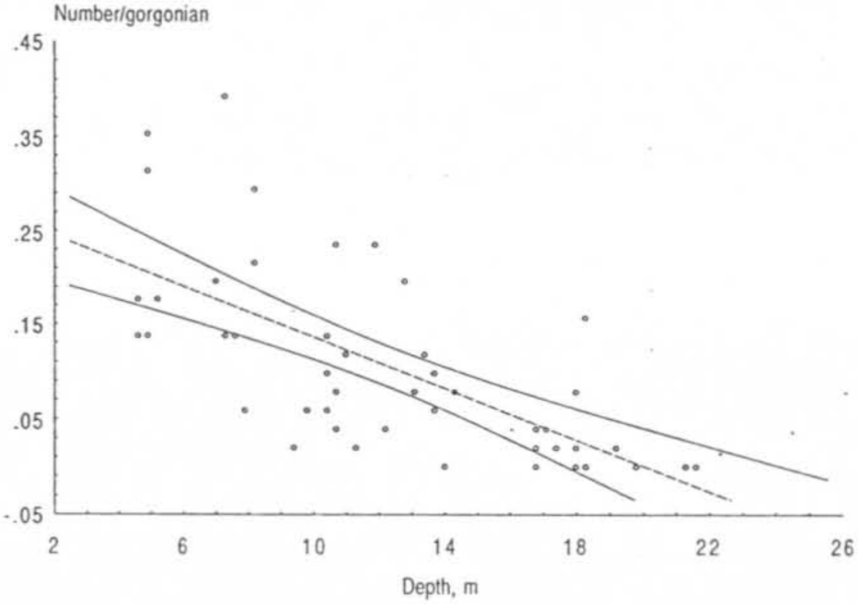


Fig. 3

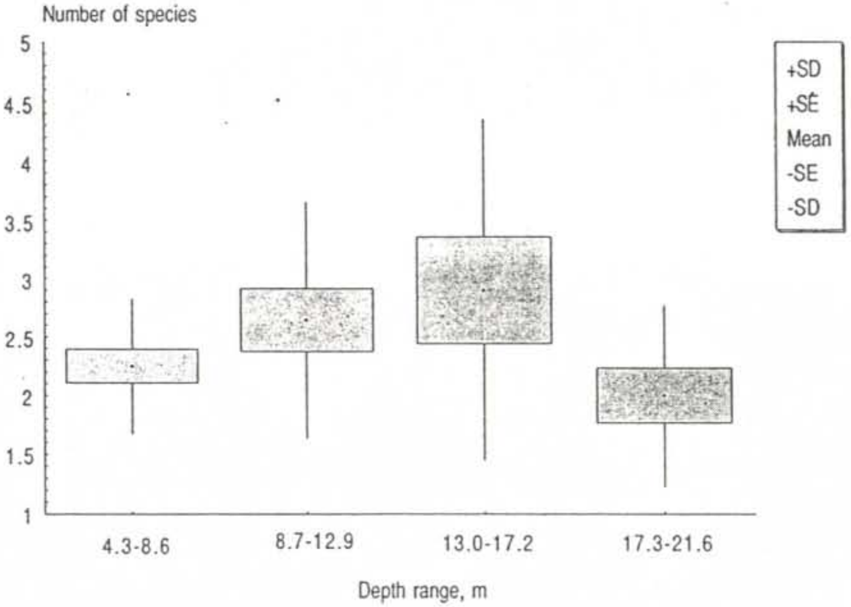

Number of species
5
4.5
4
3.5
3
2.5
2
1.5
1
4.3-8.6
8.7-12.9
13.0-17.2
17.3-21.6
Depth range, m
+SD
+SE
Mean
-SE
-SD

Fig. 4

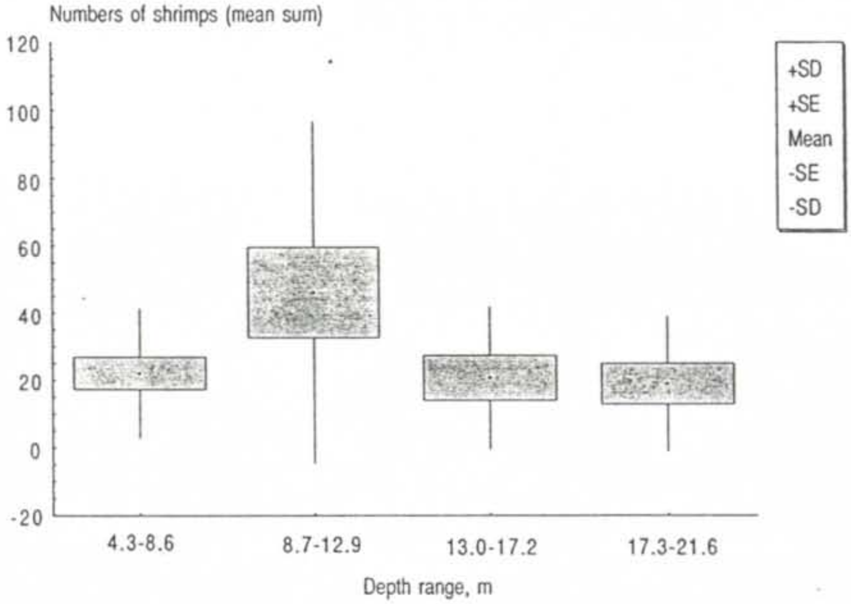
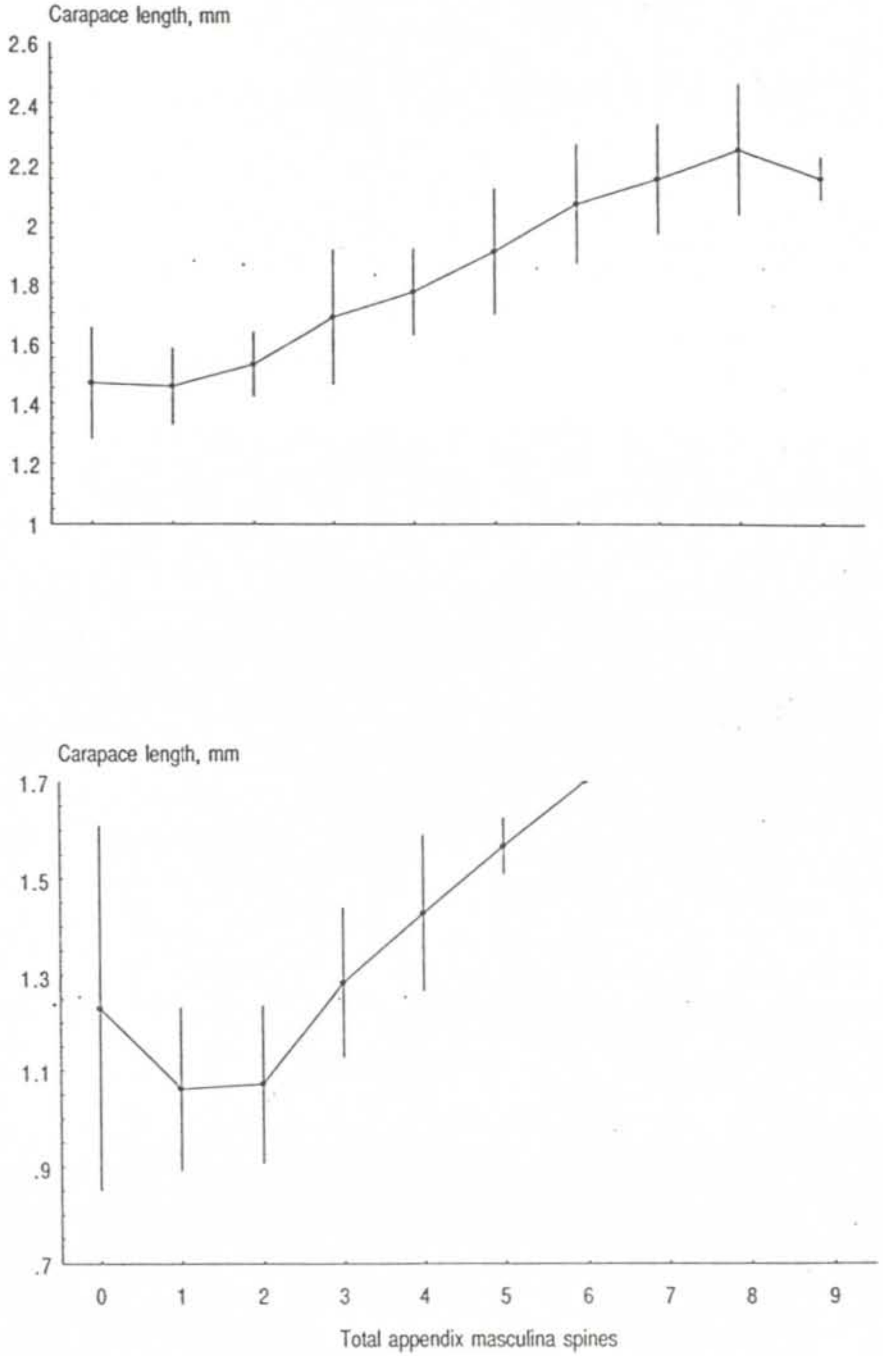

Numbers of shrimps (mean sum)
120
100
80
60
40
20
0
-20
+SD
+SE
Mean
-SE
-SD
4.3-8.6
8.7-12.9
13.0-17.2
17.3-21.6
Depth range, m

Fig. 5


Carapace length, mm
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
Carapace length, mm
1.7
1.5
1.3
1.1
.9
.7
0
1
2
3
4
5
6
7
8
9
Total appendix masculina spines

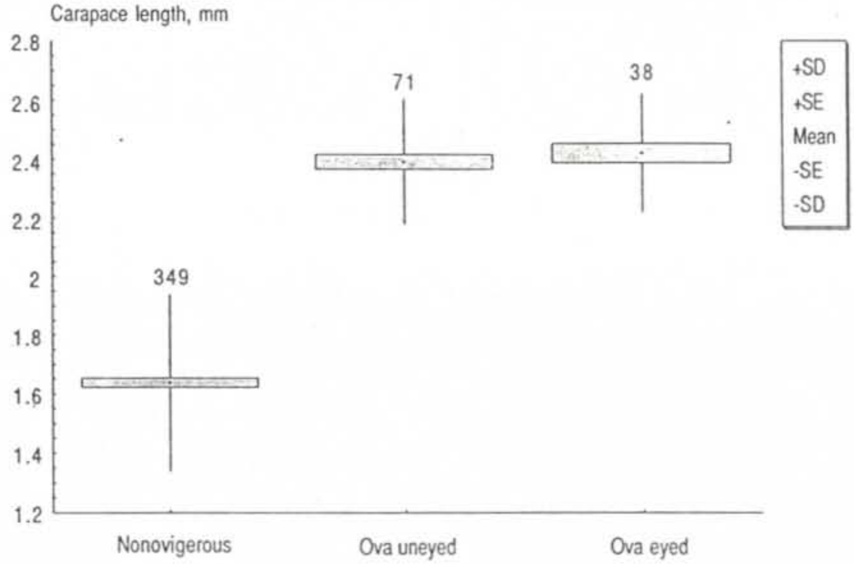

Carapace length, mm
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
71
38
349
+SD
+SE
Mean
-SE
-SD
Nonovigerous
Ova uneyed
Ova eyed

Fig. 7

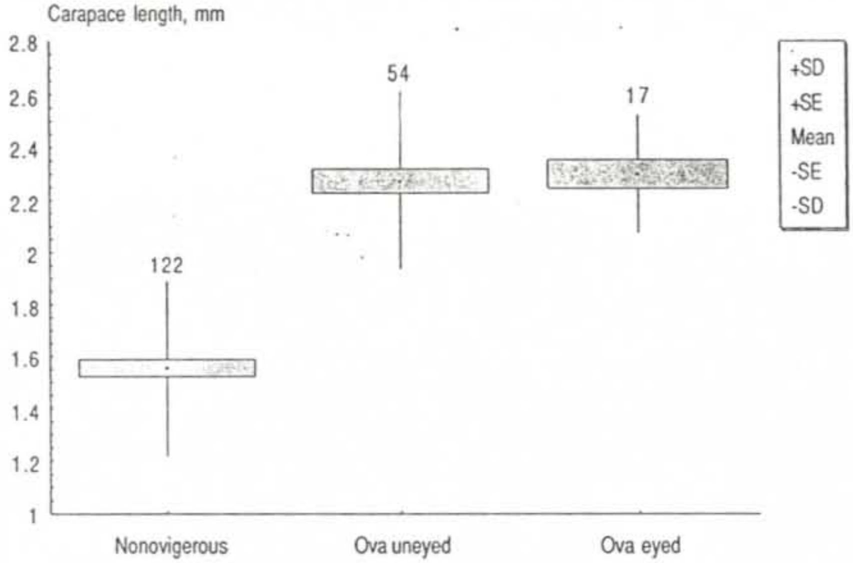
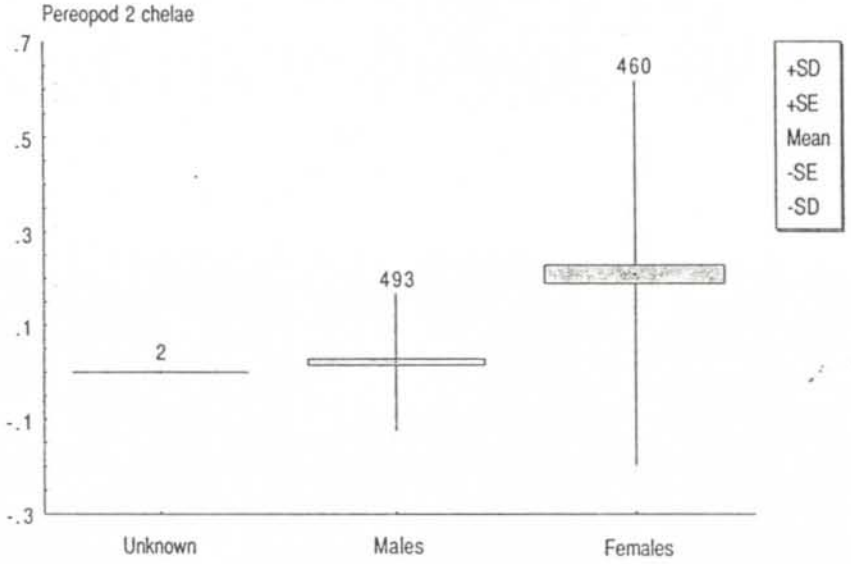

Carapace length, mm
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
54
17
122
Nonovigerous
Ova uneyed
Ova eyed
+SD
+SE
Mean
-SE
-SD

Fig. 8



Pereopod 2 chelae
.7
.5
.3
.1
-.1
-.3
2
493
460
Unknown
Males
Females
+SD
+SE
Mean
-SE
-SD

PROCEEDINGS OF THE REGIONAL SYMPOSIUM ON PUBLIC AND PRIVATE COOPERATION IN NATIONAL PARK DEVELOPMENT.

AUGUST 23–25, 1991.
TREASURE ISLE HOTEL,
ROAD TOWN, TORTOLA, BRITISH VIRGIN ISLANDS

BRITISH VIRGIN ISLANDS
NATIONAL PARKS TRUST

Thirty years
and growing stronger
1961-1991

HYPERSALINE POND ECOLOGY IN THE BRITISH VIRGIN ISLANDS

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ABSTRACT

Hypersaline ponds in the British Virgin Islands once supported a large population of native flamingos, which were completely extirpated by the 1940's. In conjunction with a Caribbean flamingo re-introduction project, this study compares plankton ecology and water chemistry of salt ponds on Anegada, Beef Island, Great Camanoe, Guana Island, Necker Island, Tortola, and Virgin Gorda. Regular monitoring of Guana Island salt pond has shown a relationship between salinity and rainfall and between salinity and species composition of zooplankton and plants. Water chemistry comparisons between salt ponds indicate that most have relatively high nutrient concentrations and that nutrients from sea water may be concentrated in ponds. Pond nutrient levels are not elevated by rain runoff from nearby hillsides. Comparatively fresher ponds (below 100 part per thousand salinity) support greater abundances and species diversity of zooplankton, as well as more stable zooplankton populations. Because of the drastic fluctuations in salinity and correlated zooplankton abundance, flamingos in the BVI would likely have to forage in a number of different ponds during the course of a year, rather than permanently residing at any particular pond.

INTRODUCTION

"Flamingos are, at the least, remarkable, at best sublimely beautiful, and at all times strange, rather remote beings inhabiting a world only they can inhabit with enjoyment... Yet they always manage to be clean and beautiful... in appalling heat and glare, in surroundings fatal to any ordinary animal and inimical to even the most determined and well-equipped human investigator... Suddenly they appear..., delight us for awhile, and then are gone again." Leslie Brown, 1959.

The Caribbean flamingo, *Phoenicopterus ruber ruber*, is the most brightly colored large flamingo species in the world. For centuries, this spectacular bird has been hunted for both food and sport, leading to its present world-wide scarcity. It is listed in the IUCN Red Book (International Union for the Conservation of Nature), and, as of June 1979, it has been granted CITES (Convention on International Trade of Endangered Species) protection, which prevents international trade of flamingos or flamingo products between most countries. Conservation measures such as this did not begin soon enough to save the native Caribbean flamingo population in the British Virgin Islands (BVI). Native flamingos once bred by the thousands at the salt ponds of Anegada, and they frequented most surrounding islands. However, people collected flamingo eggs for food and killed juveniles and adults for their meat, causing the BVI flamingo population to decline. The remaining few were shot for sport in the early 1940's, and none have resided in the BVI since

(Lazell 1986).

Caribbean flamingos inhabit hypersaline ponds (ponds having salinities greater than 40 parts per thousand), and they breed colonially along pond edges. These flamingos will only breed in large numbers, when they are in good health, and when they are undisturbed by human activity (Rooth, 1965). The salt ponds on Anegada historically provided flamingos with enough food, space, and isolation to thrive and multiply, and, unlike many other salt ponds in the BVI, Anegada's ponds remain isolated and relatively undisturbed today. Although flamingos may once have nested on other islands, Anegada undoubtedly carried the largest numbers, and, through flamingo reintroduction efforts, it could support them again. A Caribbean flamingo reintroduction project was begun in late 1987 by the Guana Island Wildlife Sanctuary with the importation of eight birds from Bermuda. Four of these birds still survive, and plans to boost this small population with more flamingos later this year are presently underway. The original birds were introduced to Guana Island salt pond, where they were completely protected and well-looked after but free to leave. They remained on Guana until October, 1990, when, presumably due to lack of food, they all flew to Belmont Pond, at the west end of Tortola. However, in May, 1991, they left Belmont Pond, and there present whereabouts are unknown. Probably because of their small number, these flamingos never attempted to breed on Guana. The preliminary introduction of a few birds to Guana Island showed that flamingo reestablishment in the BVI is feasible and that, with enough birds, time, and protection, the BVI could once again boast large breeding populations of native flamingos.

Although hypersaline ponds are harsh, inhospitable environments, viewed by many to be fit only for salt extraction projects, for solid waste dumps, to be filled for housing development, or to be dredged out for marinas, they are the sole habitat that can support flamingos. Unlikely as it may appear, the harsh hypersaline pond environment supports a highly productive ecosystem, which flamingos and other wading birds depend on for food. The Caribbean flamingo generally feeds by filtering water or mud through its specialized beak, thus capturing zooplankton or small mollusks. By their unusual filter-feeding mechanism, these flamingos eat animals ranging in size from 0.5mm to 10mm (Olgive and Olgive, 1986). Additionally, they can take larger animals, such as fish or crabs, by scooping them into their bills, and, when food is scarce, flamingos will ingest the layer of organic material (e.g. mats of cyanobacteria) that forms the surface of most pond bottoms. When prey abundance is low, flamingos will often fly to different ponds to feed and return when prey populations have recovered.

Salt ponds in the BVI host numerous species of crustaceans, insects, gastropods, phytoplankton, plants, and bacteria. Most of these species are specifically adapted to the harsh, highly saline salt pond environment. Some plankton, like the endemic variety of brine shrimp (*Artemia salina*), can tolerate salinities of 250 parts per thousand (25 percent salt) (Goodwin et al., 1984). Species composition in these ponds is largely governed by salinity, while abundances of some species, especially algae and organisms that feed directly on algae, may depend on nutrient levels in pond water. As salinity increases, living conditions become harsher, allowing survival only for those species specifically adapted to the resulting water conditions. These very specialized organisms must cope not only with high salinity, but also with low oxygen, high temperature, changing ionic concentrations as different salts precipitate, and decreasing pH as carbonate precipitates (Copland 1967). All of these changes in water chemistry are associated with increasing salinity. Thus, at high salinities species composition is very low, but abundance of individuals is often quite high, resulting in large organic biomass or productivity.

Hypersaline ponds in the BVI may go through seasonal salinity cycles correlated with periods of rain and drought. Such cycles would cause a parallel cycle in species composition and abundance. Additionally, runoff from the land during extremely rainy periods may significantly change other pond water chemical characteristics, such as nutrient concentrations. Input or dilution of nutrients in pond water would likely effect productivity of photosynthetic species. An understanding of the relationship between physical and biological cycles in local salt ponds is necessary for a successful long-term reintroduction of flamingos to the BVI. Such information can be used to assess the suitability of particular ponds for flamingo habitation and can be applied to ecologically sound development of salt pond environments.

The study presented here seeks to provide a better understanding of salt pond ecology in the BVI, particularly with respect to providing adequate habitat for flamingos. Few studies have investigated salt pond ecology directly, and little is known about the biological cycles occurring in this unique environment. General physical characteristics, zooplankton and plant species composition and abundance, and water chemistry were compared between several large and relatively undisturbed salt ponds. A more detailed analysis of Guana Island salt pond, involving regular monitoring over a three month period, was conducted to investigate the response of salt pond chemistry and community structure to rainfall and runoff. In addition, several local salt ponds were surveyed during July, 1988. The feeding behavior of flamingos, then residing in Guana's pond, and plankton abundance were also monitored in Guana's pond throughout July, 1988.

MATERIALS AND METHODS

Plankton samples were taken with a 120µm mesh net funneled into a detachable flask. Zooplankton was examined and identified microscopically. Macro algae and grasses were collected by hand, and presence of unicellular algae or bacteria, phytoplankton, or cyanobacteria was determined only when they were abundant enough to form visible, diagnostically colored patches, changes in water color, or benthic mats, respectively. Salinity was measured using an Atago refractometer, calibrated up to 100 parts per thousand. When salinities exceeded maximum reading, they were diluted using a 10 ml graduated cylinder. Dissolved oxygen was measured by siphoning pond water into 60ml BOD bottles and then by chemical titration using the Milton Roy Spectrokit for dissolved oxygen measurements. Nitrate and phosphate concentrations were measured using Milton Roy Spectrokit systems and a Mini 20 spectrophotometer. Chemical analyses performed with these kits follow procedures described in the 17th edition of Standard Methods for the Examination of Water and Wastewater, published by the American Public Health Association, the American Water Works Association and the Water Pollution Control Federation.

Two ponds on Anegada, Bones Bight Pond and Flamingo Pond, were analysed on 13 March; Belmont Pond, Tortola was analysed on 20 March, 27 April, and 30 May; Josiah's Bay Pond, Tortola was analysed on May 10; Banana Wharf Pond, Beef Island was analysed on 12 May; and the small pond on Great Camanoe was observed to be completely dry on 1 May. At Guana Island's salt pond, which had low levels of sea water constantly pumped into its west end, general physical characteristics were recorded and salinity measurements were taken at both the east and west ends two to four times a month from March to June. Complete water chemistry and plankton analyses of Guana's pond were performed several times between March and June both during generally dry periods (25

March, 8 April, 15 May) and after heavy rain (2 April and 22 May). Weekly rainfall was measured with a standard plastic rain collector calibrated in inches.

During July, 1988, observations of flamingo feeding behavior were recorded on a daily basis, and species composition and abundance of potential food items as well as salinity was monitored twice weekly. Organisms in plankton samples and mud samples were analysed microscopically. Plankton, mud, and shore fauna, and salinity were analysed at Lee Bay Pond, Great Camanoe, the two ponds on Necker Island, Biras Creek Pond, Virgin Gorda, and Josiah's Bay Pond, Tortola.

Soil samples were collected from uphill slopes near Belmont Pond, Josiah's Bay Pond, Sprat Point Pond, and Guana's pond. Nitrogen and phosphorus concentrations in soil was tested using a Lamotte soil science field testing kit according to procedures described in the Lamotte soil handbook. To test whether soil nutrients entered pond water by dissolving in rain runoff, soil from two high-nutrient sites near the pond, as well dried mud from the pond bottom, were soaked in fresh water for one hour; the water was then filtered; and nutrient concentrations in the water were measured (as described above).

RESULTS AND DISCUSSION

Characteristics of BVI salt ponds

Anegada ponds:

Both Flamingo Pond and Bones Bight Pond are very large and highly saline ponds which connect with the sea and with each other through a narrow restriction at their west ends. They were the largest and most isolated ponds in this study. Both were surrounded by mangrove, but about 20 feet of bare shore extended between the mangroves and the water line. These ponds occasionally support brine shrimp (Numi Goodyear, personal communication) but none were present in January, 1984 (Goodwin et al. 1984) or in March, 1991 (this study). The bottom of Bones Bight Pond was covered by a hard crust about one centimeter (cm) thick; this crust may be formed from gypsum and other carbonates that precipitated and settled out of the water when salinities were very high.

Water salinity was 98 parts per thousand (ppt) in Flamingo Pond and 91 ppt in Bones Bight Pond. Potential flamingo food items were plenty. Two species of water boatmen (Corixidae, Insecta) were abundant; brine flies were present on the shore and brine fly chrysalids were found in the pond; the shells of two gastropods (*Cerithium lutosum* and *Batillaria minima*) and one bivalve (*Anomalocardia brasiliana*) were extremely dense in pond mud and on the shoreline. The chrysalids of brine flies and small interstitial molluscs are major constituents in the diets of Caribbean flamingos on Bonaire (Rooth 1965). The orange-red color of the pond bottom suggested the presence of *Dunaliella salina*, a flagellated brine alga. At the west end of both ponds, in the narrow restriction connecting the ponds with the sea, salinity was 40 ppt, and water boatmen and fiddler crabs (*Uca* sp.) were in abundance. Nutrient levels (nitrates and phosphates) were high at the east end of Bones Bight Pond, while at the site of the ponds' convergence nutrient levels were similar to those in seawater (table 1).

The extensive pond systems on Anegada would provide the best habitat for flamingos in the BVI. They are well isolated, undisturbed, and extensive. Potential food items are plentiful, and, if left undisturbed, flamingos would very likely thrive and breed there. However, the success of flamingo reintroduction to Anegada's ponds would depend on long-term government protection of their habitat from nearby development or disturbance. Presently these ponds, although government-owned, enjoy no such legal protection.

Beef Island:

There are five salt ponds on this small island, at least two of which dry up seasonally. Trellis Bay Pond was completely dry in early May, 1991. *Spartina* grasses and mangrove grew along the edges of the pond bed. No gastropod shells were present in the dried sandy mud bottom. The pond east of Trellis Bay, on the far side of Sprat Point and near Banana Wharf, was examined on 12 May, 1991. A previous study of this pond described it as green and turbid, suggesting high nutrient input from rain runoff (Goodwin et al. 1984). However, in May, 1991, this pond (called Sprat Point Pond) had the characteristic red colored bottom and clear water typical of extremely saline ponds. Sprat Point Pond is isolated and undisturbed; it is privately owned and, due to the presence of unusual plant species nearby, it is government protected (Goodwin 1984). Pond salinity was 128 ppt, nutrients were high, as was water temperature (table 1). There was a washed-out area on the north east end, where it looked as though especially high tides or storms may wash sea water into the pond. There were several conch shells and a sea-turtle skeleton in this area, suggesting that sea water had washed over in the past. The bottom of this pond was covered by a thick mat of cyanobacteria covered by a layer of red algae (*Dunaliella*). Both water boatmen and brine shrimp were present, but in very low abundance. Fiddler crabs were seen along the shore. Although plankton densities were low at the time of this sampling, populations in other areas of the pond may have been much larger. Goodwin et al. (1984) describes the ephemeral nature of brine shrimp, in particular. Assuming that low plankton abundance is not generally characteristic of this pond, Sprat Point Pond should be ideal flamingo habitat. It is remote, protected from development, and supports various potential flamingo prey species.

TABLE 1: Salinity and nutrient concentrations in BVI salt ponds, and nutrient concentrations in soil samples taken from nearby uphill slopes.

					soil nutrients	
pond	date sampled	salinity	mg NO_3^-/l	mg PO_4/l	kg NO_3^-/ha	kg PO_4/ha
Bones Bight (Anegada)	13/3/91	91	1.7	1.1	-	-
Flamingo (Anegada)	13/3/91	98	-	-	-	-
Sprat Point (Beef Is.)	12/3/91	128	2.1	1.3	22.4	56
Lee Bay (Great Cam.)	7/88	36	-	-	-	-
Guana	25/3/91	54	1.1	0.9	11.2	336
	8/4/91	68	1.2	1.0	-	-
	15/5/91	96	1.8	1.5	-	-
(after 5.3cm heavy rain)	22/5/91	15	0.5	0.5	-	-
South pond, Necker Is.	24/7/88	88	-	-	-	-
North pond, Necker Is.	23/7/88	62	-	-	-	-
Belmont (Tortola)	20/3/91	120	2.1	2.4	16.8	112
	27/4/91	204	2.1	2.0	-	-
	30/5/91	244	3.2	-	-	-
Josiah's Bay (Tortola)	10/5/91	97	2.0	-	2.0	-
Biras Creek (Vir. Gorda)	7/88	91	-	-	-	-
sea water (White Bay, Guana)	2/4/91	37	1.0	0.4	-	-

Dashes (-) denote missing data. Nitrate and phosphate concentrations in pond water are given in milligrams per liter (mg/l), while those in soil are given in kilograms per hectare (kg/ha)

Great Camanoe:

Lee Bay Pond, Great Camanoe's only salt pond, is very small [about 0.5 hectares (ha)] and dries up completely during periods of drought. In early May, 1991, it was completely dry, but in July, 1988, it held water of 36ppt salinity and was up to 8cm deep. This depth was insufficient to collect a plankton sample, but a few wading birds, including a lesser yellow leg, were seen feeding in it. Small gastropod shells were abundant in the dry mud bottom in May, 1991, and these were similar to those present in Guana's pond (*Pyrgophorus*). The pond bed is completely closed off from sea water during normal tidal fluctuation, but probably is probably washed with seawater during heavy storms. The bottom is probably more than half a meter above sea level, and there seems to be no underground connection with the sea. Thus, under normal circumstances, Lee Bay Pond probably fills with water during heavy rains, and the water picks up salts from the pond bed (which are deposited by the sea during strong storms), which results in this pond having low salinities relative to most other local salt ponds. The pond shores are covered with *Spartina patens*, a grass that commonly grows in marine marshes. *Spartina* was not found near ponds that were highly saline year 'round.

Necker Island

There are two small salt ponds on Necker Island, one on the north side and one on the south. Both were examined in July 1988 but not in 1991. The northern pond was very deep (over 1 meter in everywhere but very near shore) and was very close to the sea. It's bottom was undoubtedly below sea level, and it probably had a strong underground connection with sea water. The pond salinity was 62 ppt, and sea water input from below probably kept the salinity relatively low for most of the year. Water boatmen and copepods (Maxillopoda) were present in low abundance, but no molluscs were found in the mud. The shores supported growth of *Spartina* grasses, but no fiddler crabs were found there. Necker Island's southern pond was shallower and more characteristic of local salt ponds. It's shores were surrounded by mangrove, and fiddler crabs were abundant among the mangrove roots and on bare patches of mud. The southern pond covered a larger area than the northern pond but was only 18cm deep. The water had 88 ppt salinity and contained moderate abundances of water boatmen and copepods (Cyclopioda and Harpactacoida). In some areas patches of filamentous green algae grew attached to the mud bottom. This pond was isolated from the sea and may have had only a small amount of underground sea water input.

Tortola:

Two of the six ponds on Tortola were surveyed: Josiah's Bay Pond, on the north side, and Belmont Pond, on the west end of the island. When very full, Josiah's Bay Pond overflows into Josiah's Bay through a man-made ditch cut into its north western end. The pond is situated in a fairly developed area with moderate human traffic, and it is the least isolated pond in this study. Livestock frequent the pond edges regularly, causing disturbance and high nutrient input. The pond is normally low in salinity and supports a lush flora (Goodwin 1984 and personal observations). However, this pond's salinity can get very high and was observed to be 300 ppt in July, 1984, at which time the pond was nearly dry. On May 10, 1991, Josiah's Bay Pond was undergoing a transition from a dominant growth of filamentous green algae (*Rhizoclonium* and *Cladophora*) and *Ruppia maritima*, a salinity-tolerant grass, to the unicellular red algae, *Dunaliella salina*. This succession of the very salinity tolerant *Dunaliella* over the less tolerant flora was likely due to gradually increasing salinity with drought conditions. The salinity at the time was 97ppt. Potential flamingo food items were more abundant at this pond than at any others surveyed. Two species of water boatmen were extremely abundant, as were fiddler crabs on the shore and in shallow water. Some fiddler crabs at Josiah's Bay Pond were over twice as large as fiddler crabs seen at other ponds. Black-necked stilts were common, and a couple seemed to be guarding nests. This pond supports a very productive ecosystem with an abundant food supply for wading birds. Although this pond could serve as an important temporary feeding site for flamingos, it probably experiences too much human-related activity for the birds to reside there.

Belmont Pond has already proven to be suitable flamingo habitat. The four resident flamingos, reintroduced to the BVI in 1987, resided at Belmont Pond between October 1990 and May 1991. It is a fairly isolated, undisturbed large pond. It's salinity is generally high and large seas during storms wash sea water into it. Its bottom is close to sea level, and sea water probably percolates into it from underneath. This pond was analysed on 20 March and 27 April, while the flamingos resided there and on 30 May, after the flamingos had flown away. These visits showed a gradual water level decrease and salinity increase coinciding with dry weather. As the pond became shallower and more saline, plankton abundance decreased dramatically. In early March, Belmont Pond was teeming with adult brine shrimp (Numi Goodyear and Ralph Rusher personal communication), but on 20 March, only a few juveniles were found. Water boatmen, on the other hand, were plentiful. Multitudes of small elliptical white eggs of undetermined origin were collected with the plankton sample. By the end of April, Belmont Pond's salinity had increased to 204 ppt. During the intervening month, only 3.8 cm of rain were recorded to have fallen on Guana, and this was the driest period so far in 1991. The water line at Belmont Pond had receded about considerably since March, and the pond was very shallow. Water temperature was high and the bottom was very loose. Dunaliella covered the pond bottom and shoreline. The local residents reported that the flamingos had started to fly high circles over the pond every morning, a behavior they displayed prior to leaving Guana's pond in October, 1990. By late May, the flamingos were no longer present, and the pond had dried even further. The bottom was extremely loose to a depth of 60 cm, and the water was even shallower and hotter (42°C) than in April. Pond salinity had increased to 244 ppt even though 7.9cm of rain had fallen in the preceding month (as measured on Guana). Although several stilts were wading in the pond, no plankton was found in the water. It is probable that the drastic salinity increase caused the plankton populations in Belmont Pond to crash, thus forcing the flamingos to seek a new pond where food was abundant. As of late June, 1991 the flamingos had not returned to Belmont Pond or to their previous home on Guana.

Virgin Gorda:

Biras Creek Pond, Virgin Gorda was surveyed in July 1988. This pond was constantly pumped with water to keep it full all year. Water sampled at the end farthest from the sea water input was 88 ppt saline and contained water boatmen, copepods, and fiddler crab larvae in great abundance. Live snails (larger than those found dead in Lee Bay Pond and Guana's pond) and small red annelids were found in the mud samples. This pond is part of a resort hotel and there is usually much human activity closeby.

Guana Island:

The pond on Guana Island covers about 1.5 ha. and is completely isolated from the sea except during severe hurricanes (e.g. Hugo in 1989). Its north and east shores are bordered by red and white mangroves, while its southern shore is covered with *Spartina patans* . Guana's pond is highly productive and hosts a great abundance and diversity of plankton and plants. Many wading birds breed along the shores, including black-necked stilts, Bahama pintail ducks, and thick-billed plovers. Salinity is relatively low for most of the year, but under natural conditions it nearly dries up seasonally. It has been pumped with sea water (averaging about 23 liters/min) to keep the pond full since the importation of flamingos in 1987. The bottom of the pond is less than 19cm above sea level in its deepest point, and water from the pond percolates through the ground and into the sea when the pond is full. Thus the constant high-volume pumping of sea water effectively flushed the pond slowly, keeping the salinity down. This pumping was decreased substantially as of March 1991, and the area farthest from sea water input became hypersaline. The slow concentration of salts due to the decrease in sea water pumping and dry weather provided an opportunity to document species turnover with increasing salinity in this pond from April to June, 1991.

During July, 1988, observations of salinity, plankton diversity and abundance, and flamingo feeding behavior were made at Guana's pond. Salinity throughout the month averaged 79 ppt and fluctuated only 1ppt up or down. Copepods (mostly cyclopoid) and water boatmen were very abundant. Their abundance was fairly constant throughout the month and their distribution was fairly even across the pond. A few small patches of filamentous green algae grew attached to the mud bottom, and *Ruppia maritima* covered the bottom in shallow areas near the south shore. Fiddler crabs were abundant on the shore, and their larvae were present in the water. Recently dead shells of the gastropod, *Pyrgophorus* (Hydrobiidae), were dense on the pond bottom. Flamingos generally spent about half the day feeding, of which the majority took place in the morning and late afternoon. Mostly, the flamingos waded slowly around the pond with their heads in the water sweeping from side to side or just moving forward as they walked. This behavior is associated with filtering food items from water or mud (Rooth 1967). Water boatmen and copepods, being of the appropriate size to be caught in Caribbean flamingo beaks, probably made up most of their diets, while fiddler crab larvae, being less abundant, were probably taken less frequently. On many occasions during the early evenings, the flamingos were observed picking adult fiddler crabs from around mangrove roots.

Sometime during the middle of 1990, the flamingos started to fly high circles over Guana every morning. Sometimes they left for a few hours (Liao Wei Ping, personal communication). It was suspected that the flamingos were running low on their natural foods, and so Dr. Liao, the resident scientist at the time, began supplementing their diet with dried dog food. The flamingos pecked this from the surface of the pond when it was thrown in, and they even learned to come when called. However, in October, the Bahama pintail duck population in the pond became very high (up to 50 ducks were reported), and these birds, being quite aggressive, often ate all the dog food before the flamingos could get it. Thus, by the end of October, the flamingos had gone. Although this scenario suggests that the flamingos' natural food source was becoming depleted, no plankton samples were taken at the time. However, this behavior is consistent with those of flamingo populations elsewhere. Flamingos in the wild generally feed in large groups, and once food concentrations in a pond become low, flamingos will fly to another pond to feed. Even while nesting, Carribean flamingos have been recorded to fly 288 km from Bonaire to the coast of Venezuela and back on daily feeding excursions (Olgive and Olgive, 1986). It is probable that native Caribbean flamingo populations in the BVI, both past and future, will not feed permanently at any particular pond, but will rotate feeding ponds, thus allowing prey populations to renew themselves until the next feeding bout. In fact, the four resident BVI flamingos have already shown this behavior. When food abundance declined, they left *en masse* to find another pond. For this reason, the establishment of a BVI flamingo population will depend on the preservation of many different salt ponds rather than just one large area.

Salt pond salinity and species turnover:

A gradual salinity increase in Guana's pond between May and June, 1988, was paralleled by changes in zooplankton and plant species composition. Because of the input of sea water at the west end of Guana's pond, a salinity gradient developed across the pond. The east end, which is deepest, was generally more saline than the west end, except after heavy rain, when the east end was temporarily fresher than the west. Salinity at the west end, about 42ppt, varied little between March and June, while salinity at the east end increased gradually throughout this period. However, heavy rains during May slowed this trend.

In March, Guana's pond was dominated by a thick growth of filamentous green algae (mainly *Rhizoclonium*, but also *Cladophora*\) that was both attached to the substrate and floating in large mats. This algae was seen in small quantities during July 1988, and it was reported to have bloomed soon after the flamingos departed in October, 1990, after which dense algal mats soon covered most of the pond (Ralph Rusher, personal communication). A number of factors probably contributed to this sudden algal bloom, including clear water, high nutrient concentrations, and low-saline water. The presence of flamingos over the years likely increased pond nutrients (through flamingo defecation and stirring up nutrient-laden mud), but their constant wading made the water turbid, slowing algal growth as long as they were present. When the flamingos left, the mud probably settled out of the water, allowing the then benthic algae exposure to sunlight. Additionally, sea water input and much rainfall over the winter resulted in low pond salinity. When the present study began in March 1991, the pond salinity was 46ppt. By early May, salinity had risen to 134 ppt, and the green filamentous algae was dying. *Ruppia maritima,* a grass growing in shallow areas, was mostly dead at this time. Large patches of bright green water developed in the pond; the color was produced by an abundance of unicellular green algae, possibly *Dunaliella viridis* (this species is quite salinity-tolerant but less so than *Dunaliella salina*). The eastern pond edges were attaining an orange-red color, indicating some growth of *Dunaliella salina*. Small patches of bright pink bacterial colonies were growing very near shore on dying mats of green algae. Heavy rains during May, especially on the 22nd (figure 1) decreased pond salinity substantially, but by the middle of June, pond salinity was up to 95ppt. By this time, both the pink bacteria and the bright green unicellular algae had disappeared. The majority of the green macro-algae was completely dead, except for a few patches near the sea water pump. Most of the pond had taken on the orange-red color characteristic of *Dunaliella salina* growth. The gradual substitution of plants that prefer low salinities by the salinity tolerant phytoplankton, *Dunaliella* sp., may occur seasonally in relatively low-salinity hypersaline ponds throughout the BVI. Results from both Josiah's Bay Pond and Guana's pond indicate that this species turnover occurs at about 100 ppt salinity (fig 2).

Zooplankton species composition also followed a succession with increasing salinity (figure 2). During March, pond salinity rose from 46 ppt on the 10th to 54 ppt on the 25th. Throughout this month, water boatmen (*Trichocorixa reticulata*) and clam shrimp (Branchiopoda, Conchostraca) were very abundant, and fiddler crab larvae and mosquito larvae were also found (figure 2). Between 7 April and 16 April, salinity rose from 68 ppt to 83 ppt. Copepods, both harpactacoid and cyclopoid, appeared in great abundance, although water boatmen and clam shrimp were also abundant. A few fiddler crab larvae but no mosquito larvae were found in April. East end pond salinity reached a high point of 134 ppt in early May, but dropped after freshwater input from rain (fig 1 and 2). In the east end of the pond, water boatmen and clam shrimp were no longer present, but copepods were very abundant (harpactacoids dominated over cyclopoids). Both harpactacoid and cyclopoid copepods were carrying eggs. Also abundant in the plankton sample were tiny, brown, shelled animals that moved like rotifers and were not identified. These organisms were abundant in the west end of the pond through June. Although the east end was becoming increasingly saline, the west end was still receiving sea water input, and its salinity remained low (39 ppt). Plankton at this end included the same species as at the east end in addition to water boatmen and clam shrimp. During June, pond salinity at the east end remained near 95 ppt. Plankton species composition, abundance and distribution was similar to that during May. Fiddler crab larvae were found in the fresher west end.

The pattern of species turnover with salinity increase observed for both plants and zooplankton in Guana's pond (figure 2) may be representative of seasonal cycles in salt ponds throughout the BVI. In other salt ponds studied, many species present in low salinity ponds were not present in high salinity ponds (figure 2), following a pattern similar to Guana's pond. Salinity in most local salt ponds cycles with seasonal wet and dry weather patterns, and should be paralleled by a cycle in species composition following the successional pattern shown in figure 2. Clam shrimps, mosquito larvae, fiddler crab larvae, filamentous green algae, and Ruppia grass were found when pond salinities were relatively low; water boatmen were abundant in a wide range of salinities, but disappeared after salinity reached about 90 ppt or more. In some ponds, copepods were abundant at intermediate salinities, between about 60 and 130 ppt. Brine shrimp occurred only in more saline ponds, with salinities over 120 ppt. At high salinities, over about 120 ppt, all zooplanktonic species except brine shrimp disappeared.

On the basis of food abundance alone, relatively fresher hypersaline ponds should be preferred by flamingos. These ponds generally contain greater prey species diversity and abundance, while in very saline ponds, species diversity is low and zooplankton populations are very ephemeral. However, factors other than food abundance (such as remoteness) are also important to flamingos colonies, and flamingos would probably not visit highly disturbed ponds no matter what the plankton density.

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Characteristic salinities of salt ponds:

The discussion above showed the importance of water salinity to zooplankton species composition and abundance. Although rainfall is the most immediately obvious factor affecting pond salinity, the amount of seawater input into a pond may be equally or more important in determining long-term average salinity. Of the ponds studied, those that were well isolated from the sea, thus receiving little sea water input either overland or underground, were generally fresher than those with more frequent sea water input. However, when a pond receives so much sea water on a regular basis that it is effectively flushed, the salts in the pond water are not given time to concentrate through evaporation, and salinity remains low. Ponds that are well isolated from sea water input, such as Lee Bay Pond, receive their water from rain, and they dry up completely during the dry season. A certain amount of salt, present in the pond bed, dissolves into the fresh water as the pond fills during rainy periods. These salts originate from infrequent occasions, such as severe storms, when the sea washes into the pond, and they are recycled during the pond's seasonal filling and drying. In ponds that have some regular access to sea water, but are not flushed, year-'round salinity is generally high. Moderate input of sea water only increases salinity by adding more salts to the pond which are then concentrated through evaporation. Salinity in these ponds decreases from rain and probably also when heavy storms flush the ponds with sea water. Most large ponds in the BVI, including Belmont Ponds, Sprat Point Pond, and the ponds on Anegada, are of this sort. Ponds such as Josiah's Bay Pond and the southern pond on Necker Island are intermediate between having nearly no sea water input and moderate input, and they probably cycle between low and high salinity depending on amount of rainfall.

Ponds that have permanent direct interchange with the sea, such as the northern pond on Necker Island, have low salinities. Sea water exchange with pond water is so frequent in such ponds that any hypersaline concentration of salts within the pond water is soon mixed with fresher sea water. Under these conditions, rainfall has little effect on pond salinity. Ponds that have constant low volume sea water input into a localized area of the pond may not be completely flushed. Instead, low volume sea water input causes a salinity gradient across the pond. Areas near the sea water input remain low in salinity, while areas far from the input become very saline. Biras Creek Pond and Guana's Pond, both of which have sea water pumped into them, are examples of such a ponds. Previous to March, when the volume of sea water pumped in was quite high (about 23 liters/minute), Guana's pond was probably closer to a completely flushed pond.

Physical factors affecting biological productivity in salt ponds:

In most aquatic ecosystems, nutrients are limited and thus play an important part in determining biological productivity. Because hypersaline ponds are such harsh environments, few organisms can live there, and nutrients are often not efficiently used (Copeland, 1967). Incomplete use of nutrients and organic compounds in an ecosystem suggests that the input of excess nutrients would not increase productivity. However, Goodwin et al. (1984) found that fertilizing hypersaline ponds would increase algal growth, thus providing more food for brine shrimp. Hypersaline ponds tested in this study had nitrate and phosphate concentrations up to three times (for nitrates) and six times (for phosphates) greater than sea water (table 1). In an effort to determine whether rain runoff from land carries nutrients into ponds, an analysis of soil chemistry and rain water was performed. No correlation was found between pond nutrient concentration and nutrient levels in surrounding soil (table 1). Nutrients in mud from the bottom of Guana's pond were extremely high. Natural soil containing moderate nitrate and high phosphate concentrations was soaked in rain water for one hour (it was periodically shaken to encourage solution). After the soil was filtered out, nutrient levels in the soil-exposed rain water were zero. When this experiment was performed on Guana's salt pond mud, however, nutrient levels in the rain water became very high (greater than that of the salt pond's water). Water samples taken from Guana's pond after heavy rain on 22 May had very low nutrient concentrations (table 1). These results indicate that most ponds do not receive nutrients from rain runoff. Alternatively, nutrient levels in salt ponds may rise through concentration of sea water. As sea water, which has low nutrient levels, enters a pond and concentrates by evaporation, nutrient levels within the pond should increase. By using salinity as a indication of evaporation and concentration of sea water in salt ponds, the idea that pond nutrient levels increase through the evaporation of sea water can be analysed. As salinity increased in Guana's pond, nutrients increased, and, in the various ponds studied, higher salinity ponds had higher nitrate and phosphate concentrations (figure 3). This suggests that the concentration of sea water through evaporation provides high nutrients in pond water. However, if the source of pond nutrients is internal (i.e. from biological cycles), low salinities may merely represent a dilution of pond water rather than an indication of little concentration of sea water. This is especially problematical for comparisons between ponds with different levels of sea water input, but the pattern held within Guana's pond in which sea water input was constant and regulated.

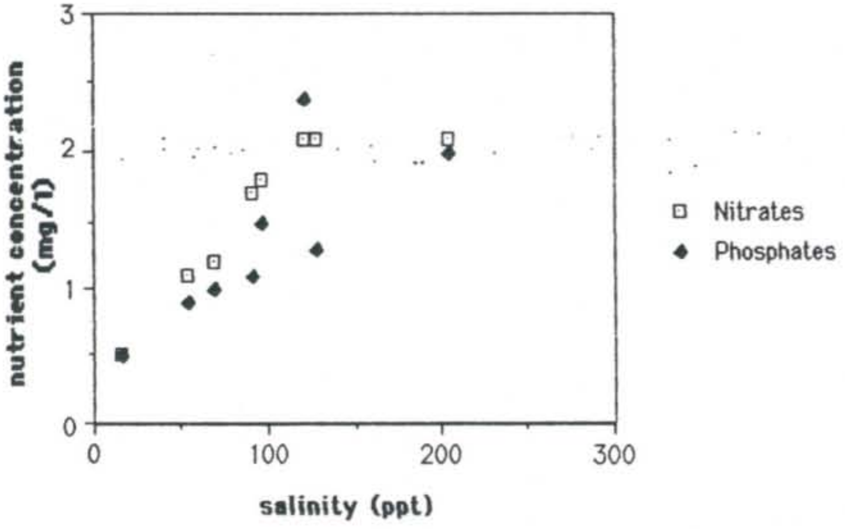

FIGURE 3: Plot of pond nutrients (phosphates and nitrates) versus salinity, showing a linear increase of both nutrients with increasing salinity.

<u>Conservation of salt pond habitats:</u>

Salt ponds in the BVI are, for the most part, highly productive and could provide rich food sources for flamingos. Some salt ponds are still well preserved and undisturbed and should provide ideal flamingo habitat. If these ponds, in particular, are protected from any disturbance or development of the surrounding land, a successful reintroduction of flamingos is likely. With enough habitat, flamingos will reproduce, and in a number of years, BVI ponds could be graced with large flocks of these magnificent birds. The success of the flamingo reintroduction project depends on the number of healthy flamingos that are brought (they are more likely to breed in large flocks), and the ability of BVI ponds to support them. The ponds of Anegada, being both productive and very isolated, provide the most ideal flamingo habitat. However, any flamingo colony established there would most likely need to feed from ponds on surrounding islands even before their population gets large. Thus, there is, primarily, a need to establish government protection of Anegada ponds, and, secondarily, efforts should focus on protecting a number of other still well-preserved ponds. Ponds such as Belmont Pond (Tortola) and Sprat Point Pond (Beef Island), being well-preserved and isolated, may provide important food resources for flamingo populations and deserve protection. Although other ponds, such as Josiah's Bay Pond are highly productive, many are likely too disturbed to attract flamingos, but measures to exclude human traffic and livestock from areas around these ponds could turn them into suitable flamingo habitat. Most salt ponds in the BVI provide feeding and breeding grounds for native wading birds such as black-necked stilts, Bahama pintail ducks, and thick-billed plovers. Thus, legal protection of salt ponds would benefit many waterfowl, and, furthermore, it would assure the preservation of the unique salt pond ecosystem in the BVI.

GENERAL CONCLUSIONS:

1. Gradual increases in pond salinities are paralleled by a succession of less salinity-tolerant to more salinity-tolerant organisms. Species composition in BVI salt ponds probably cycles with changes in salinity, which, in turn, is effected by seasonal wet and dry periods.
2. Low salinity ponds support a greater diversity of zooplankton than do extremely hypersaline ponds.
3. BVI salt ponds have relatively high nutrient concentrations, and the source of these nutrients may be external. Runoff from heavy rains does not increase pond nutrients, but concentration of nutrients from sea water input to ponds may result in high nutrient levels characteristic of local salt ponds.
4. For a particular pond, average yearly pond salinity may be determined more by the amount of sea water input than by the amount of rainwater input that a pond experiences.
5. The ponds on Anegada, being both remote and biologically productive, should provide the best flamingo habitat in the BVI. However, resident flamingos would probably have to travel regularly to neighboring islands to feed.
6. Salt ponds in the BVI could provide ideal habitat for the once-native Caribbean flamingos, but long term success of a flamingo reintroduction project depends on legal protection of salt ponds.

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