Acropora spp. coral farming and restoration activities in the face of increasing local human stress and climate change: Lessons learned and recommendations

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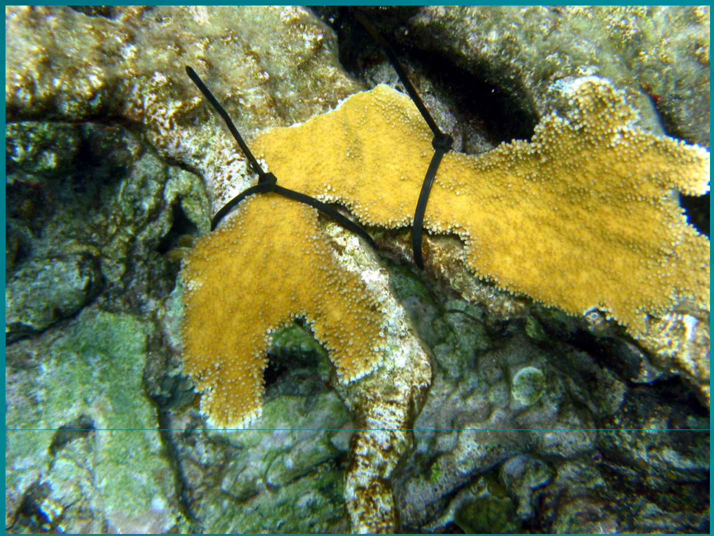
Objectives

- Address some key issues regarding the success of low-tech community-based Acroporid coral farming and reef restoration in PR.
- Discuss examples of case studies from PR.
- Address some of the lessons learned.
- Recommendations.

Brief history of low-tech coral farming and transplanting in PR



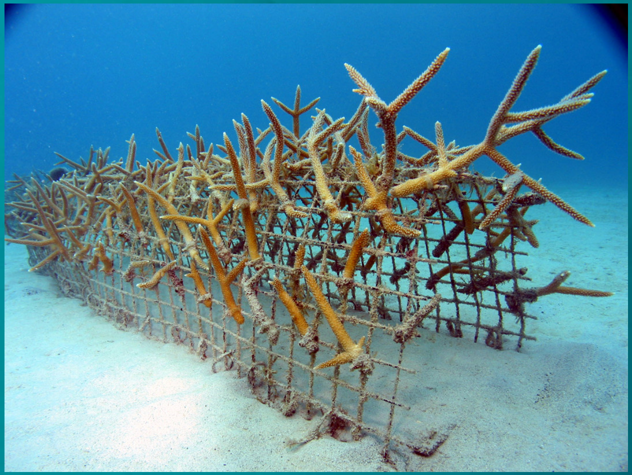
- 1996-2000 – First experiments of low-tech coral farming in La Parguera (Bowden-Kerby, Ortiz, Ruiz)
- 2000 – Seascape coral reef rehabilitation on shallow trampled areas in Culebra (Hernández, Rosado and Suleimán)
- 2003-Present – Coral farming and reef rehabilitation in Culebra (Hernández, Suleimán, Lucking, Soto).

Brief history of low-tech coral farming and transplanting in PR

- 2003-Present – Coral reef rehabilitation of bombarded coral reefs in Culebra (Hernández et al.)
- 2003-2005 – Small-scale coral farming experiment at Guanica (Pacheco-DNER, Ortiz, Ruiz)
- 2004-Present – Several emergency restoration joint efforts by DNER, UPR and/or small local NGOs.
- 2008-Present - Emergency restoration of Elkhorn coral thickets in Vega Baja (Hernandez, Laureano, et al.), in collaboration with DNER personnel and NOAA.

Advantages of low-tech coral farming and reef restoration

- Low-cost and easy to implement.
- Successful hands-on educational tool.
- Empowers traditionally underserved base communities and small NGOs in coral reef conservation through fostering hands-on participation.



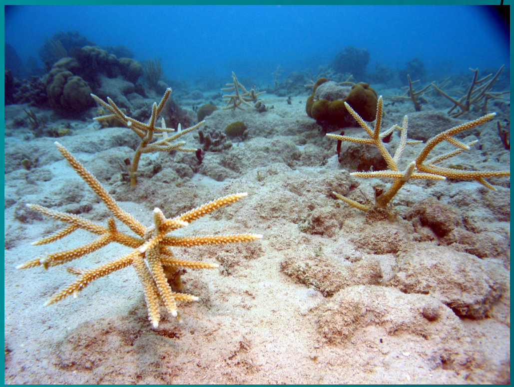
The *Acropora cervicornis* case study: Culebra Island

The Culebra Case Study: Community-based alternatives for coral reef rehabilitation

- ***Culebra Island Coral Aquaculture and Reef Rehabilitation Program***
- Aimed at low-tech coral propagation for the rehabilitation of coral reef ecological functions and ecosystem resilience.
- Joint effort between academia, traditionally underserved base communities and small local NGOs.

Rehabilitation of bombarded coral reefs

- Seascape **reconstruction** of bomb-cratered reefs.
- **Repair** benthic tridimentional structure.
- **Rehabilitation** of ecological functions.

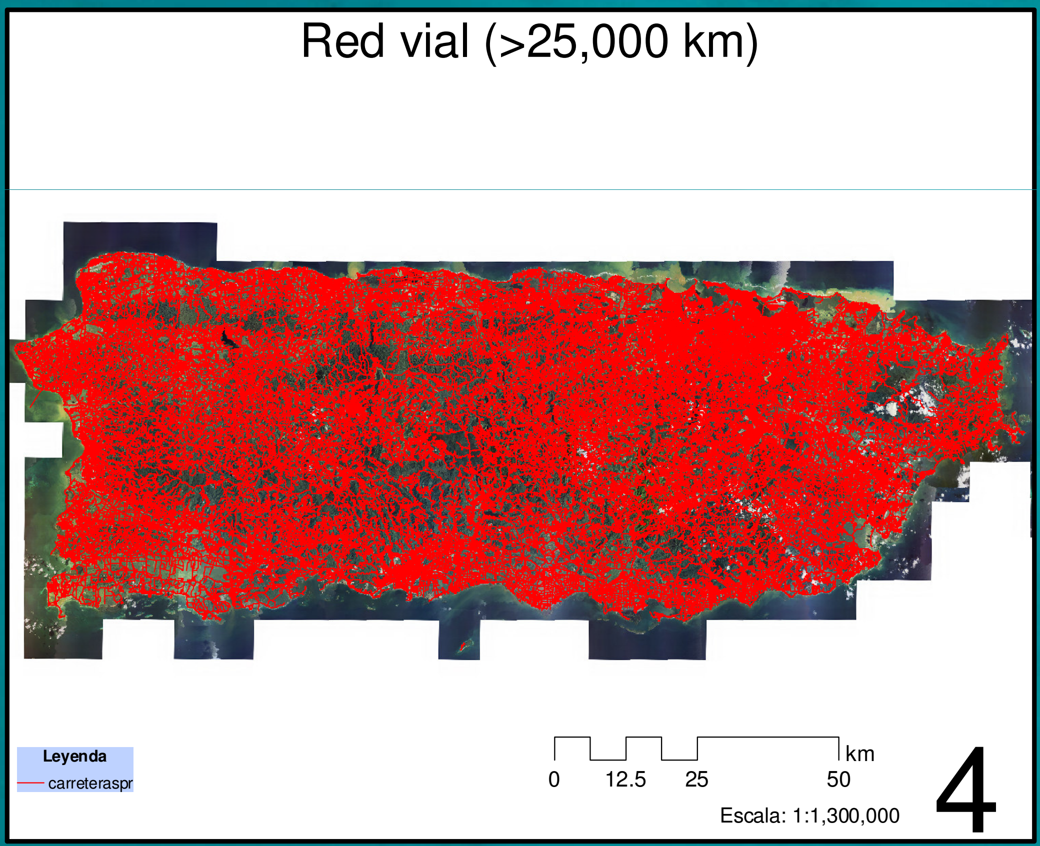


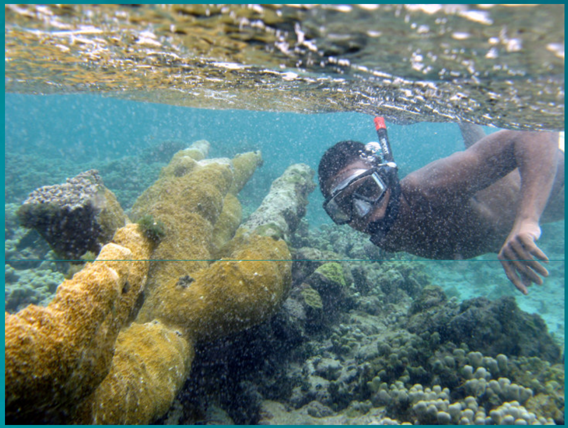
Creation of nursery habitats

- Species **reintroduction**.
- **Rearing** of high-temperature resistant clones.
- Coral reef **restoration**.
- **Rehabilitation** of functional redundancy.
- Seascape **reconstruction**.
- Foster coral sexual **reproduction**.

Nassau grouper (Mero cherna)
Epinephelus striatus

Low-tech coral farming and reef restoration in PR successful in spite of outrageous construction trends and poor land use





Low-tech coral farming and reef restoration in PR successful in spite of lack of adequate funding

Small communities, fishers, and NGOs can not compete with large organizations

1:1 match outrageous
for underserved communities

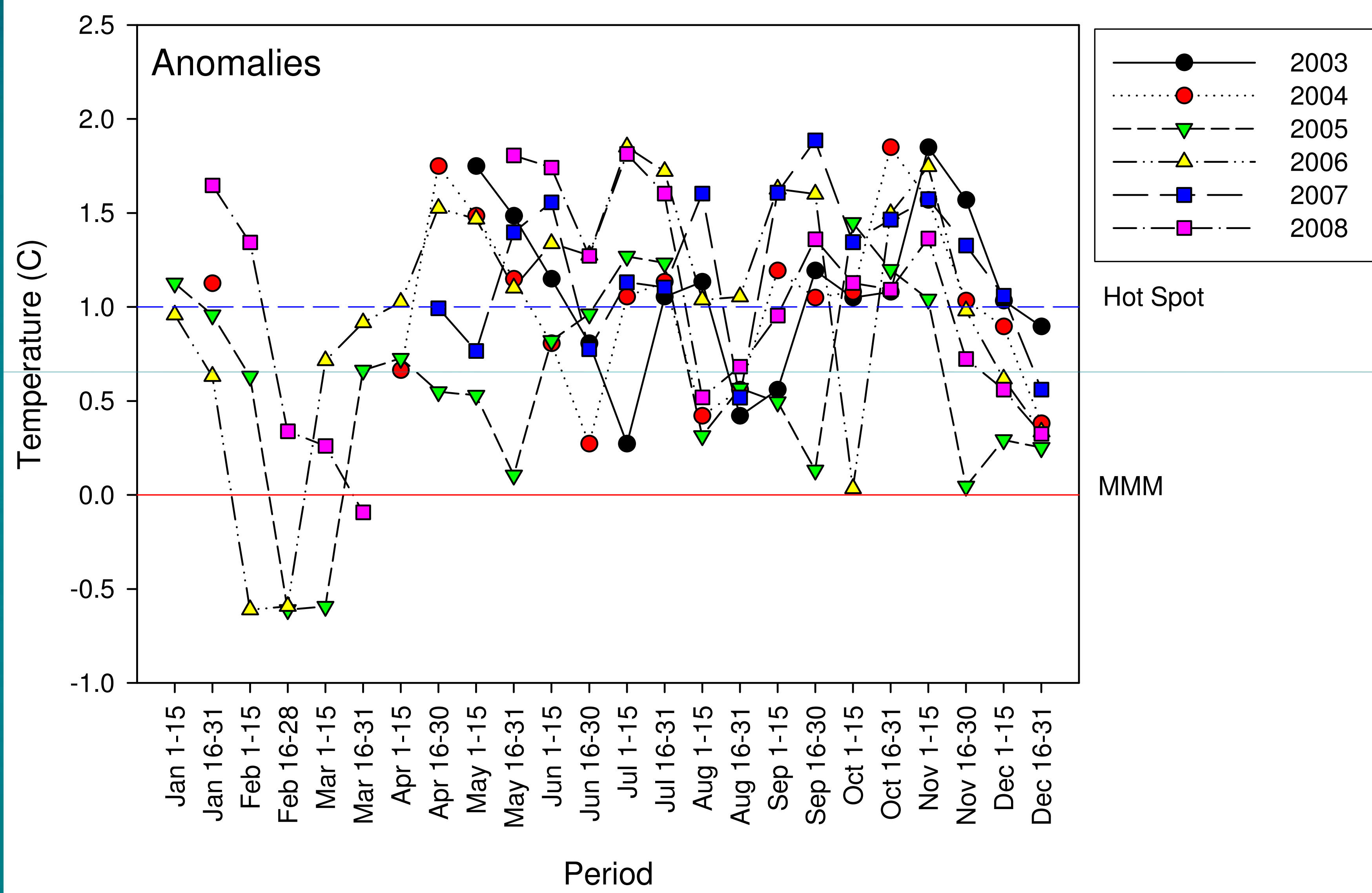
Low-tech coral farming and reef restoration in PR successful in spite of major social challenges

- Historic military firing ranges.

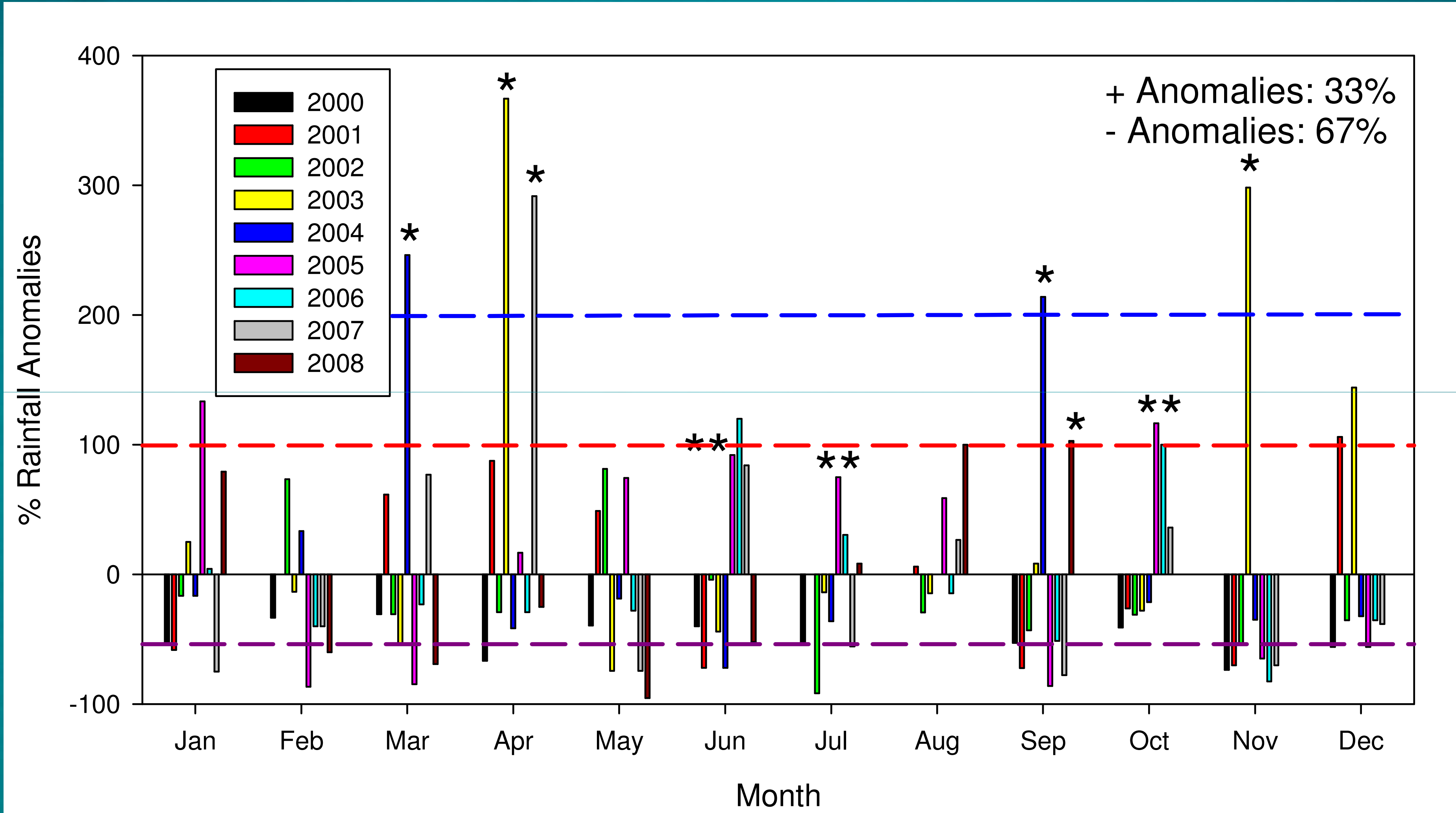
- Traditionally underserved, isolated and socio-economically marginalized communities.
- "At Risk" characterized youth.

- Significant impacts of fishers from remote areas outside of the community.
- Rampant imperialistic approaches to non-sustainable development.
- Community sectors not even recognizing coral decline as an issue!

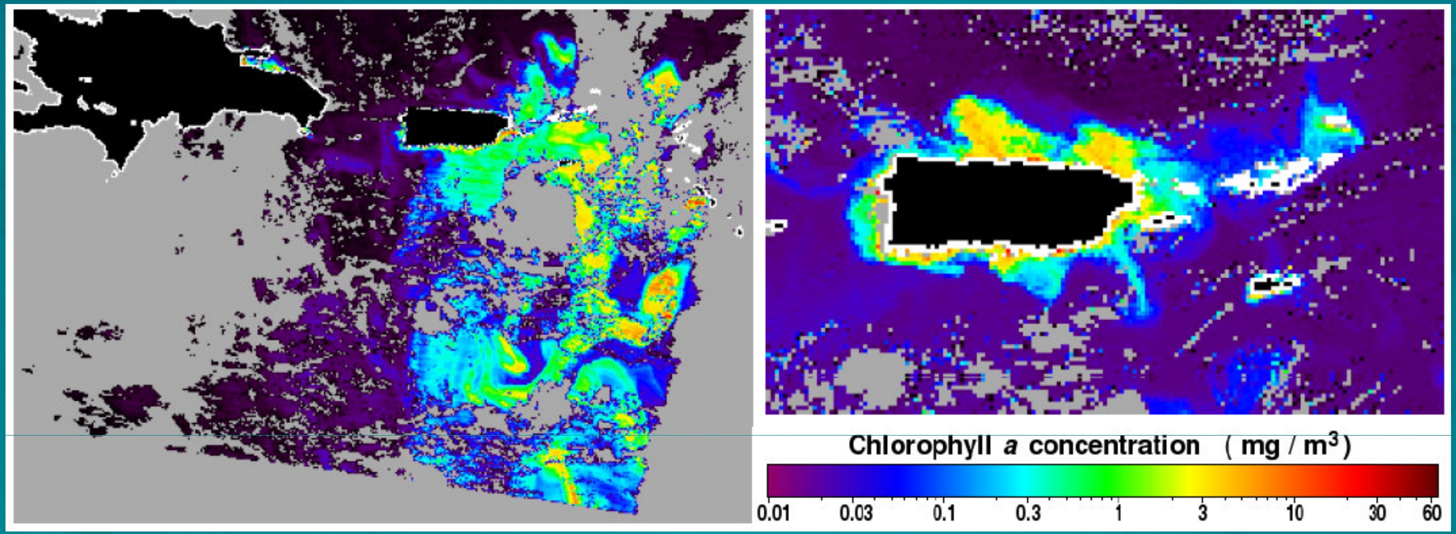
But increasing sea surface temperatures



Coral mortalities from major rainfall + runoff



Nutrient pulses from meso-scale gyres



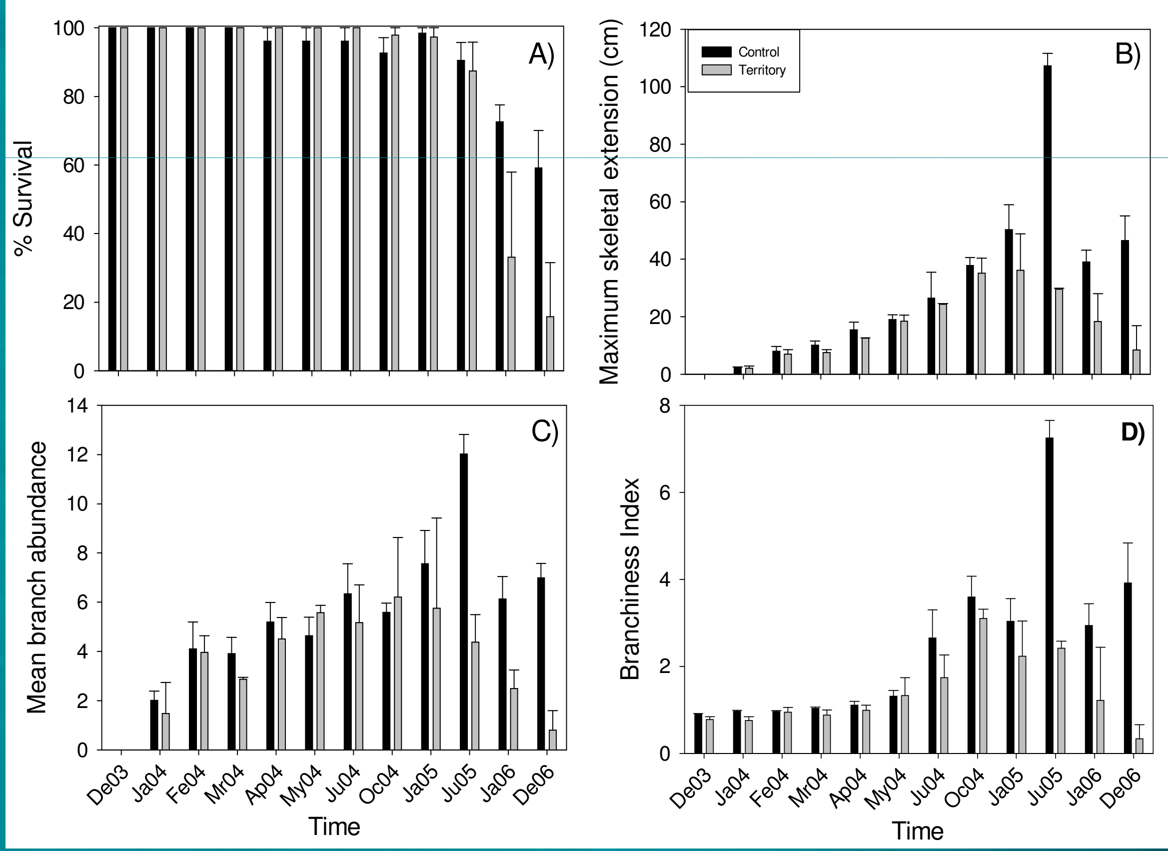
Meso-scale gyres and major local runoff pulses bring significant nutrient pulses to coral reefs.

Left: Meso-scale gyre from a Amazon River water plume (April 23, 2009) that lasted over a month. Chlorophyll *a* (Chl-*a*) concentrations increased up to 10-fold from background 0.1-0.3 mg/m^3.

Right: Runoff pulse event associated to major rainfall (Nov. 23, 2003) that produced a 2 to 5-fold increase in Chl-*a* concentrations.

- *Following sea surface warming and bleaching*
- > recent mortality
- > total mortality
- > fireworm predation
- > damselfish predation
- > cyanobacterial overgrowth
- > sponge overgrowth

Impacts on coral transplants



Anchoring impacts

- Destruction by accidental anchoring, even in the presence of anchoring buoys.

- Requires emergency restoration responses.

- Can be rapidly restored by trained base communities.

In spite all that…

- The combination of a sort of community-based harvesting and transplanting methods have proven successful under different types of habitats, creating a mosaic of biological corridors for other reef fauna.

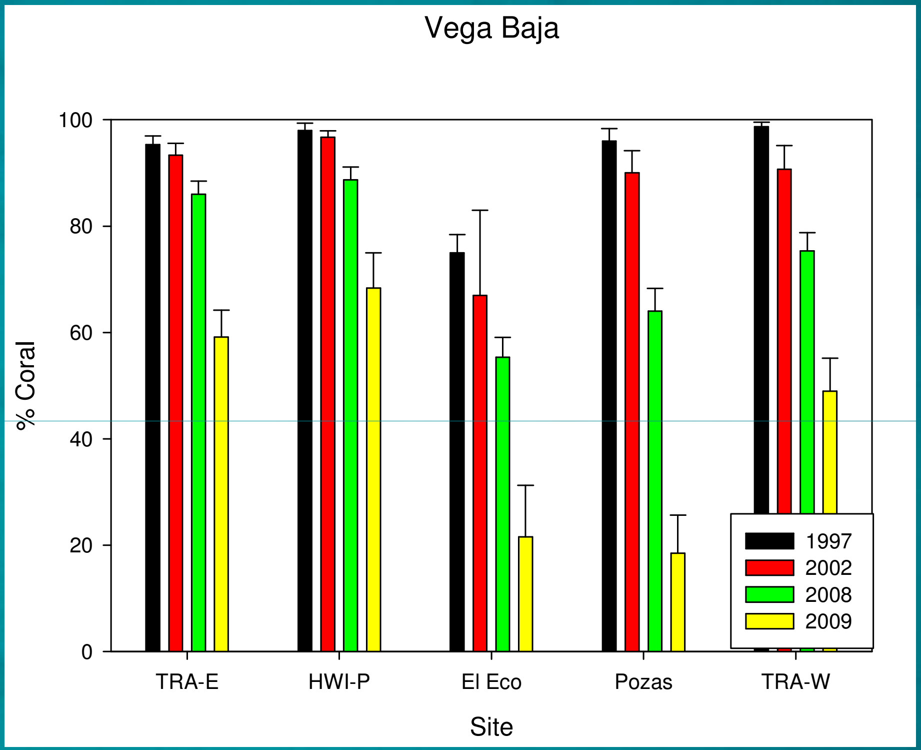
The *Acropora palmata* case study: Vega Baja

- Largest known thickets in the U.S. Caribbean.
- Among the highest densities and % living coral cover.
- Critical resources for the maintenance of genetic connectivity.

Playa Tractores

Raw sewage and beach renourishment are killing corals!!!

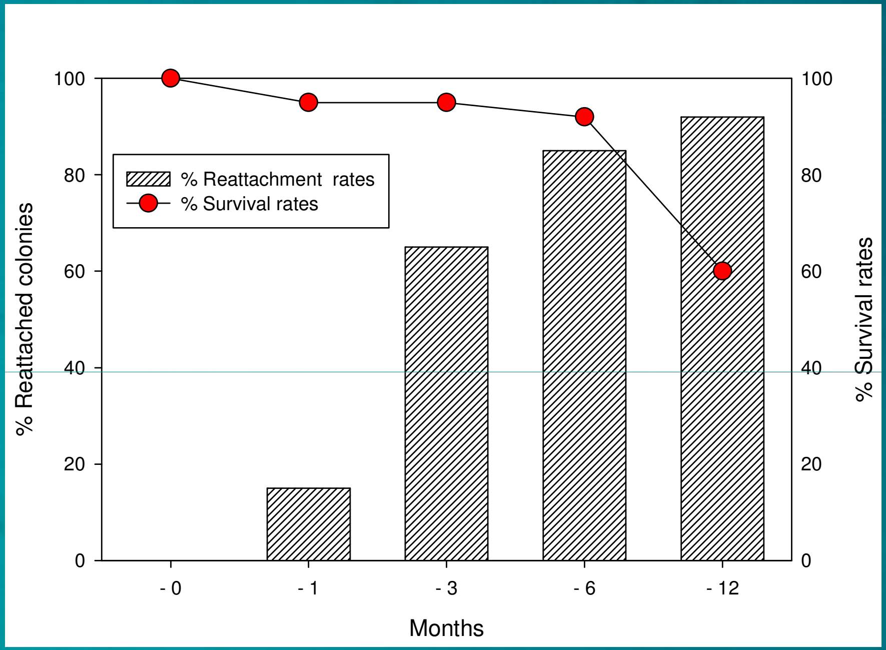
- Recurrent illegal dumping of raw sewage from variable non-point sources and illegal beach renourishment activities.
- Significant coral mortality following these impacts.



Drowned *palmata*

Raw sewage and beach renourishment are killing replanted corals too!!!

- Rapid recovery of low-tech replanted coral fragments (VIDAS, UPR, DNER).
- High colony survival rates, skeletal growth and branching production.
- Sewage and sediments have screwed up the community-based effort!



Sewage impacts on *Acropora palmata* assemblages in PR already documented in two papers

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Detection of spatial fluctuations of non-point source fecal pollution in coral reef surrounding waters in southwestern Puerto Rico using PCR-based assays

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A R T I C L E I N F O

Keywords:
Bacteroides
Clostridium coccoides
Coral reefs
Microbial source tracking
Non-point source coastal fecal pollution
PCR

A B S T R A C T

Human fecal contamination of coral reefs is a major cause of concern. Conventional methods used to monitor microbial water quality cannot be used to discriminate between different fecal pollution sources. Fecal coliforms, enterococci, and human-specific *Bacteroides* (HF183, HF134), general *Bacteroides-Prevotella* (GB32), and *Clostridium coccoides* group (CP) 16S rDNA PCR assays were used to test for the presence of non-point source fecal contamination across the southwestern Puerto Rico shelf. Inshore waters were highly turbid, consistently receiving fecal pollution from variable sources, and showing the highest frequency of positive molecular marker signals. Signals were also detected at offshore waters in compliance with existing microbiological quality regulations. Phylogenetic analysis showed that most isolates were of human fecal origin. The geographic extent of non-point source fecal pollution was large and impacted extensive coral reef systems. This could have deleterious long-term impacts on public health, local fisheries and in tourism potential if not adequately addressed.

1. Introduction

Fecal contamination of coastal waters is a paramount concern in tropical developing countries (Byamukama et al., 2005). Wastewater pollution can negatively affect both the marine environment and human health (Fong and Lipp, 2005). In this context, it is important to determine sources of fecal contamination in order to prevent diseases and assure water quality (Scott et al., 2002), since many of these areas are used for fishing and recreational purposes. Non-point source fecal pollution is a major threat to coral reefs, often resulting in an increased stress to benthic communities (Pastorok and Bilyard, 1985), an increased frequency of coral mortality (Frías-López et al., 2002; Kaczmarsky et al., 2005), and in long-term phase shifts in benthic community structure (Done, 1992). Chronic sewage pollution often prevents natural coral reef recovery following natural disturbance (Jokiel et al., 1993). However, long-term fecal pollution impacts in coral reefs have been poorly documented. This could often be the result of lack of funding, trained personnel or laboratory facilities, or the inadequacy of standard microbial indicators to detect potential impacts.

The United States Environmental Protection Agency (USEPA) recommended the use of *Escherichia coli*, a member of the fecal coliform group, as well as enterococci, as microbiological indicators of fecal pollution for marine waters (USEPA, 2000). However, it has been suggested that *E. coli* may not be a reliable indicator in tropical and subtropical environments, because of its ability to replicate in polluted soils (Desmarais et al., 2002; Solo-Gabriele et al., 2000), as well as in tropical freshwater and coastal environments (Hazen and Toxanzos, 1990; Hernández-Delgado, 1991). Members of *Bacteroides* spp. have been suggested as alternate fecal pollution indicators (Allsop and Stickler, 1985; Fiksdal et al., 1985; Dick et al., 2005) as it constitutes one of the most numerous members of the human colonic flora (Finegold et al., 1983; Sghir et al., 2000). *Bacteroides* spp. is Gram-negative, anaerobic bacilli or cocco-bacilli, each species is morphologically distinct, and most are encapsulated, and are capable of outcompeting other members of the gastrointestinal flora. They can also be opportunistic pathogens, causing a variety of infections throughout the body (Sheehan and Harding, 1989). However, their use as indicator organisms using standard plate culturing techniques has been very limited due to their complicated growth requirements.

Recently, a series of novel culture-independent microbial source tracking (MST) methods have been developed to determine the source of fecal contamination (Field et al., 2003; Simpson et al., 2004; Shanks et al., 2006). One of these methods consists in detecting host-specific molecular markers using the 16S rRNA gene of *Bacteroides* (Bernhard and Field, 2000a,b). These molecular markers can amplify DNA sequences from this potential microbial fecal indicator and identify its source (whether it is human or animal)

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Impacts of non-point source sewage pollution in Elkhorn coral, *Acropora palmata* (Lamarck), assemblages of the southwestern Puerto Rico shelf

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Abstract. Non-point source sewage pollution represents a major threat to coral reefs. Impacts are typically associated with chronic eutrophication, water turbidity, and microbes potentially pathogenic to corals. Sewage pollution can produce variable system- and species-specific responses, as well as cascading direct and indirect effects, that could result in major long-term phase shifts in coral reef benthic community structure. This study was aimed at characterizing the ecological condition of eight shallow-water (<5 m) Elkhorn coral (*Acropora palmata*) assemblages located across a non-point source sewage pollution gradient along the southwestern Puerto Rico shelf. Non-point source pollution was a key stressor structuring local coral reef communities. Long-term phase shifts have favored dominance by macroalgae and non reef-building taxa at inshore locations under chronic pollution. Non reef-building taxa correlated with fecal pollution indicators. *Acropora palmata* and crustose coralline algae (CCA) are dominant at offshore remote reefs. Coral reef degradation is already beyond the point of recovery at most inshore habitats. Coral reef communities within local Marine Protected Areas were also undergoing significant degradation as a result of variable impacts, including non-point source sewage pollution. There is a paramount need to implement adequate management measures to prevent further water quality degradation across the region.

Key words: *Acropora palmata*, Coral reefs, Non-point source sewage pollution, Puerto Rico

Introduction

Marine non-point source sewage pollution is a major cause of concern in coral reef communities. Negative sewage impacts have been mostly associated to eutrophication and turbidity (Pastorok and Bilyard 1985; Cloern 2001). Kaczmarsky et al. (2005) also documented a high prevalence of Black Band Disease and White Plague-Type II in coral colonies exposed to sewage. Coral survival rates (McKenna et al., 2001), as well as reef-building activity (i.e., skeletal extension rates), are highly susceptible to sewage impacts, although effects seem to be species-specific (Tomascik and Sander 1985; Spencer-Davies 1990). Sewage impacts often result in a combination of system- and species-specific responses, as well as cascading direct and indirect effects that could result in major long-term phase shifts in benthic community structure, favoring dominance by fleshy macroalgae and non reef-building taxa. Such phase shifts could be irreversible in long-term scales (Knowlton 1992; Hughes 1994). Sewage-associated eutrophication impacts can also result in an accelerated reef decline often due to a combination of synergistic impacts, mostly from sedimentation and turbidity (Meesters et al. 1998; Szmant 2002), as well as to recurrent pulses of increased biological oxygen demand and declining dissolved oxygen concentration that can create a hypoxic condition in coastal waters (Desa et al. 2005).

Sewage impacts can produce a major decline in the socio-economic value of coral reefs and associated communities due to the loss of ecological services (i.e., coastal protection, sinkhole of greenhouse gases, food-protein production, source of bio-active compounds), and reef aesthetics (i.e., SCUBA, snorkeling, educational excursions). Declining reefs may also represent a permanent phase shift to fisher community livelihoods and a loss of cultural heritage. Sewage has been previously implicated in coral reef degradation in Puerto Rico (Goenaga and Boulon 1992; Hernández-Delgado 2000, 2005). In spite of

Final thoughts

- Low-tech coral farming and reef rehabilitation is a cheap easily-implemented effort that can foster permanent reintroduction and the long-term sustainability of threatened coral populations.

- It also fosters long-term sustainability of coral sexual reproduction and ecological functions, including food production.

- But poor land uses, lack of enforcement and political will have had severe impacts on coral reef rehabilitation success.

Final thoughts

- There is a need to engage traditionally underserved base communities and small NGOs into participatory processes and hands-on experiences.

- This means the need to establish standard operating procedures (SOPs) for coral farming and issuing permits for non-academic investigators.

Final thoughts

- Effective coral reef restoration requires significant behavior modifications from the people and from the government itself.

- *Acropora* spp. future in PR is largely tied up to current neo-liberal economic development plans, that include the proposed flexibilization of permitting processes and/or the partial elimination of environmental regulations.

Proposed tourist resort “Villa Mi Terruño” site, Culebra Island

Final thoughts

- Local academia, traditionally underserved communities, small NGOs, and DNER should cooperatively explore alternative ways to seek funding and continue to expand currently successful coral farming and reef rehabilitation efforts in PR.

- Participatory models in direct collaboration with DNER and the academia should be one of the most sound strategies to empower base communities and NGOs, but also to strengthen severely weakened DNER's management capabilities.

Thanks…

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