Presentations

Connectivity Science & Coastal Reef Management in the Caribbean
Best Western Belize Biltmore Plaza, Belize City
9-11th November 2009

Monday, 9th November

Session 1: Links between Connectivity Science and Reef Management

Building scientific capacity for reef management – Connectivity in the CRTR project
Peter F. Sale, UNU-INWEH, Chair, Connectivity Working Group, Hamilton ON, Canada
Presented by: Anthony J. Hooten, AJH Environmental Services, Bethesda, MD, USA

Connectivity and resilience of coral populations: why we need to protect pristine reefs no matter in whose country they reside
Alina Szmant, University of North Carolina, Wilmington NC, USA

Spiny lobster connectivity in the Caribbean – management outside the MPA box
Mark J. Butler IV, Old Dominion University, Norfolk VA, USA

Research in Belize: assisting in decision making
James Azueta, Belize Department of Fisheries, Belize City, Belize

Seaweed as indicators and drivers of coral reef health, new thoughts on confronting the coral reef crisis
Robert S. Steneck, University of Maine, Walpole ME, USA
Building scientific capacity for reef management

Connectivity in the CRTR project

Peter F Sale
UNU-INWEH

The CRTR Project

- A global project
- 6 working groups
- 4 centers of excellence
- New science on critical questions
- Science to build better management
- Connectivity Working Group
- A Mesoamerican focus
- 4-5 September 2002, RSMAS

The Connectivity Plan

- Develop methods to directly measure connectivity in seafish, corals, and lobster
- Develop new modeling methods for characterizing connectivity patterns
- Use recruitment patterns to test models
- Work with the management community throughout

Akumal, December 2004
What is connectivity? Why is it important for management?

- “the flux of stuff”
- Connections between populations or places because of transfer of items between them
- Transfer of nutrients or pollutants between sites
- Transfer of eggs, larvae or older organisms between populations
- Must be maintained

What science did we attempt?

- Nassau Grouper ‘flux’ experiment
- Connectivity in Bicolor damselfish
- Coral post-settlement survivorship
- Genetic studies of coral connectivity
- Coral ‘flux’ experiment
- Lobster larval biology & recruitment
- Modeling of lobster connectivity

And what worked?

- Nassau Grouper ‘flux’ experiment
- Connectivity in Bicolor damselfish

And what worked?

- Very high cost
- Recruits few and cryptic
- Sometimes the science cannot be done

- White rats can be useful
And what worked?

- Nassau Grouper ‘flux’ experiment
- Connectivity in Bicolor damselfish
- Coral post-settlement bottlenecks
- Genetic studies of coral connectivity
- Coral ‘flux’ experiment

Putting Science into Management

- Seven workshops with cadre of managers from region
  - Akumal, Dec 2004
  - Calabash Caye, June 2005
  - Akumal, April 2006
  - Miami, September 2006
  - Roatan, April 2007
  - Fort Lauderdale, June 2008
  - Belize City, November 2009
- Managers assisted in two projects
- Pamphlets and handbooks
- Personal interactions

Do our Managers now Understand Connectivity?

Do our Scientists now Understand Managers’ Needs?

Do we have a Framework for Future Cooperation to Build Sustainability?
This Workshop

- Our final chance to interact in a workshop environment during Phase One of CRTR.
- Update on what has been achieved
- Refresher on how connectivity science contributes to good management
- Some reflections on management issues beyond connectivity
Connectivity and resilience of coral populations: Why we need to protect pristine reefs no matter in whose country they reside...

Investigators:
Alina Szmant, UNCW
Barry Ruddick, Chris Taggart, Dalhousie U.
Brian Dixon, U of Waterloo
Ainhoa Zubillaga, PhD student, U Simon Bolivar

TAKE HOME MESSAGE

- Managers need to know where coral larvae could come from to re-seed their degraded reefs if they want to be pro-active in restoring their coral reefs
- Coral reefs that still have healthy coral populations should be protected because they are the hope for coral population recovery; international cooperation will be needed
- It has been difficult to get information on coral transport patterns and connectivity outside of using extrapolations from population genetics and hydrographic models
- We have developed new approaches to directly measure or estimate larval transport
- There is a need for effective collaboration among managers and scientists to generate connectivity information

Why are you managers in this room concerned about your coral reef systems?

Because over the past few decades, many Caribbean coral reefs have changed from looking like this...

In other words, because the corals have died and are not replacing themselves
What we all would like to see happen in the near future is coral population recovery. Coral dominated Reef Substrate: Coral dominated Resilience is based on the ability of coral populations to resist disturbances without change in their fundamental community structure and function.

Coral adult abundance > Fecundity > Fertilization success > Loss of corals due to bleaching, disease and storm mortalities > Phase shift: Coral to Algal dominated reef: Algae colonize dead coral areas, decreased grazing, eutrophization, etc.

Coral Reef Resilience = High Coral Recruitment

Recruitment of Reef Corals:
- Adults are sessile
- Only larvae disperse
- Therefore, the supply of coral larvae will be the first determinant of recruitment potential.

If Coral Reef Resilience requires High Coral Recruitment
THEN
Coral Reef Resilience depends on there being healthy coral populations to serve as larval sources.

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Coral Reef Resilience = High Coral Recruitment

Healthy spawning corals

Spawning output

Hydrography and Circulation patterns

Environmental challenges in plankton
Elevated SW temperatures
Salinity (rain, river outflow)
Predation

Suitable reef condition for settlement
Clean, algae-free substrate
Grazers
Low sedimentation

Spatial Context (Abundance)

Post-sett. Survival – Larval Condition

Available Settlement Habitat

Larval Dispersal + Mediated Behavior

Larval Dispersal

Settlement

Larval Condition

Coral adult abundance

Fecundity

Fertilization success

Loss of corals due to bleaching, disease and storm mortalities

Phase shift: Coral to Algal dominated reef: Algae colonize dead coral areas, decreased grazing, eutrophization, etc.

Coral Reef Resilience = High Coral Recruitment

Time and distance
○ The longer the time and further the distance, chances of larval transport and survival decrease

Cowen and Sponaugle in review
If your reefs are depleted of reproductive adults, you want healthy, reproductive corals upstream of your reefs, and it serves your long-term interests if they are also protected.

This brings us to 'Connectivity' questions:

- How far apart can reefs be and still be connected?
- How far can the larvae of any given reef coral travel and still settle?
- How do we answer these questions?

**Difficulties in Measuring Coral Connectivity**

- Coral larvae are < 1 mm in length
- Difficult to collect from plankton without damaging.
- Difficult to ID (sea anemones, gorgonians etc)
- This limits our ability to spatially sample them as is done for fish larvae and those of conch and lobster
- New approaches and methods were needed to tackle this problem
- That was the motivation for our component of CRTW Connectivity Working Group

**Coral Larval Dispersal:**

*We need to know biological characteristics:*

- Development pattern of each species (passive vs active behaviors)
- Time to competency (days...weeks)
- Duration of competency (days...weeks)

*We also need to know physical determinants:*

- Hydrographic patterns of source and receiving areas
- Weather during larval period
- Distribution and distances among source and receiving sites
- How cohorts of spawn particles disperse over time and space
OBJECTIVES FOR CONNECTIVITY
PROJECT C:

1. Study the developmental time courses of major Caribbean hermatypic coral species, and estimate mortality and the duration of their competency periods (Szmant)
2. Develop new methods to detect coral larvae as they disperse (Dixon)
3. Develop new methods to track dispersal of cohorts of larvae (Ruddick and Taggart)

1. Larval behaviors

Question 1: How long are coral larvae simply buoyant, passive particles?
- Two to three days (60 - 70 hrs) after fertilization before they lose their buoyancy and begin to swim; varies by species

Question 2: How long does it take before larvae begin to swim down and explore substrate?
- Minimum of 3 days for Montastraea faveolata and 4 to 6 days for Acropora palmata

Question 3: How long before larvae become competent?
- Only 3 days for Montastraea cavernosa, ca. 4 days for M. faveolata and Diploria strigosa, and as long as 6-8 days for Acropora palmata

Question 4: What is an estimate of larval mortality from spawn to competency?
- In the lab we can achieve 10 to 30 %. In nature????  likely much lower

Question 5: How long can larvae remain competent in the plankton?
- In lab, 3 weeks for A. palmata and 4 for Montastraea spp

Coral Connectivity: A function of larval development time course and behavior patterns

- These data are available to be used to construct biological-physical coupled hydrographic models to predict dispersal & connectivity in areas of interest where hydrography and coral population distributions are known
- More coral species need to be studied because they are not all the same
What can we predict from these results:

1) At slow transport rates of 10 cm/s, coral larvae that do not reach full competency for 4 days (e.g. *Montastraea faveolata*) could be transported 35 km from their natal reef

2) A longer competency requirement of 8 days (e.g. *Acropora palmata*) at similar flow would predict transport of 70 km from natal reef

3) At higher current regimes, transport distances could be even further
2006 Florida Keys
- Very few *A. palmata* larvae in Key Largo area
- Larger populations in lower FL Keys
- Data suggests transport of larvae from lower to upper FL Keys

### Where are we now:
- These assays are currently being improved to make them more quantitative
- They are ready to be used to assess richness of larval pool in any given area during the time frame surrounding spawning
- Results could provide both assessment of:
  - larval supply originating from healthy reefs
  - supply of larvae reaching any given target reef
- Methods are easy to learn and relatively inexpensive. We could organize a network of teams to make these surveys annually.

3. New methods to track dispersal of cohorts of larvae: *Exciting new approach to MEASURE actual connectivity potential*

**Magnetic beads and magnetic collectors as a new approach to trace larval dispersal**

- Small magnetic beads constructed to be of similar size and density of biological targets (= mini drift beads)
- Beads deployed into the spawn mass (= point source)
- Magnetic collectors deployed at various distances from point source (km to 100s km)
- Collectors left to passively accumulate magnetic beads
- Collectors sampled at various times after spawning & magnetic particles recovered & counted
SUMMARY:

1) We have working antibody assays for two major reef building groups, the Montastraea spp complex and Acropora palmata & cervicornis,

2) These assays can be used to map larval presence, abundance and recruitment potential for reef areas of interest (= LARVAL SUPPLY)

3) We have a magnetic bead tracer method that can be used to follow water masses with larvae from source to target restoration reefs

4) We know much more about the biology of coral larvae and can now provide estimates of the biological limitations and potential for dispersal and connectivity
What Next:
1) Funding to continue work, and apply new methods
2) Studies need to be of a large spatial scale to encompass potential larval sources within and coming into the MBRS
3) Problems with international jurisdictions, different management systems, laws, and levels of interest, need to be over-come
4) Eliminate the politics of Permits for collecting and research that benefits the region
5) Collaboration, involvement and co-funding of overall program by all concerned
6) Common recognition that all countries and management units will benefit from understanding the role of their reef systems in regional connectivity

Ideas for future work:
1) Network of research groups that search for coral ‘hot spots’ and then endeavor to protect them
2) Teams to sample for coral larval abundance during the annual spawning periods: document larval supply patterns
3) Teams to participate in multiple-synchronous bead releases to trace potential larval dispersal patterns
4) Modeling of larval dispersal from hot spots using local hydrography and reef distribution

Recent estimates of coral connectivity based on genetics is up to 10s to 100s of KM
We need to know where all the ‘hot spots’ of high coral cover are and where the spawn from these sites goes (also role of deep reefs)
Spiny Lobster Connectivity in the Caribbean: Management Outside the MPA Box

Mark Butler¹, Claire Paris², & Robert Cowen²

¹Old Dominion University, Norfolk, Virginia USA
²RSMAS, University of Miami, Miami, Florida USA

…while the lobster fisheries outside the “MPA Box” are collapsing.

Problem:
Declining spawning stock, particularly too few big lobster, because:
(1) Fisheries are generally over-exploited
(1) Well-enforced MPAs are too few & likely to remain so

In well-enforced MPAs, lobsters become numerous and large because of high site fidelity by the largest individuals and this is often judged a success story...

Where long-term data sets exist, the evidence suggests that the down-turn in Caribbean lobster stocks is due to a loss of recruits.

Cuba (south)

Florida

14
Immediate Action for Lobster Management:
(1) Studies of larval connectivity to guide management on spatial scales relevant to lobster (i.e., beyond political borders)
(2) An ecologically sound, pragmatic management strategy for rebuilding stocks of the large, reproductively most important lobsters

Studies of connectivity in spiny lobsters hampered by:
- poor population structure resolution using genetic techniques
- no known natural or artificial tags for larvae
- long pelagic larval duration & unknown larval biology

Palinurus elephas (Mediterranean)
Panulirus homarus (Indian Ocean)
Panulirus ornatus (Great Barrier Reef)
Panulirus argus (Caribbean)
Panulirus cygnus (Western Australia)
Jasus edwardsii (Australia/New Zealand)

Pearl Larval Duration (months)

Coral Reef Targeted Research Program
Connectivity Working Group: Lobster Project

Objective:
Examine connectivity of lobster populations in the Caribbean using an empirically parameterized and validated bio-physical oceanographic model.

Approach:
(1) Modify existing biophysical model for fish; parameterized with:
   - spatio-temporal patterns of adult lobster spawning in Caribbean
   - larval & postlarval lobster behavior
(2) Validate model predictions by comparing to data on lobster postlarval supply from recruitment monitoring stations distributed throughout the Caribbean

Lobster Connectivity Modeling Using BOLTS
(Biophysical Lagrangian Tracking System)
Biological Module Input Coupled to GIS

- Spawning abundance & seasonality

Biological Module Input Coupled to HYCOM

Larval Attributes:
- stage-specific PLD
- stage-specific diel & vertical migration
- larval mortality

Model Validation: Predicted vs. Observed Postlarval Supply

★ sampling locations established

Model Validation: Predicted vs. Observed Postlarval Supply

★ useable sampling locations
Results of Collaboration with Mesoamerican Partners

- Training and data on local recruitment patterns
- Modeling predictions of larval connectivity (i.e., “larval ties” among stocks in the Caribbean)
- Graduate education for students

Lobster Recruitment Monitoring Results

- Insufficient data at many sites
- Peaks in fall in Mesoamerica; spring in Florida, Puerto Rico, and Venezuela.
- Low variability: Honduras, south Mexico, Venezuela
- High variability: Florida, San Andres Islands, Puerto Rico, north Mexico

Biological Data for Modeling: Laboratory Studies

- First successful rearing of *P. argus* to settlement (mean PLD = 174d; range: 140 – 198d)
- Provided data on stage-specific growth and duration for modeling & comparison with field data
Biological Data for Modeling: Planktonic Distribution

- Size-specific larval vertical distribution in plankton samples from monthly cruises from Miami (USA) to Bimini (Bahamas)

Biological Data for Modeling: Laboratory Studies

Age-specific larval vertical movement

- Tested swimming response of larvae of different ages to light intensity and spectra equal to day & night at 0, 25, 50 & 100m depths

Initial Model Simulations

- Release of larvae at 13 locations in June from Caribbean regions representing > 95% of spawning stock
- PLD: 157 – 179d; includes constant larval mortality
- Postlarval orientation to coastal nurseries from 20 km
- Simulations with and without larval behavior (DVM & OVM)
Example of Modeled Spiny Lobster Larval Trajectories

Simulation Results: Dispersal and Larval Behavior

Even for spiny lobster larvae with 6 month long PLDs,

**LARVAL BEHAVIOR:**
- Increases recruitment by ~2.5x compared to passive transport
- Reduces mean dispersal to <200 km, about 20% of dispersal distance predicted for passively dispersing larvae (mean ~ 800 km)
- Increases asymmetry of dispersal kernel by enhancing “local” retention

The Caribbean is a Kaleidoscope of Connectivity

... even for lobster & even in Mesoamerica!

Preliminary Connectivity Matrix for *P. argus* in Caribbean

High

Low

Self-recruitment

Florida

Gulf of Honduras

Gulf of Panama

SW Cuba

Bahamas
**CRTR Lobster Connectivity Accomplishments:**
- First successful rearing of *P. argus* through all larval stages
- Described PLD & behavior of lobster larvae
- Discovered processes for coastal orientation by postlarvae
- Simulations indicate that larval behavior (even for *P. argus*) results in higher recruitment success & often more localized recruitment (~ 200km), but connectivity varies regionally

**Next Steps:**
- Detailed simulations incorporating regional variation in spawning magnitude and timing
- Comparison of simulations with empirical estimates of postlarval supply for model “validation”
- New project to examine connectivity of viral disease in Caribbean spiny lobster.

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**Discovery of a Lethal Viral Disease in Spiny Lobster**
- We first reported it in 1999: PaV1 (*Panulirus argus* virus #1)
- First viral disease described in any species of lobster
- Lethal in > 90% juvenile infections; much less so in adults

**Symptoms:**
- Discoloration of hemolymph & lack of clotting
- Lethargy; no molting or grooming
- Isolation

**Confirmation of Infection:**
- Histology
- Viral DNA PCR assay

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**PaV1 Disease Prevalence**

**Demographic:**
- Prevalence declines with size (age) – “a disease of the young”
- However, adults are carriers (10% in FL) & display no symptoms

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**Pathogen Connectivity: The Diadema Die-off**

- General pattern of *Diadema* mortality 1983 - 1984

- 93% to 99% *Diadema* mortality in Caribbean in 1 yr

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**PaV1 Disease Prevalence**

**Demographic:**
- Prevalence declines with size (age) – “a disease of the young”
- However, adults are carriers (10% in FL) & display no symptoms
**Viral Transmission**

**Laboratory Trials (80d duration):**
- **Inoculation:** 95% transmission
- **Ingestion:** 42% transmission
- **Contact:** 11 – 63% transmission; declines with size
- **Water:** 10 – 50% transmission over 1 – 3m; also declines with size

**Alternative Hosts?**
No transmission to sympatric decapods via inoculation

![Spotted Spiny Lobster](Image)
![Spider Crab](Image)
![Stone Crab](Image)

**Evidence for Caribbean Connectivity in PaV1**

**Biogeographic Occurrence & Heterogeneity**
- Confirmed infections in: Florida, Belize, Mexico, Cuba, & USVI
- Multiple viral alleles or “strains”
- No evidence for viral hypermutation in lab studies, suggesting viral diversity likely to be biogeographic in origin

**Mode of Dispersal?**
- Virus only infective in water < 3d
- Presence of PaV1 in postlarvae!

**Objectives: Lobster Disease Connectivity Project**

(1) To investigate the dynamics and mechanisms of PaV1 infection of larvae and effect of infection on larval behavior and mortality, which influence dispersal and demographic connectivity.

(2) To examine the importance of large-scale connectivity by PaV1-infected larvae on the maintenance of local disease dynamics and patterns of disease prevalence at local scales.

(3) To explore the ramifications of planktonic pathogens and the hydrodynamic environment on large-scale patterns of disease connectivity in the sea.

**Immediate Action for Lobster Management:**

(1) Studies of larval connectivity to guide management on spatial scales relevant to lobster (i.e., beyond political borders)

(2) An ecologically sound, pragmatic management strategy for rebuilding stocks of the large, reproductively most important lobsters
Effect of Fishing on Adult Size Structure

Caribbean Spiny Lobster (Panulirus argus)

Fished Population

<table>
<thead>
<tr>
<th>Carapace Length (mm)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>70</td>
<td>10</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
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<tr>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>110</td>
<td>50</td>
</tr>
</tbody>
</table>

Unfished Population

<table>
<thead>
<tr>
<th>Carapace Length (mm)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>70</td>
<td>10</td>
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<td>80</td>
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<tr>
<td>110</td>
<td>50</td>
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</tbody>
</table>

Females n= 200

Males n= 300

Female Size & Brood Size … is Only Part of the Story

Well-known, relationship between female size and brood size in many species of spiny lobsters.

Fishing removes larger individuals from the population, so the effect of fishing on fecundity is obvious … but this is just half the problem.

Fishing Effects on Male Size

- Males attain a larger size than females, so male size decreases disproportionately more in fished populations.

% Decline in Size in Fished Sites

<table>
<thead>
<tr>
<th>Species</th>
<th>Male</th>
<th>Female</th>
<th>Marine Reserves</th>
<th>Fished Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. edwardsii New Zealand</td>
<td>46%</td>
<td>33%</td>
<td>46%</td>
<td>33%</td>
</tr>
<tr>
<td>P. argus Florida</td>
<td>52%</td>
<td>62%</td>
<td>62%</td>
<td>54%</td>
</tr>
</tbody>
</table>

Large males:

- Dominate matings in natural populations
- Produce larger spermatophores
- Mate more times/yr & recharge sperm faster

Spermatophore Weight (g)

Spermatophore Weight fuc Size of Male & Female Mates

From MacDiarmid & Sainte-Marie 2006
Male size also effects on fertilization success

- Sperm:egg ratios are low (~ 30:1)
- Large males “ration” sperm transferred to females depending on female mate size
- Small males are unable to fertilize the entire clutch of large females.

- Laboratory experiments show that male size contributes nearly as much to clutch weight as female size.

Panulirus argus clutch size:
- Female size explains 55%
- Male size explains 45%

Maintaining Lobster Size Through Management

Potential approaches:
- Habitat or area protection (MPA)
- Maximum size restrictions on catch
- Both!

No reserves & no max. size

Reserves & no max. size

Marine Reserves

No reserves with max. size limit

Reserves, but no max. size limit

No reserves & no max. size limit
Concluding Remarks

- The most important fishery in the Caribbean is in decline & the best evidence suggests it is due to diminished recruitment.
- Studies of connectivity reveal recruitment connections among nations that are crucial for managing this resource.
- Lobster larval dispersal is less than expected in many areas, but still rarely "local".
- Loss of large individuals in population diminishes female fecundity but also causes sperm-limited fertilization success, changes in lobster movement, & potentially increased disease.
- Building lobster spawning stocks should be the objective, and may be best achieved combining MPAs with maximum size limits.

Preliminary Results: Linking MPAs with Maximum Size Limits

- Stage-based population model; parameterized with fishing effort and lobster population dynamics from Florida.
- Currently using a more sophisticated spatial model to explore this idea in more detail:
  - % area MPA
  - Fishing mortality
  - % Self-recruitment

My sincerest thanks to:

- Dr. Peter Sale for inviting me to join the CRTR Connectivity Working Group.
- The other members of the Connectivity Working Group for their collegiality & sincere efforts to help in Mesoamerica.
- The CRTR & NSF for funding our project.
- The CRTR local partners who stuck with us.
RESEARCH IN BELIZE: assisting in decision making

Connectivity Science and Coastal Reef Management in the Caribbean Workshop
Biltmore Plaza
Belize City, Belize
November 9 – 11, 2009
James Azueta

PRESENTATION OUTLINE

- Aquatic Research Policy
- Research: assisting in decision making
- Aquatic Research Legislation
- How to obtain a Research License
- Research Permit Sample
- Marine Research from a Fisheries Perspective
- Research Statistics
- Research Partners
- Future Research in Belize

MARINE RESEARCH POLICY

- Encourage and support research programs, projects and studies that generate valuable information on our natural marine resources in order to make informed management decisions;
- Marine research should be non-destructive and cause no negative environmental impacts.

Research: assisting in decision making

- Years ago there was no control on research in Belize;
- Blanket licenses were given to institutions;
- There was no reporting to the Fisheries Department by the researchers;
- Institutions now ask the Fisheries Department what are its research priorities;
- Reporting has improved tremendously.
MARINE RESEARCH LEGISLATION

- Researchers need a research permit to operate in Belize;
- Belizean observers shall participate in a research project if deemed necessary by the Fisheries Department;
- Copies of raw data has to be given to the Fisheries Administrator upon request;
- Results and conclusions should be forwarded to the Fisheries Administrator;
- No result shall be published without the consent of the Fisheries Administrator.

MARINE RESEARCH LEGISLATION Cont…

- A research application needs to be filled;
- A research application fee shall be paid;
- No person shall engage in bio-research without a special license;
- The Fisheries Department is custodian for any genetic materials collected;
- Entities engage in bio-prospecting shall train Belizeans;
- 10% of revenue derived from bio-prospecting shall be for the Government of Belize;
- A bio-research needs a transfer agreement.

MARINE RESERVE LEGISLATION Cont…

Visit www.belizelaw.org
Chapter 210 Substantive Laws
Chapter 210s Subsidiary Regulations
Chapter 210-1 High Seas Fishing Regulations

HOW TO OBTAIN A RESEARCH LICENSE

- A research application needs to be filled & submitted;
- The researcher must submit a scientific proposal along with the application;
- Proposal is vetted & approved/not-approved;
- The proponent is notified of proposal status;
- An application fee of $200 Bz is paid = outside of reserve/$500 Bz inside a marine reserve;
- A research license is issued with conditions.
RESEARCH LICENSE

00001-09
MARINE SCIENTIFIC RESEARCH PERMIT
TO WHOM IT MAY CONCERN

Permission is hereby granted to Dr. Do Good to conduct Scientific Marine Research in the waters of Belize.

The objective of the research is to perform genetic assessments of Montastrea colonies at SCMR.

THIS PERMIT IS SUBJECT TO THE FOLLOWING CONDITIONS:
1. This permit does not absolve the holder from compliance with all Fisheries, Customs and other relevant regulations.
2. Any specimen collected is for scientific purposes only and may not be sold.
3. Copies of all raw data, reports, findings, reprints of articles, publications or any published material originating from the study must be made available to the Fisheries Administrator prior to leaving the country, before a permit renewal or upon request.
4. That the research shall be conducted in such a way as to eliminate wanton and indiscriminate destruction of other resources in the waters of Belize.
5. That local scientists or observers are allowed to participate in the research program wherever applicable.
6. That all actions confirm with the project proposal submitted, and if any changes are to occur, then permission must first be granted by the Fisheries Administrator.
7. That any samples to be taken out of the country for further study be inspected by the Fisheries Administrator, and the relevant permit be given by same.
8. This permit does not allow the researcher(s) to subcontract any research or documentation either by interview or videography before prior consultation with the Fisheries Administrator.
9. If any or all of these conditions are not adhered to, it may result in the immediate cancellation of this permit.

This permit is valid for the period January 1 to December 31, 2009.

_________________
Beverly Wade (Ms)
Fisheries Administrator
CC: Comptroller of Customs
Controller of Supplies
CEO, Ministry of Agriculture and Fisheries

MARINE RESEARCH FROM A FISHERIES PERSPECTIVE

- Research is necessary in order to understand the status of our natural resources;
- It is vital to make informed management decisions;
- Research in priority areas is encouraged and sanctioned;
- Priority Areas: lobster, conch, finfish, coral reef and associated habitats health; socio-economic studies especially in coastal communities; human impacts; climate change impacts.

RESEARCH STATISTICS

RESEARCH COMPOSITION 2008
RESEARCH STATISTICS

Research Institution Composition 2008

- Smithsonian: 44%
- WCS: 13%
- IZE: 4%
- CI: 4%
- Independent: 31%

Research Titles

- Fisheries economic valuation at Turneffe & Lighthouse Atolls;
- Reserve effects from no-take zones on reef communities;
- Spawning aggregation ecotourism;
- Cross shelf connectivity on the Belize Barrier Reef;
- Genetic conservation of fish, lobster and conch;
- Effectiveness of SCMR in protecting conch populations.

RESEARCH PARTNERS

- Smithsonian Institute
- Earthwatch Institute
- Wildlife Conservation Society
- World Wildlife Fund

FUTURE RESEARCH IN BELIZE

- Collaborative agreements;
- Continue to prioritize areas of research;
- Fisheries will be strict on getting reports, updates and publications on research conducted in Belize;
- Fisheries will continue to get researchers to collaborate on same research topics in order to avoid duplication.
FAILURE TO COMPLY WITH THE FISHERIES RESEARCH REGULATIONS: A FINE UP TO $2,000 OR 6 MONTHS IN JAIL OR BOTH.

THANK YOU
Seaweed as Indicators and Drivers of Coral Reef Health: New Thoughts on Confronting the Coral Reef Crisis

Dr. Robert S. Steneck
University of Maine
(with help from lots of friends)

Define ecosystem "drivers"
With examples and experiments show seaweed is a driver and indicator of coral reef health
Monitoring health coral reefs 1999 - 2009 (an example)
Management recommendations

Algae as Drivers and Indicators of Coral Reef Health

- We need to identify and manage for the STRONG drivers of coral reef ecosystems structure and function.
- Strong drivers of ecosystem processes should show clear population effects at a variety of scales.
- Resilient reefs cope with disturbances to an unfavorable state and/or recover rapidly when disturbed.
- Good drivers should maintain healthy resilience.
- How do we recognize good drivers vs bad drivers?

Good drivers
- Strong drivers have strong population effects
- They are evident at multiple scales from mm to 100s of km
- Algae are strong drivers of coral recruitment
- There are causes for optimism
- First: some examples

Bad drivers
- Good results (fewer surprises)
- Bad (often surprising) results

Good drivers
- Good Driver
  Crustose Coralline Algae
- Bad Driver
  Macroalgae

What do managers need to know?
Algae are strong drivers of coral reef ecosystem health
"Coral reefs" are becoming "seaweed reefs" in some areas, such as Jamaica and Mexico. Although many have become seaweed reefs, others have not, as seen in the Bahamas. The shift from coral reefs to seaweed reefs is indicative of environmental changes and can have significant impacts on the ecosystem.
What's different about Bonaire?

Very little macroalgae

Herbivores Drive Macroalgae

Herbivore Biomass (g/100 m²) (Scarids, Acanthurids & Microspathodon)

Bonaire Saba & Statia

Herbivore Drive Macroalgae

R² = 0.5

Caribbean-wide study

ADGRR 2003

(a) All herbivorous fish

So what?

Algal carpets ...
Stress corals (reduced feeding)
Smother corals
Reduce reproductive output
Make corals more disease-prone
Make reefs less receptive to baby corals
Make reefs less healthy

AGTRA 2003

Williams & Polunin 2001 (based on marine reserves vs control areas)
Bottlenecks in Coral Recruitment

1. Larval availability = Connectivity
2. Propensity to settle
3. Nursery habitats = Juvenile mortality is low

Survival

Settlement
Sexual Maturity
40 mm (ca 4-5 yrs)

AGE/SIZE

1. Measuring rates of settlement, growth and early post-settlement mortality (standardized terracotta substrata)
3. Evaluates coral recruitment relative to the recruitment potential of the reef (including herbivory, algal community structure)
4. See if these factors scale up to larger regional scales

CORAL RECRUITMENT

Survival

Settlement
Sexual Maturity

AGE/SIZE

Individual baby corals were identified as were what they were growing on... We also monitored over time via an x-y coordinate scale used for each plate.
Porites baby coral over time on settlement plate

Carrie Bow, Belize

Carrie Bow - Death of a baby Porites

Carrie Bow - Agaricia overgrown by the seaweed “macroalga” Lobophora (a coral recruitment “inhibitor”)
Coral Settlement and Coralline Algae: coral recruitment “facilitator”.

Settlement vs. Coralline alga Titanoderma by Site

Coral recruit facilitators = “good drivers”
Coralline alga (Titanoderma prototypum)
Coral recruit inhibitors = “bad drivers”

Bonaire

No damselfish
Full parrotfish grazing
Less seaweed, more coralline = Good Drivers!

Damselfish
Less parrotfish grazing
More seaweed, less coralline = Bad Drivers!

A natural experiment: Inside vs outside damselfish territories

Plates a meter apart can have very different algal turf biomass

Increased Algal Turf Abundance in Damselfish Territories

Arnold & Steneck in review
Baby Coral Survival Relative to Grazing Pressure

Proportion Surviving

<table>
<thead>
<tr>
<th>Time</th>
<th>Aug-04</th>
<th>Sep-04</th>
<th>Oct-04</th>
<th>Nov-04</th>
<th>Dec-04</th>
<th>Jan-05</th>
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<th>Apr-05</th>
<th>May-05</th>
<th>Jun-05</th>
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</thead>
<tbody>
<tr>
<td>Good Drivers</td>
<td>Corals survive</td>
<td>All corals die</td>
<td></td>
<td></td>
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</tbody>
</table>

Arnold & Steneck in prep.

"PED" = Parrotfish Exclusion Device

Parrotfish Exclusion Devices
Global Studies with Pete Mumby and Susie Arnold
And Mehdi Adjeroud (Tahiti)

Belize
Palau
Bonaire
Tahiti

Experiment: Effects of parrotfish grazing on macroalgae and coral recruitment

PED control
Cage control
Bare plate

Belize

36
**Frustrated Big Parrotfish**  
Grazing Control PED

**Parrotfish Exclusion Device**  
Treatment effects from Belize (Glover’s Atoll and Carrie Bow Caye)

**Ineffective Small Parrotfish**

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**Video analyses of parrotfish bite rates by size classes**

**Parrotfish size class (cm)**

PED's reduce herbivory from large parrotfish

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**Bite marks on plates after 1 year**

PED's reduce herbivory from large parrotfish

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**Parrotfish Exclusion Device**  
Parrotfish Exclusion Device Control

Belize
Seaweed abundance (macroalgae)

Maximum Number of Coral Spat Per Plate

PED Results from:
Glovers Atoll, Belize
Carrie Bow Cay, Belize
Bonaire, NA

Algal Biomass
(Algal Index Proxy)
Larger Scale Within Region Comparison

- Good drivers
- Bad drivers
- Macrolgae
- Corallines

Cayos Cochin, Honduras

Baby Corals on Settlement Plates (Honduras)

R² = 0.75

Coral Spat Density (#/plate)

Percent Cover Seaweed

Juvenile Coral & Seaweed (Honduras)

R² = 0.83

Juvenile Coral Density (# < 40 mm/m²)

Percent Cover Macrolgae

Coralline Percent and Juvenile Coral Density (Honduras)

R² = 0.62

Juvenile Density (#/m²)

% Cover Crustose Coralline Algae
**Large-scale trends over time & space**

**Reef Recovery Following the 1998 Bleaching Event**

A good opportunity to learn about the resilience of reefs.

- **Palau after 1998 Bleaching**
  - 2 years
  - 7 years
  - Macroalgae were rare, corallines common (Good Drivers!)
  - Coral recruits were abundant
  - Reefs are now in full recovery with 50–70% live coral
  - Clearly resilient reefs

**Mesoamerican Study Regions**

<table>
<thead>
<tr>
<th>Belize</th>
<th>Guatemala</th>
<th>Honduras</th>
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<tr>
<td>Turneffe Atoll</td>
<td>Guanacaste, Costa Rica</td>
<td>Carrie Bow, Belize</td>
</tr>
<tr>
<td>Carrie Bow Cay</td>
<td>Pt. de Manabique, Cayos Cochinos</td>
<td>Glovers, Belize</td>
</tr>
</tbody>
</table>

**Algal Abundance & Juvenile Coral Densities Caribbean-wide**

- Study Regions
  - Bonaire, NA
  - Calabash, Belize
  - Carrie Bow, Belize
  - Cayos Cachinos, Honduras
  - Glovers, Belize
  - Guatemala

- Algal Biomass (Algal Index Proxy)

- Bad Driver (macroalgae)

- R² = 0.74

**Palau**

- Suffered 80–90% mortality after 1998 bleaching
- 7 years later
  - Macroalgae were rare, corallines common (Good Drivers!)
  - Coral recruits were abundant
  - Reefs are now in full recovery with 50–70% live coral
  - Clearly resilient reefs
Two Reefs Bleached in 1998

Indopacific  
Caribbean

- The frequency of disturbance is not that different
- But often Indopacific reefs recover more rapidly than Caribbean reefs
- They are more resilient! But, Caribbean reefs can recover...

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Grazing Sea urchins

Progress in Jamaica

**Macroalgae**

- Good drivers

Aronson and Precht 2000
Algae are strong drivers of resilience of coral reef ecosystems

- Strong Drivers have strong population effects
- They are evident at multiple scales from mm to 100s of km
- Algae are strong drivers of coral recruitment and survival
- Clearly, there are good and bad drivers
- So, here’s my management advice...!

Just Say No to Bad Drivers!

- Abundant seaweed reduces the receptivity of coral reefs to settling baby and juvenile corals
- It appears largely the result of reduced herbivory but there also could be interaction effects from nutrients
- This supports some new paradigms on the contribution of feedback loops related to alternate ecological states

Coral reef management and conservation in light of evolving ecological paradigms

Feedback Loops

Using the latest science to improve the management of coral reef ecosystems

Coral reef ecosystems are complex with many stressors.

However, relatively few factors are key drivers of the healthy resilience of these ecosystems.

Managers should monitor key drivers to determine the health of coral reefs.
So how do we determine the health of reefs?

Monitoring vital signs...

In 2005 the Bonaire Marine National Park asked Dr. Tim McClanahan and me to develop a coral reef monitoring protocol.

Our advice:
1. Keep it simple
2. Keep it focused on known drivers and indicators of reef health
3. Monitor trends in drivers of reef health

Suggested Approach to Monitor Coral Reefs

Positive Trends
- Coral Cover
- Macroalgae
- Nutrients
- Corallines
- Herbivory
- Large Parrotfish
- Diadema
- Other herbivorous fish
- Territorial Damselfishes
- Large carnivorous fishes (Groupers, snappers & barracuda)
- Coral Recruitment (density of corals < 40 mm diam)

Negative Trends

Monitoring Stations 1999 - 2009
**Parrotfish Bite Rate**

- **TREND**
- Parrotfish Bite Rate (Bites/5 min/m²)
- 1999: ND
- 2003: 20
- 2005: 15
- 2007: 10
- 2009: 5

**Grazing Sea Urchin (Diadema) abundance**

- **TREND**
- Diadema Population Density (#/20 m²)
- 1999: ND
- 2003: 0.5
- 2005: ND
- 2007: 0.2
- 2009: ND

**Territorial Damselfishes**

- **TREND**
- Damselfish Biomass (g/100 m²)
- 1999: ND
- 2003: 600
- 2005: 800
- 2007: 1000
- 2009: 1200

**Predatory Fishes of Damselfish (Groupers, Snappers & Barracuda)**

- **TREND**
- Fish Population Density (#/100 m²)
- 1999: ND
- 2003: 10
- 2005: 8
- 2007: 4
- 2009: 2
So how are Bonaire’s reefs doing?

Doctor, How am I doing?

We have causes of concern!

Monitoring vital signs...

Conclusions from Monitoring

Bonaire’s reefs may look relatively healthy. But we are seeing warning signs of increasing macroalgae, declining herbivory from parrotfish and declining juvenile corals.

The emerging picture suggests healthy ecosystems result from positive feedbacks of key drivers. For example: Anything that reduces seaweed (bad driver) is good.

Managers should continue efforts to limit nutrient runoff. Bonaire is now considering a ban fishing on herbivores in general and fishing of parrotfish in particular. They are also considering a fish trap.
I lived in St. Croix 1972 - 1974

Fish traps were rare then, but now they are common. Parrotfish like to sleep in traps. They die in traps.

Eventually markets developed:
Parrotfish in St. Thomas. USVI
February 2005

Parrotfish are the preferred food for some cultures (Photo from a store in Boston, Massachusetts, USA)

In Belize:
Parrotfish may not be preferred fish to eat by Belizians but they are heavily fished (in one study they were the second most commonly caught fish species).

One reason for this was, parrotfish fillets were sold to restaurants as ‘snapper’ or ‘grouper’ fillets.

A new law passed in Belize outlaws the harvest of any herbivorous fish and all fish fillets provided to restaurants must include the skin.

Parrotfish may not be preferred fish to eat by Belizians but they are heavily fished (in one study they were the second most commonly caught fish species).

Thoughts for confronting the coral reef crisis

Coral reef ecosystems are complicated and they have many stressors.

However, relatively few factors are key drivers of the resilience and health in these ecosystems.

Managers can and should monitor and manage key drivers such as seaweed abundance (and herbivory) to improve the health of coral reefs.

“Surgical” management measures such as reducing fishing on herbivores should mesh with local traditions and make sense to fishing communities.
Thoughts for confronting the coral reef crisis

Coral reef ecosystems are complicated and they have many stressors. However, relatively few factors are key drivers of the resilience and health in these ecosystems. Managers can and should monitor and manage key drivers such as herbivory and seaweed abundance to improve the health of coral reefs.

“Surgical” management measures such as reducing fishing on herbivores should mesh with local traditions and make sense to fishing communities.

Ecosystems can “flip” from healthy to an unhealthy state. We are often surprised by these “flips.”

Caribbean reefs  Aleutian kelp forests  Black Sea