QUEEN CONCH

PRINCIPAL INVESTIGATOR: **John A. Cigliano, Ph.D.**

POSITION/TITLE: Associate Professor of Biology

AFFILIATION: Cedar Crest College

THE PROJECT

Introduction

Fisheries around the world are severely threatened by overfishing and traditional management methods, which include limits on catch size, amount and fishing effort, and seasonal closures have not been effective in protecting these stocks. An alternative to traditional fishery management techniques that has become popular is the designation of Marine Protected Areas (MPAs). MPAs are discrete geographic areas that are "permanently protected from at least one preventable [anthropogenic] threat" (Crowder and Norse 2005). A specific type of MPA is the Marine No-take Reserve, or just Marine Reserve (MR), where all extractive or consumptive activities, including harvesting, are prohibitive and other forms of disturbances are minimized. The assumptions that underlie how MPAs, and specifically MRs, can protect marine fisheries include increasing biomass and density of protected species inside the reserve, due to lower mortality from the prohibition on harvesting, and an increase or maintenance of populations outside the reserve by supplying the non-protected areas outside with recruits through the emigration of post-settlement individuals ("spillover effect") and through the dispersal of pelagic larvae ("dispersal effect").

While there is ample evidence that reserves maintain species diversity and lead to an increase in density and biomass of the protected fisheries (e.g. Roberts 1995, Jennings *et al.* 1996, Halpern and Warner 2002), there is less evidence for the spillover effect (e.g. Roberts *et al.* 2003). The "dispersal" assumptions of MPAs have rarely been tested directly and this holds especially true for invertebrates (National Research Council 2001, Palumbi 2001, Sobel and Dahlgren 2004).

The two largest fisheries in Belize are the lobster (spiny lobster, *Panulirus argus*, and spotted lobster, *P. guttatus*) and the queen conch (*Strombus gigas*). Both of which appear to be severely over-harvested. Traditional regulations for queen conch require that conch be at least 7 in (18 cm) in length with a minimum weight of 86 g for cleaned meat. There is also a closed season (July 1-September 30) and the use of SCUBA is prohibited. A network of 13 MPAs has been established to protect these as well as other fisheries. One of these is the Sapodilla Cayes Marine Reserve (SCMR), which is where this study will take place. SCMR was established in 1996 and is 15,619 ha in area. The reserve is located at the southern end of the Mesoamerican Barrier Reef close to the countries of Honduras and Guatemala and consists of various cayes and the surrounding marine habitats, down to the 30 m depth contour. The reserve has been divided up into zones of varying levels of protection: a General Use Zone (GUZ), where commercial extractive activities are allowed but managed, two Conservation Zones (CZ), where no extractive activities are allowed but other activities such as SCUBA and snorkeling are allowed, and a Preservation Zone (PZ), where entry is prohibited except with a special permit for research. However, the management plan has not yet been signed into law and, as such, it not being enforced.

The broad, long-term objectives of this project are to:

- Determine the effectiveness of the Sapodilla Cayes Marine Reserve in protecting and replenishing queen conch (*Strombus gigas*) populations
- Provide information for adaptive management of the marine reserve
- Build capacity in all stakeholders to insure the long-term effectiveness of the reserve

We will accomplish the objectives by:

- Mapping queen conch aggregations and habitat within the reserve and surrounding areas
- Conducting surveys as part of a long-term monitoring of queen conch populations and as part of a Before-After-Control-Impact (BACI) study to determine the effectiveness of the reserve in protecting queen conch populations
- Determining the extent of demographic connectivity of the reserve with surrounding areas through post-settlement migration (spillover effect) and larval dispersal (dispersal effect) and the overall level of self-recruitment of queen conch populations within the Sapodilla Cayes and Port Honduras region
- Developing a strong collaborative relationship with local stakeholders and the Fisheries Department to help build capacity in the community
- Conducting educational outreach activities with local stakeholders

Volunteers will assist in all aspects of the study. In the field, they will assist in juvenile and adult surveys, veliger (larval) surveys, mapping of conch aggregations, habitat assessment, and tagging and recapture of conch. In the lab, they will be responsible for veliger identification, data recording and reduction. And they will have the opportunity to work with local stakeholders in capacity building and educational activities.

The broad significance of this project is that it will test the fundamental and critical assumptions of MRs. If MRs do not replenish harvested populations with recruits, the effectiveness of MRs in conserving and managing fisheries will be severely limited. However, if these assumptions are supported, the use of MRs to manage fisheries will be validated. On a more local level, this project will provide valuable information that is needed for the local conservation and management of queen conch and lobster. And it will help build the capacity of the local community for long-term, successful management of the reserve.

Queen Conch (*Strombus gigas*) Ecology, Natural History and Conservation

The queen conch is a large marine gastropod that is found from Venezuela to southern Florida, Bermuda and throughout the Caribbean (Randall 1964). Females produce demersal eggs that are deposited in long, crescent-shaped, sand-covered masses (Robertson 1959). A female produces an egg mass, containing 313,000-485,000 eggs (Randall 1964 and spawn approximately nine egg masses per reproductive season (Davis *et al.* 1984). The larvae (veligers) are pelagic and, based on time to metamorphic competence (i.e. larvae is ready to settle out of plankton), spend two weeks (Davis 1993) to as long as two months (Noyes 1996) in the plankton. The actual dispersal rates for queen conch veligers are unknown (Appeldoorn 1997), but the prevailing view is that queen conch larvae disperse over long distances (Stoner 1997), even though recent models of larval dispersal in the Caribbean (Cowen *et al.* 2003) suggest otherwise. Furthermore, ecological (Stoner and Sandt 1992, Stoner *et al.* 1992, Posada and Appeldoorn 1994, Stoner *et al.* 1996, Appeldoorn 1997) and genetic evidence (Mitton *et al.* 1989, Campton *et al.* 1992) suggest that self-recruitment of larvae might be significant in queen conch populations.
Once veligers settle out of the plankton, they bury themselves in sand for at least one year, after which they emerge and migrate in early spring to shallow (2-4 m) nursery habitats that are typically seagrass beds of intermediate seagrass density in areas of good water movement (e.g. at reef cuts where there is strong tidal flux) (Randall 1964, Weil and Laughlin 1984). At 2-3 years of age, juveniles move from the shallow nursery grounds to deeper seagrass meadows and the

characteristic broad shell lip begins to form (Randall 1964, Weil and Laughlin 1984). Conch move to deeper water as they grow older, with adults found as deep as 30 m (Stoner and Sandt 1991; pers. obs.). These deep-water adult aggregations might act as important refugia in heavy exploited populations (Thiel 2001). There appears to be at least two deep-water aggregations in SCMR (P. Wood *pers. comm*.). Gonadal maturity is reached when shell lip thickness is 4 mm, at approximately 3-4 years of age (Appeldoorn 1988). However, mating and spawning might not occur until the shell lip is > 11 mm (Gascoigne and Lipcious 2004).

Reproduction generally occurs from March-September; however, in Belize spawning may occur year round (Thiele 2001). Sexually mature adults generally migrate from deep-water to shallow-water sand plains for mating and spawning (Stoner *et al.* 1992). However, deep water (approx. 30 m) mating might be occurring in the Sapodilla Cayes (P. Wood *pers. comm*.). Fertilization is internal and spawning may follow copulation by several weeks (D'Asaro 1965). During the winter, queen conch migrate to deeper waters (Weil and Laughlin 1984, Stoner *et al.* 1992). Only a few studies have attempted to measure migration rates and distances of juvenile and adult queen conch, and these were limited in duration and area (Hesse 1979, Stoner *et al.* 1988, Stoner 1989, Stoner and Sandt 1992, Stoner and Ray 1993).

RESEARCH OBJECTIVES AND METHODS

The long-term objectives of this project include:

- To determine the effectiveness of the Sapodilla Cayes Marine Reserve
- To provide information for adaptive management of the marine reserve
- To build capacity in all stakeholders to insure the long-term effectiveness of the reserve

The fact that the reserve is not presently being enforced actually offers a unique opportunity to test rigorously and experimentally the effectiveness of the reserve by allowing us to use the Before-After-Control-Impact method (BACI) (see below). This is preferable to doing reserve-non-reserve comparisons because of stronger experimental controls in the BACI method.

Accomplishing the following specific objectives will allow us to fulfill our long-term objectives.

Objective 1

Objective 1 is to map queen conch aggregations and habitat within the reserve and surrounding areas. During the first field season (2006) we located shallow-water queen conch "crèches" (nurseries) at the reef cuts between Hunting Cay and Nicholas Cay (Nicholas Cut) and Franks Cay and Nicholas Cay, and Franks Caye and Northeast Caye, and in shallow water behind the cayes of Tom Owens, Hunting, Ragged, Franks and Seal, and deep water (30 m) spawning sites occur in the cut between Nicholas Cay and Hunting Cay and off of Lawrence Rock. Mapping queen conch aggregations is necessary so that we can determine whether all queen conch life-history stages and the associated habitats are present in the reserve.

Objective 2

Objective 2 is to conduct BACI surveys to determine the effectiveness of the reserve in protecting and replenishing queen conch populations. It is expected that the enforcement of No-take Zones will positively affect population growth of queen conch within these zones by eliminating non-natural mortality. Thus, we predict that the density of conch will increase after enforcement in the No-take Zones and also in relation to the control sites. We also expect that the enforcement of the No-take Zones will increase the biomass of queen conch within these zones because larger individuals are no longer being harvested, and we predict that there will be an increase the average individual size of conch (i.e. siphonal length).

Recent surveys have found that queen conch populations (and now harvests) are dominated by juveniles (i.e. there is a reduction or loss in non-juvenile age classes) due to the over-harvesting of adults (Theile 2001). Therefore, protected populations are expected to show an increase in the number of individuals in the adult (i.e. harvestable) in the population compared to harvested populations. Thus, we predict that the age structure of "impacted" queen conch populations will differ significantly between "before" and "control" populations; specifically, there will be an increase (perhaps reappearance) in the number of individuals in the adult and subadult age classes.

Objective 3

Objective 3 is to conduct long-term monitoring of queen conch populations. It will be necessary to survey queen conch populations well after enforcement of the reserve and after Objective 2 is fulfilled, to be sure that the reserve maintains it effectiveness and to provide constant information on the workings of the reserve to TASTE-SCMR and the Fisheries Department so that the reserve can be adaptively managed.

Objective 4

Objective 4 is to determine if the populations of queen conch are reproductive. There is evidence that queen conch exhibit both an Allee effect (a minimum density is required for reproduction) and delayed functional maturity (gonadal development and reproductive behavior are not linked; gonads are mature when shell lip thickness is approximately 5 mm but mating might not occur until shell lip thickness is > 11 mm) (Gascoigne and Lipcius 2004). Both can have major implications for management.

- *Allee effect:* Stoner and Ray-Culp (2000) found evidence that the Allee threshold for queen conch appears to be 56 adult conch/ha for mating to occur and 48 adult conch/ha for spawning to occur. Unfortunately, many populations throughout the Caribbean are near or below these densities (Thiele 2001), which suggests that recovery even after protection may be slow or impossible if larval recruitment into these populations is mainly from exogenous sources. Currently, we do not know the density of adult queen conch the SCMR, therefore, it is critical to determine the average density of adult conch in the SCMR and whether this population exhibits an Allee effect.
- *Delayed functional morphology:* Many countries impose a minimum shell lip thickness for the harvest of queen conch (and many do not). However, no country imposes a minimum greater than 11 mm. If Gascoigne and Lipcius (2004) are correct, reproductive stocks in Belize, and elsewhere, are not being protected. If delayed functional maturity does occurs in this population, we expect that the average lip thickness of reproducing conch will be significantly greater than 5 mm.

Objective 5

Objective 5 is to determine the extent of demographic connectivity of the reserve with surrounding areas through post-settlement migration (spillover effect) and larval dispersal (dispersal effect).

- *Spillover effect:* One of the most important functions of a marine reserve is to replenish the surrounding areas with recruits. The reasoning for this is that as the density of post-settlement individuals increases inside a reserve (due to decreased fishing mortality), there will be an increase in density-dependent emigration due to reduced per capita availability of limiting resources (e.g. food) (Sobel and Dahlgren 2004). Thus, if spillover of queen conch occurs in SCMR, we predict that there will be a statistically significant increase over time in the number of recaptures in non-protected areas of conch tagged while inside the No-take Zones. This increase will parallel the increase in density of conch inside the reserve. We also expect that conch will migrate between the shallow water habitats behind the cayes and the deep-water populations outside the reef through reef cuts.

  Dispersal effect: It is also assumed that marine reserves will supply fished areas with pre-settlement (i.e. pelagic larvae) recruits. This suggests that self-recruitment of larvae is more significant than recruitment from exogenous sources. If this is occurring, we expect that the distribution of queen conch larvae (veligers) exhibit an offshore (seaward side of barrier reef above dee-water spawning sites) to nearshore (crèches in SCMR) density gradient through the reef cuts with all veliger stages found in SCMR. If veligers come from exogenous sources (i.e., from outside the SCMR), we would expect to find a shallow or non-existent gradient of veliger density; only late stage (near-competent and competent) veligers will be found in shallow water habitats.
- (Leis *et al.* 1998, Swearer *et al.* 2002).

Objective 6

Objective 6 is to develop a strong collaborative relationship with local stakeholders and the Fisheries Department to help build capacity in the community, and conduct educational outreach activities with local stakeholders. The most exciting, and arguably most important, characteristic of an Earthwatch regional initiative is that it is partnership-based program that engages local stakeholders to build capacity within the community. Earthwatch has partnered with TASTE, TIDE, and the University of Belize in the development and implementation of the *Earthwatch Belize* regional initiative. We will build on this relationship whenever, and however, we can..

<u>Methods</u>

In an effort to use sampling protocol that is consistent with the protocol used by the Fisheries Department, we have based our protocol on Acosta (2002).

Method 1: Aggregation and Habitat Mapping

Volunteers will assist in mapping queen conch aggregations inside and outside the various reserve zones of the SCMR. Conch aggregations in all zones of the park were located and marked (waypoint) during the 2006 field season using the Global Positioning System (GPS). We will re-locate these aggregations using by navigating to the GPS coordinate (waypoint) for each aggregation . The GPS coordinates will be mapped using ArcView software (Environmental Systems Research Institute, Inc.) and will be done at the Keck Bioinformatcs lab at Cedar Crest College.

We will determine habitat type by randomly placing 10 0.25 m^2 quadrats along each randomly chosen 50 m transect in each aggregation (see Method 2). The percent cover of each substrate type (e.g. coral rubble, sand, seagrass, etc.) in each quadrat will be recorded. Benthic plants and algae and invertebrates will be identified to lowest taxonomic rank possible and density of invertebrates, algae and seagrass (blades/m^2) will be determined. Canopy height will also be determined for non-encrusting algae and seagrass. We will also harvest seagrass from three quadrats from each transect to determine the average percentage of epiphytic cover on seagrass blades. This, as well as the invertebrate survey, will provide baseline data in support of a study to determine if seagrass community structure is affected by changing queen conch densities.

Method 2: Population Censuses

We will place a 50 m baseline transect along the lagoon-ward edge of each conch aggregation. We will then place a 50m transect perpendicular to the baseline transect every10m. A team of three snorkelers will swim slowly along the transect to locate conch. A 2m PVC pole, centered over the transect, will be used to define the sample area. All queen conch found within the 2m sampling area will be counted, measured and aged by measuring lip width and lip thickness (at the point of greatest thickness) to the nearest 0.1 mm (Appeldoorn 1988, Acosta 2002). Queen conch are considered adults if shell lip thickness is ≥4.0 mm (Appeldoorn 1988, Tewfik and Béné 2000, but see Gascoigne and Lipscious 2005). Juveniles will be further categorized as small, medium, large or subadult; adults will be categorized as young adult or old adult (Tewfik and Béné 2000). Sampling will begin at the mid-point of the baseline transect. We will add additional 50X2m transects until no conch are found along two consecutive transects. Aggregations will be designated as nursery, adult feeding or spawning as determined by size, age and behavior.

Method 3: Queen Conch Reproduction

We will determine if populations in the SCMR are reproductive by recording all mating and spawning events observed during population censuses.

Method 4: Effectiveness of SCMR

Data will be collected as described above (Population Censuses) from all conch aggregations from each impacted site (Conservation Zones, Preservation Zone) and from aggregations in the General Use Zone (controls) before and after enforcement of the no-take regulations. Aggregations from treatment and control will be matched for type (e.g. spawning).

- *Density and biomass:* We will use a BACI protocol to determine whether the SCMR is effective in protecting queen conch populations. In conducting a BACI study, surveys are conducted in an area before and after an anthropogenic impact (Kaly and Jones 1997), which in this case is the enforcement of no-take regulations in the reserve. Control areas are also surveyed before and after the impact. It is predicted that protected populations will increase in density and biomass after enforcement and that we would see no difference between control before, control after and impact before.

  Kaly and Jones (1997) suggest a minimum of three control sites and a minimum of two surveys before and two surveys after impact to account for natural temporal variation in population characteristics. Rarely is more than one site impacted, thus, the SCMR offers a unique opportunity in that there will be three impacted sites – the two Conservation Zones and the Preservation Zone. This will provide the opportunity to determine whether the level of protection will have a significant effect. Kaly and Jones (1997) also suggest that surveys should be conducted at irregular intervals. However, conch density within a site changes seasonally (e.g. spawning season vs. winter) and within seasons. Therefore, aggregations (winter, spawning, adult-feeding, nursery) will be surveyed during the same time interval each year. This will also allow us to construct a statistical time series, as recommended by Acosta (2002).

- *Population age structure:* The mean proportion of individuals in each age category will be used to determine if population age structure is affected by enforcement.

Method 5: Post-settlement Migration (Spillover Effect) and Larval Dispersal (Dispersal Effect)

- *Spillover effect:* We will determine post-settlement migration by tagging all individuals (from all zones) around the spire with a FT-4 Bar-Lock Tag (Floy Tag and Mfg., Inc.). We tagged 975 conch (deep and shallow-water) during 2006. The date, location and habitat for each individual and for each re-sighting will be recorded. Sightings will be mapped to determine the migration pattern of conch.
- *Dispersal effect:* We will sample larvae following the procedure of Stoner *et al.* (1996). Conical plankton nets (0.5 m in diameter, 2.5 m in length, and 202 mm mesh) will be towed at ~1 m sec^{-1} for 15 minutes during the day (queen conch veligers are photopositive [Barile *et al.* 1994]). Tow volume will be determined by suspending a General Oceanics flow meter from the mouth of the net. Sampling will be conducted over nursery habitats and 25 randomly selected shallow water non-nursery sites. Sites will be selected by placing a 100 x 100 m grid over a topographic map of SCMR and randomly choosing grids that do not contain nursery sites. Similarly, we will randomly sample from areas in the reef cuts and over deep-water (i.e., outside the barrier reef) spawning aggregations and 25 randomly selected sites over deep-water that are not over spawning aggregations.

  Plankton samples will be rinsed and sorted using a dissecting microscope. Queen conch veligers will be measured (shell length) and assigned to one of the three size classes: early-stage (<500 µm SL), mid-stage (500-900 µm), and late-stage (>900 µm) (Stoner *et al.* 1997). Early stage veligers are about 1-5 days old, while late stage veligers are near-competent or competent (Davis 1993, Stoner *et al.* 1997).

TEAM ITINERARY

Day 1: Rendezvous Day. You will be met by a staff member and transported by truck or minivan to your accommodations. That evening, there will be an introduction to staff and an overview Earthwatch Belize and the project. You will then have time to unpack and settle in your room, which will be shared with another team member.

Day 2: Early morning travel to the Sapodilla Cayes (approximately 2 hours by boat). Settle into cabañas or dorm style rooms at the Sapodilla Cayes Living Reef Center that sleep 2-4 people. Rooms will be shared with 2-4 team members. Project overview and field training.

Day 3-8: Variable schedule including fieldwork and lab work and some down time.

Day 9: Return to Punta Gorda

Day 10: Depart from Punta Gorda airstrip to final destination at 7:00 am local time (this flight arrives Goldson International Airport, Belize City at 8:10 am).

DAILY SCHEDULE AND TASKS

The following is an example of a research day for volunteers participating in this project:

6:30-7:30 am	Wake up, breakfast
7:30-8:00 am	Transportation to field site
8:00-12:00 am	Surveys, fieldwork
12:00 am-1:30 pm	Lunch, rest and return to fieldwork
1:30-6:00 pm	Surveys, fieldwork, lab work
6:00-8:00 pm	Return from field, leisure time, dinner

8:00-9:00 pm	Informal talks, reports of field observations, data entry, leisure time
9:00 pm	Suggested bed time

VOLUNTEER TRAINING AND ASSIGNMENTS

Training

Earthwatch expeditions provide both a scientific research experience and an educational experience. Educating the volunteers about coral reef ecosystems, queen conch, marine conservation issues and Belize is as important as making sure that we conduct a rigorous scientific study. Thus, throughout the study we will have lectures, discussions and nature walks.

The team will be on shore for the first day of the expedition. Over dinner and coffee, we will get to know each other and will also go over the general daily structure of the expedition. Day 2 of the expedition will consist of a morning boat ride to the Living Reef Center. Once at the center we will have an orientation to the site and a talk about safety. After settling in and eating lunch, we will discuss the project background and experimental and data recording techniques. We will then practice the field techniques on land and in the shallow water off the boat dock until all volunteers are comfortable with the techniques. That evening we will discuss the day's activities and will clarify any confusion about the techniques. The rest of the expedition will be devoted to data collection. Each night after dinner, we will conduct a debriefing about the day, record data, process samples and discuss the next day's schedule.

During the expedition the project staff will lead lectures/discussions on marine conservation, focusing on marine reserves, tropical marine conservation and the need to build capacity in local stakeholders. When possible, colleagues from the University of Belize, TASTE, TIDE and the Fisheries Department will be invited to discuss local culture and conservation-related issues. We will also take the volunteers on island walks and lead snorkeling trips to the adjacent barrier reef. In addition to these scheduled discussions, we will encourage discussions during breaks, meals and all other periods of "down time." We want the volunteers to be curious and to ask questions.

Assignments

Volunteers are needed because of the labor-intensive nature of this project and will assist in all aspects of the study. In the field, you will assist in queen conch surveys, veliger surveys, mapping of conch aggregations, habitat assessment and tagging and recapture of conch. In the lab, you will be responsible for veliger identification, data recording and reduction. Volunteers will also assist in basic housekeeping chores such as meal preparation and cleanup. And you will have the opportunity to work with local stakeholders in capacity building and educational activities.

RECOMMENDED READING

Books

- Dee Carstarphen. 2000. The Conch Book: All You Ever Wanted to Know About the Queen Conch, from Gestation to Gastronomy.2nd edition. Pen & Ink Press. ISBN 0960754458 (~US$12)
- Ian Peedle. 1999. *Belize in Focus: A Guide to the People, Politics, and Culture*. Published by Interlink Publishing Group. ISBN 1-5665-6284-8 (~US$11)
- Katherine S. Orr and Carl J. Berg Jr. 1987. Queen Conch. Windward Pub Co. ISBN 0893170380 (~US$4)

Field Guides

- **Highly recommended:** Chicki Mallan and Joshua Berman. *Moon Handbooks: Belize 6th Edition* (includes new manatee and mangrove articles by PI Caryn Self-Sullivan and is available online at http://www.amazon.com/exec/obidos/ASIN/1566915759/sirenian)
- Les Beletsky. 1999. *Belize and Northern Guatemala. The Ecotravellers' Wildlife Guide*. ISBN 0-1208-4811-2 (~US$23)
- Eric Hoffman. 1994. *Adventuring in Belize: The Sierra Club Travel Guide to the Islands, Waters, and Inland Parks of Central America's Tropical Paradise*. Published by Sierra Club Books. ISBN 0-8715-6592-7 (~US$13)

PROJECT STAFF

Principal Investigator

Dr. John A. Cigliano, 43, is an Associate Professor of Biology at Cedar Crest College. His research specialties include marine conservation ecology, design of marine reserves, queen conch ecology, octopus behavioral ecology and natural history. His field responsibilities include oversight of the entire project, leading field teams, education of field teams on queen conch ecology and marine reserve theory, research design and data analysis. Dr. Cigliano has conducted research on queen conch conservation ecology in the Bahamas (Andros) and in the Turks and Caicos Islands (South Caicos).

RESULTS AND OPPORTUNITIES

The broad significance of this project is that it will test the fundamental and critical assumptions of MRs. Thus, marine reserve managers, conservation biologists and marine biologists will benefit from this study.

On a more local level, this project will provide valuable information that is needed for the local conservation and management of queen conch and lobster. Queen conch is a major export of Belize. This study will contribute significantly to the management, and thus the protection, of these important species. All data will be shared with TASTE and the Fisheries Department, as well as other stakeholders. It is anticipated that this project will lead to several publications in peer-reviewed journals. It is also likely that this project, along with the other *Earthwatch Belize* projects, will be attractive to popular publications, including *Earthwatch Magazine*.

Findings from this study and other *Earthwatch Belize* projects will be disseminated to local NGOs and to the Fisheries Department. The expectation is that these findings will be incorporated into policy related to the management of t SCMR. It is also hoped that these findings will be disseminated to managers of other marine reserves in Belize and, thus, might influence public policy related to these reserves. Queen conch and lobster are also important exports in other Caribbean countries. Our findings will be applicable to the management policies in these other countries as well.

LITERATURE CITED

Acosta, C. A. 2002. Field Protocol for Monitoring Coral Reef Fisheries Resources in Belize. World Conservation Society.

Appeldoorn, R.S. 1988. Age determination, growth, mortality and age of first reproduction in adult queen conch, *Strombus gigas* L., off Puerto Rico. Fish. Res. 6: 363-378.

Appeldoorn, R.S. 1997. Status of queen conch fishery in the Caribbean Sea. Pp. 40-59 *in* J.M. Posada and G. García-Moliner, eds. Proceedings of the International Queen Conch Conference. Caribbean Fisheries Management Council, San Juan, Puerto Rico.

Barile, P.J., A.W. Stoner and C.M.Young. 1994. Phototaxis and vertical migration of the queen conch (*Strombus gigas* Linne) veliger larvae. J. Exp. Mar. Biol. Ecol. 183: 147-162.

Campton, D.E., C.J. Berg, Jr., L.M. Robinson and R.A. Glazer. 1992. Genetic patchiness among populations of queen conch (*Strombus gigas*) in the Florida Keys and Bimini. U.S. Fish. Bull. 90:250-259.

Cigliano, J.A. and B.S. Bugler. Status of Queen Conch (*Strombus gigas*) populations of Andros Island, The Bahamas, and an assessment of the potential effectiveness of recently established marine replenishment zones. In preparation.

Cowen, R.K., C.B. Paris, D.B. Olson, and J.L. Fortuna. 2003. The role of long distance dispersal versus local retention in replenishing marine populations. Gulf Carib. Res. 14: 129-137.

Crowder, L.B. and E.A. Norse. 2005. Place-based management of marine ecosystems. Pp. 261-263 *in* E.A. Norse and L.B. Crowder, eds. Marine Conservation Biology. Island Press, Washington, D.C.

Davis, M. 1993. A comparison of larval development, growth, and shell morphology in three Caribbean *Strombus* species. The Veliger 36: 236-244.

Davis, M., Mitchell, B.A., Brown, J.L. 1984. Breeding behavior of the queen conch *Strombus gigas* Linne held in a natural enclosed habitat. J. Shell. Res. 4: 17-21.

Gascoigne, J. and R. N. Lipcius. 2004. Conserving populations at low abundance: delayed functional maturity and Allee effects in reproductive behaviour of the queen conch *Strombus gigas.* Mar Ecol Prog Ser 284: 185–194.

Halpern, B.S. and R.R Warner. 2002. Marine reserves have rapid and lasting effects. Ecol. Letters 5: 361-366.

Hesse, K.O. 1979. Movement and migration of the queen conch, *Strombus gigas*, in the Turks and Caicos Islands. Bull. Mar. Sci. 29: 303-311.

Jennings, S., Marshall, S. S., and Polunin, N. V. C. 1996. Seychelles' marine protected areas: comparative structure and status of reef fish communities. Biological Conservation 75:201-209.

Kaly, U.L. and G.P. Jones. 1997. Minimum sampling design for assessing the magnitude and scale of ecological impacts on coral reefs. Proc. 8th Int Coral Reef Sym 2: 1479-1484.

Leis, J.M., T. Trnski, P.J. Doherty, and V. Dufour. 1998. Replenishment of fish populations in the enclosed lagoon of Taiaro Atoll: (Tuamotu Archipelago, French Polynesia) evidence from eggs and larvae. Coral Reefs 17: 1-8.

Mitton, J.B., C.J. Berg and K.S. Orr. 1989. Population structure, larval dispersal, and gene flow in the queen conch, *Strombus gigas*, of the Caribbean. Biol. Bull. 177: 356-362.

National Research Council. 2001. Marine Protected Areas: Tools for Sustaining Ocean Ecosystems. National Academies Press, Washington, D.C.

Noyes, K.H. 1996. Ontogeny of settlement behavior in queen conch (*Strombus gigas*) larvae. M.S. Thesis. Florida Institute of technology, Melbourne.

Palumbi, S.R. 2001. The Ecology of Marine Protected Areas. Pp. 509-530 *in* M. Bertness, S.D. Gaines and M.E. Hay, eds. Marine Ecology: the New Synthesis. Sinauer Assoc., Sunderland, MA.

Pomeroy, R.S., Parks, J.E. and Watson, L.M. 2004. *How is your MPA doing? A Guidebook of Natural and Social Indicators for Evaluating Marine Protected Area Management Effectiveness.* IUCN, Gland, Switzerland and Cambridge, UK. Xvi+216 pp.

Posada, J. and R.S. Appeldoorn. 1994. Preliminary observations on the distribution of Strombus larvae in the Eastern Caribbean. Pp. 191-199 *in* R.S. Appeldoorn and Q. Rodríguez, eds. Queen conch biology, fisheries and mariculture. Fundación Científica Los Roques, Caracas, Venezuela.

Randall, J.E. 1964. Contributions to the biology of the queen conch *Strombus gigas*. Bull. Mar. Sci. Gulf and Carib. 14: 246-295.

Roberts, C.M. 1995. Rapid build-up of fish biomass in a Caribbean marine reserve. Conservation Biology 9:815-826.

Roberts, C.M., S. Andelman, G. Branch, R.H. Bustamante, J.C. Castilla, J. Dugan, B.S. Halpern, K.D. Lafferty, H. Leslie, J. Lubchenko, D. McArdle, H.P. Possingham, M. Ruckelshaus and R.R. Warner. 2003. The science of marine reserves: ecological criteria for evaluating candidate sites for marine reserves. Ecol. Appl. 13: 199-214.

Robertson, R. 1959. Observations on the spawn and veligers of conchs (*Strombus*) in the Bahamas. Proceed. Malacol. Soc. London 33: 164-170.

Sobel, J. and C. Dahlgren. 2004. Marine Reserves: A guide to science, design, and use. Island Pres, Washington, D.C. xviii+383 pp.

Stoner, A.W. 1989. Winter mass migration of juvenile queen conch *Strombus gigas* and their influence on the benthic environment. Mar. Ecol. Prog. Ser. 56: 99-104.

Stoner, A.W. 1997. The status of queen conch research in the Caribbean. Pp. 23-39 *in* J.M. Posada and G. García-Moliner, eds. Proceedings of the International Queen Conch Conference. Caribbean Fisheries Management Council, San Juan, Puerto Rico.

Stoner, A.W., R.A. Glazer and P.J. Barile. 1996. Larval supply to queen conch nurseries: relationships with recruitment process and population size in Florida and the Bahamas. J. Shellfish Res. 15: 407-420.

Stoner, A.W., R.N. Lipcius, L.S. Marshall, Jr. and A.T. Bardales. 1988. Synchronous emergence and mass migration in juvenile queen conch. Mar. Ecol. Prog. Ser. 49: 51-55.

Stoner, A.W. and M. Ray. 1993. Aggregation dynamics in juvenile queen conch (Strombus gigas): population structure, mortality, growth, and migration. Mar. Biol. 116: 571-582.

Stoner, A.W. and M. Ray-Culp. 2000. Evidence for Allee effects in an over-harvested marine gastropod: density-dependant mating and egg production. Mar. Ecol. Prog. Ser. 202: 297-302.

Stoner, A.W. and V.J. Sandt. 1992. Population structure, seasonal movements and feeding of queen conch Strombus gigas, in deep-water habitats of the Bahamas. Bull. Mar. Sci. 51:287-300.

Stoner, A.W., V.J. Sandt and I.F. Boidron-Metairon. 1992. Seasonality in reproductive activity and larval abundance of queen conch *Strombus gigas*. Fish. Bull. 90: 161-170.

Stoner, A.W., N. Mehta and T.N. Lee. 1997. Recruitment of *Strombus* veligers to the Florida Keys Reef Tract: relation to hydrographic events. J. Shellfish Res. 16: 1-16.

Swearer, S.E., J.S. Shima, M.E. Hellberg, S.R. Thorrold, G.P. Jones, D.R. Robertson, S.G. Morgan, K.A. Selkoe, G.M. Ruiz and R.R. Warner. 2002. Evidence of self-recruitment in demersal marine populations. Bull. Mar. Sci. 70: S251-271.

Tewfik, A. and C. Béné. 2000. Densities and age structure of fished versus protected populations of queen conch (*Strombus gigas* L.) in the Turks & Caicos Islands. Proc. Gulf Carib. Fish. Inst. 51: 60-79.

Weil, E. and R. Laughlin. 1984. Biology, population dynamics, and reproduction of the queen conch, *Strombus gigas* Linne, in the Archipelago de los Roques National Park. J. Shellfish Res. 4: 45-62.

EXPEDITION PACKING CHECKLIST

Essential Items

- ☐ **This Expedition Briefing**
- ☐ **Photocopies of your passport, flight itinerary and credit cards in case the originals are lost or stolen; the copies should be packed separately from the original documents**
- ☐ **Passport and/or visa (if necessary)**
- ☐ **Certification of inoculation (if necessary)**

Required Items

Clothing/Footwear for Fieldwork

- ☐ Reef shoes, booties or sandals (corals can be sharp and cut your feet)
- ☐ Bathing suits (2)
- ☐ Casual shoes/flip flops
- ☐ Easy drying/lightweight shorts (2-3)
- ☐ Easy drying/lightweight shirts or tops (2-4)
- ☐ Long-sleeved shirt(s) to prevent sunburn (1-2)
- ☐ Windbreaker or rain jacket (1)
- ☐ Loose fitting, quick-drying, comfortable pants/trousers, such as canvas field pants (1-2)
- ☐ Hat with wide brim (a chin strap or toggle is recommended on the boat)

Clothing/Footwear for Leisure

- ☐ One set of clothing to keep clean for end of expedition
- ☐ Warm fleece sweater for overcast days on the water

Field Supplies

- ☐ Small daypack/rucksack
- ☐ Drybag to protect all luggage from water on trip to Cayes
- ☐ Plastic sealable bags such as Ziplock brand (important for protecting equipment such as camera and other personal items from dust, humidity and water)
- ☐ Insect repellent spray with DEET for mosquitoes, as well as an oil or oil-based repellant (e.g. olive oil, AVON Skin-so-Soft Original Bath Oil, citronella oil repellent, Bit Blocker) for sand flies
- ☐ Sunscreen (waterproof with SPF 30 or higher)
- ☐ Water bottles (minimum of two 1-liter bottles)
- ☐ Polarized sunglasses with a strap to hold them around your neck
- ☐ Small notebook and pencil(s) to bring in the field

- ☐ Alarm clock/watch
- ☐ Mask, snorkel and fins (optional for Team 4 volunteers)
- ☐ Thin (3 mm) wetsuit if you are prone to get cold in the water (optional for Team 4 volunteers)
- ☐ Extra mask and fin straps (optional for Team 4 volunteers)

Bedding and Bathing

- ☐ Beach Towel

Personal Supplies

- ☐ Personal toiletries (we recommend bringing biodegradable soaps and shampoos)
- ☐ Antibacterial wipes or lotion (good for "washing" hands while in the field)
- ☐ Personal first-aid kit (e.g. anti-diarrhea pills, antibiotics, antiseptic, itch-relief, pain reliever, oral anti-histamine, bandages, blister covers, etc.) and personal medications

Miscellaneous

- ☐ Spending money (approximately US$300 cash recommended)
- ☐ Camera, film, extra camera battery
- ☐ Pack-towel or sarong

SCUBA Gear (For Certified Divers Only)

- ☐ Certification card and dive log (showing at least last eight dives after certification)
- ☐ Mask, snorkel and fins
- ☐ Buoyancy compensator (BC)
- ☐ Regulator with octopus
- ☐ Webbing style weight belt and buckle (weights provided at site)
- ☐ Emergency whistle
- ☐ Exposure protection (a 1-3 mm wetsuit should be fine, depending upon your personal comfort in the water conditions described in Section 8 *'Project Conditions'*)
- ☐ Depth and pressure gauge (s) (minimum required, though a dive computer is optional)
- ☐ Spare batteries for dive computer/other equipment
- ☐ Repair kit with extra parts for all SCUBA gear (O rings, fin and mask straps, BC patch kit)
- ☐ Inflatable "safety sausage" that can be clipped to your BC
- ☐ Dive knife

Optional Items

- ☐ Flashlight/torch or headlamp with extra batteries and extra bulb
- ☐ Earplugs
- ☐ Binoculars
- ☐ Camera
- ☐ Video camera