Application of Coral Reef Decision Models in Guánica Bay, Puerto Rico

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U.S. Environmental Protection Agency
Office of Research and Development

National Academy of Science Committee on Interventions to Increase the Resilience of Coral Reefs—Meeting 4
October 30, 2018
Guánica Bay –
USCRTF Watershed Initiative

• Concern over effects of watershed stressors on corals led to designation of Guánica Bay as a US Coral Reef Task Force Watershed Initiative
• This led to development of a Guánica Bay Watershed Management Plan

Decision Tools

• Structured decision process
• Systems framework
• Alternatives formulation
• Consequence tables
• Scenario testing
Recommended Management Actions in the Guánica Bay Watershed Management Plan

Maximize planting of cleared home sites & dirt roadways
Dredge reservoirs
Restore lagoon marshes
Sustain and slow reservoir releases
Create incentives for shade grown coffee
Remove relic irrigation structures
Treat stormwater outflows
Treat sewage effluent
Enhance riparian planting
Enforce sediment erosion regulations
Establish wastewater treatment wetlands
Minimize pet waste
Encourage hydroseeding
Upgrade sewage treatment facility
Increase cover crop plantings
Establish rainwater collection systems
Maximize economic benefits
Enhance social well-being
Minimize threats to human health
Meet political and legislative requirements

Maximize ecological integrity

**Fundamental objectives**

**WMP means objectives**

- Reduce physical/chemical/bacterial stressors from municipal loadings
- Reduce physical/chemical stressors from agricultural loadings
- Preserve farmland/topsoil
- Conserve freshwater supplies

**WMP recommended decisions**

- Enforce sediment erosion regulations
- Maximize planting of cleared home sites & dirt roadways
- Minimize pet waste
- Treat sewage effluent
- Restore lagoon marshes/establish treatment wetlands
- Treat stormwater outflows
- Dredge reservoirs
- Sustain and slow reservoir releases
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- Enhance riparian planting
- Increase cover crop plantings
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Carriger et al. 2013
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Carriger et al. 2013
Means-Ends Networks – Guánica Bay

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**Why is this important?**

**How do I achieve this?**

Carriger et al. 2013
Watershed Sediment

- The Guánica watershed has gone through many changes resulting from agricultural and municipal growth
- These changes have altered the quantity and quality of water flowing from the watershed into Guánica Bay and coastal coral reefs, particularly in terms of sediment discharge
Guánica Bay Watershed Management Plan
Proposed actions for reducing sediment discharge

Shade-grown coffee
Dredging reservoirs
Lagoon restoration
Hydro-seeding
Riparian planting
Remove relic irrigation
Structured Decision Making

A process to elicit and organize key *stakeholder values* and relevant *scientific knowledge* for making decisions.

**Strengths of SDM**
- Facts and values
- Multiple perspectives
- Holistic
- Democratic
- Flexible
- Multiple knowledge sources
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A process to elicit and organize key *stakeholder values* and relevant *scientific knowledge* for making decisions

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Stakeholder engagement
Stakeholder Workshops
Informing the SDM process

**Decision Workshop on Watershed Mgmt Plan 2010**
- Proposed management options
- Systems (DPSIR) framework
- Ecosystem goods and services

**Historic Decisions Workshop 2012**
- Decisions made outside of communities
- Desire for local empowerment
- Desire for equitable opportunities
- Better enforcement of regulations

**Coral Reef Condition Workshop 2012**
- Objectives for management and regulatory protection of coral reefs
- Attributes and measurements for reef protection

**Public Values Forum 2013**
- Identify broader stakeholder objectives
- Examine tradeoffs and consequences of decisions
- Prioritize actions for achieving multiple values
- Translate decision tools for community application

Bradley et al. 2013; Gregory and Gonzalez 2013
Coral Reef Protection—A Plethora of Issues

- Acroporids
- Shoreline protection
- Reef building corals
- Endangered species
- Disease
- Climate change
- Coastal development
- Reef habitat
- Commercial fishing
- Marine products
- Beach replenishment
- Photosynthetically-active radiation
- Predation
- Sediment
- Contaminants
- Symbiosis
- Tourism
- Scleractinia
- Biodiversity
- Partial mortality
- Recreation
- Carnivores
- Macroalgae
- Seagrasses
- Mangroves
- Apex species
- Recreational fishing
- Symbiodinium
- Coral cover
- Bleaching
- Coral reef
- Zoolxanthellae
- Predation
- Herbivores
- Sponges
- Hurricanes
- Pharmaceutical products
- Water quality
- Sewage treatment
- Marine protected areas
- Temperature
- Soft corals
- Sea turtles
- Diadema

What does it all mean?
DPSIR Systems Framework
Essential for understanding relationships and assessing tradeoffs
Sediment

Agriculture

Coral reefs

Tourism/Recreation

Reef ES

(Interventions)
Coral reef systems model

- Control practices of:
  - Agricultural Best Management
  - Fisheries regulations
  - Energy policies
  - Environmental education & outreach
  - Tourism policies

- Influence:
  - Fishing
  - Agriculture
  - Pharmaceuticals
  - Tourism & Recreation

- Controlled by:
  - Construction
  - Manufacturing
  - Transportation

- Supported by:
  - Landuse zoning
  - Discharges & runoff
  - Atmospheric emissions

- Distributed by:
  - Landscape changes

- Led to:
  - Dredging
  - Vessel groundings
  - Trampling
  - Harvesting
  - By-catch

- Cause mortality & alter interactions

- Influence:
  - Contaminants
    - Temperature
    - CO2
    - Sea level
    - Hurricanes
    - Pathogens
  - Nutrients
  - Sediment

- Influence distribution of:
  - Coral

- Influence survival

- Influence:
  - Shoreline protection
  - Sand production

- Essential for:
  - Fish & Invertebrate Habitat
  - Fishing stock
  - Biological diversity

- Research potential for:
  - Aesthetic value for
  - Contribution to

- Scientific monitoring
  - Restoration activities

- Control activities of:
  - Fishing regulations
  - Boating regulations
  - Marine Protected Areas

- Control:
  - Discharge permits
  - Emissions regulations
  - Improved technology

- Reduces flooding & benefits
Coral reef systems model

- Land use zoning
- Construction, Manufacturing, Transportation
- Discharge permits, Emissions regulations, Improved technology
- Agricultural Best Management, Fisheries regulations, Energy policies
- Environmental education & outreach, Tourism policies
- Control practices of production activities
- Coral reef systems
  - Landscape changes
  - Discharges & runoff, Atmospheric emissions
    - Contaminants, Nutrients, Sediment, Pathogens
      - Temperature, Sea level, CO2, Hurricanes
    - Dredging, Vessel groundings, Trampling, Harvesting, By-catch
  - Coral
    - Algae
      - Compete for space, Graze & maintain
    - Fish & Invertebrates
      - Provide essential for survival
        - Fish & Invertebrate Habitat
          - Fishing stock
            - Essential for biological diversity
ReefLink Database—Coral Reef DPSIR Model

On-the-fly stakeholder input to DPSIR model-Agriculture
On-the-fly stakeholder input to DPSIR model-Lagoon restoration
What do mosquitoes have to do with coral reef protection?

Lagoon footprint

Restoration of Guánica Lagoon
- Town of Fuig has grown out to edge of the lagoon footprint
- Waterbody so close to town will likely result in an increase of mosquitoes

Tradeoffs to consider for town inhabitants
Recreation and aesthetics vs. dengue, chikungunya and pesticides
Public Values Forum – Guánica Bay Watershed

Goals:

• Identify stakeholder objectives across the Guánica Bay watershed (not just for corals)
• Develop alternatives for achieving those objectives
• Examine tradeoffs and intended/unintended consequences
• Explore possible management actions for achieving multiple values
• Translate decision tools for future application
### Alternative Decisions from Stakeholders

#### Area

**Economic**
- Protect agricultural land (Fully utilize potential?)
  - **Values**
    - Reduce % fallow land
    - Diversify crops
    - Promote BMP
    - /Ha of production (by type of crop)
    - Salinity of soil
    - S farm production loss due to land under water
  - **Performance Measures**
    - Implement development plans
    - Ensure continuity of plans
    - Implement BMP incentives plan
    - Ensure no net loss of agricultural land
    - Avoid practices that increase soil salinity
    - Improve mechanism for water drainage (clean channels to increase water flow)
  - **Actions**
    - Implement development plans
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**Aquatic ecology**
- Improve water quality (in rivers and ocean?)
  - **Values**
    - Turbidity
    - Solids in suspension
    - Nutrients
    - Coliforms
  - **Performance Measures**
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**Land ecology**
- Restore fauna and habitat
  - **Values**
    - Index of species biodiversity
    - Kilometers of ecological corridors
    - Ha habitat suitable for trust species
  - **Performance Measures**
    - Improve water quality before, during and after lagoon restoration
    - Educate community about
    - Convert Guánica WWTP to tertiary
    - Restore marshes ability to filter sediments
    - Consistent enforcement of regulations
  - **Actions**
    - Improve water quality before, during and after lagoon restoration
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**Social**
- Promote education
  - **Values**
    - Environmental attitude survey
    - Number of community members acting in projects
  - **Performance Measures**
    - Reduce % fallow land
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**Forest healthy, viable aquatic community**
- Improve quality of the aquatic environment
  - **Values**
    - Reduce % fallow land
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#### Performance Measures

- **Action**
  - Implement development plans
  - Ensure continuity of plans
  - Implement BMP incentives plan
  - Ensure no net loss of agricultural land
  - Avoid practices that increase soil salinity
  - Improve mechanism for water drainage (clean channels to increase water flow)

- **Key Performance Indicators**
  - Economic
    - Improve water quality
  - Aquatic ecology
    - Improve water quality
  - Land ecology
    - Improve water quality
  - Social
    - Improve water quality

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**Gregory and Gonzalez 2013**
### Alternative Decisions from Stakeholders

<table>
<thead>
<tr>
<th>Area</th>
<th>Values</th>
<th>Performance Measures</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>Protect agricultural land (Fully utilize potential?)</td>
<td>• Reduce % fallow land</td>
<td>• Implement development plans (?)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Diversify crops</td>
<td>• Ensure continuity of plans</td>
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</tr>
</tbody>
</table>

### Aquatic ecology
- **Improve water quality (in rivers and ocean?)**
  - Turbidity
  - Solids in suspension
  - Nutrients
  - Coliforms
- Actions: • Restore lagoon
  - Monitor water quality before, during and after lagoon restoration
  - Educate community about (?)
  - Convert Guánica WWTP to tertiary
  - Restore marshes ability to filter sediments (?)
  - Consistent enforcement of regulations

### Land ecology
- **Restore fauna and habitat**
  - Index of species biodiversity
  - Kilometers of ecological corridors
  - Ha habitat suitable for trust species
- Actions: • Convert sun grown to shade grown coffee
  - Establish riparian buffers
  - Reforestation
  - Forest enhancement
  - Restore Guánica lagoon
  - Land acquisition for conservation purposes

### Social
- **Promote education**
  - Environmental attitude survey
  - Number of community members acting in projects
- Actions: • Promote pro-environmental attitudes via formal and informal education
  - Implement adopt a beach program
  - Promote capacity building and in schools and communities

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**Gregory and Gonzalez 2013**
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## Consequence Table for Lagoon Restoration
### Stakeholder Discussion Example

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Alt. 1</th>
<th>Alt. 2</th>
<th>Alt. 3</th>
<th>Alt. 4</th>
<th>Alt. 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance Measure</td>
<td>Current status</td>
<td>Full lagoon restoration</td>
<td>2008 mgmt. plan</td>
<td>Adaptive mgmt. plan</td>
<td>Other plan</td>
</tr>
<tr>
<td>Protect and create economic opportunities</td>
<td>$/hectare of crop production</td>
<td>$ of jobs created</td>
<td>Cost of water infrastructure</td>
<td>Predicted consequences from models or expert judgement</td>
<td></td>
</tr>
<tr>
<td>Restore and conserve the land environment</td>
<td>Index of species biodiversity</td>
<td>% reduction in soil erosion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Restore and conserve the aquatic environment</td>
<td>Water turbidity</td>
<td>Diversity of aquatic life</td>
<td># of recreation activities</td>
<td>Hectares forested</td>
<td></td>
</tr>
<tr>
<td>Promote social &amp; cultural opportunities</td>
<td>Environmental attitude</td>
<td>% people connected to wastewater treatment plants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land Ecology</td>
<td>Aquatic Ecology</td>
<td>Economics</td>
<td>Social</td>
<td></td>
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<td>----------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Research opportunities</td>
<td>1. Promote shade grown coffee</td>
<td>1. Encourage more shade-grown coffee and reforestation</td>
<td>1. Best management and conservation practices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Improve river quality</td>
<td>2. Reforestation and buffer zone</td>
<td>2. Establish riparian buffers</td>
<td>2. Measure effectiveness of BMPs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Diversify economic opportunities</td>
<td>5. Education and investigation about drainage system in Lajas valley</td>
<td>5. Restore drainage system</td>
<td>5. No agricultural land loss</td>
<td></td>
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</table>
 Scenario Preferences
Anonymous nonbinding voting by watershed stakeholders

Group 2: Aquatic ecology

- Promote shade grown coffee: 4%
- Reforestation and buffer zone: 14%
- Promote BMP (soil, water, sea): 20%
- Monitor water quality in the watershed: 20%
- Education and investigation about drainage system in Lajas valley: 13%
- Educate public and industry in reduction and recycle of waste: 13%
- Education and enforcement of water laws: 15%

Gregory and Gonzalez 2013
Structured Decision Making

A process to elicit and organize key **stakeholder values** and relevant **scientific knowledge** for making decisions

**Strengths of SDM**
- Facts and values
- Multiple perspectives
- Holistic
- Democratic
- Flexible
- Multiple knowledge sources

Value added scientific research
Benefits of Reservoir System
High priority objective from Public Value Forum

- Irrigation
- Flood protection
- Hydroelectric power
- Drinking water
- Aesthetics
- Recreation
- Fishing
- Sediment trapping

Decline of 60 yr-old reservoir system
- Reservoirs are nearly 50% filled with sediment
  - Reduced water storage capacity
  - Reduced sediment capture capacity
- Increase in sediment discharge to downstream habitats, including coral reefs
Can we extend the longevity of reservoirs? (and their ability to stem sediment efflux)

Alternative 1: Conversion of sun grown to shade grown coffee

Advantages
• Reduces topsoil loss
• Reduces water quality impairment
• Reduces downstream effects on fish and wildlife habitat

Disadvantages
• Cost in time and money to replant with shade-grown varieties
• Marketing a new coffee that may or may not be accepted
Alternative 2: Dredging sediment from reservoirs

Advantages
• Increase drinking water availability
• Improve water quality, aesthetics and recreation
• Increase flood protection and hydroelectric capacity
• Increase sediment trapping capacity, which protects downstream habitats

Disadvantages
• Expensive
• Environmental damage
• Sediment disposal
Science Challenges

Assessing the sediment contribution from coffee farm erosion and the reduction in sediment if farms were converted from sun-grown to shade-grown coffee.

Estimating the loss of trapping efficiency and the increase of sediment discharge to downstream ecosystems as the reservoir fills with sediment.
Bayesian Belief Network to evaluate increased life expectancy (water storage capacity) of Lago Lucchetti by coffee conversion and dredging
## Estimated Life Expectancy* for Lago Lucchetti for Two Decision Scenarios—Coffee Conversion and Dredging

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Life Expectancy* (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coffee conversion</strong></td>
<td></td>
</tr>
<tr>
<td>No conversion</td>
<td>48 ± 16</td>
</tr>
<tr>
<td>Partial Implementation</td>
<td>52 ± 17</td>
</tr>
<tr>
<td>Full Implementation</td>
<td>56 ± 18</td>
</tr>
<tr>
<td><strong>Dredging</strong></td>
<td></td>
</tr>
<tr>
<td>No dredging</td>
<td>48 ± 16</td>
</tr>
<tr>
<td>50% of sediment</td>
<td>75 ± 18</td>
</tr>
<tr>
<td>100% of sediment</td>
<td>81 ± 19</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td></td>
</tr>
<tr>
<td>Partial Implementation/50% dredge</td>
<td>79 ± 19</td>
</tr>
<tr>
<td>Partial Implementation/100% dredge</td>
<td>85 ± 18</td>
</tr>
<tr>
<td>Full Implementation/50% dredge</td>
<td>83 ± 19</td>
</tr>
<tr>
<td>Full Implementation/100% dredge</td>
<td>89 ± 18</td>
</tr>
</tbody>
</table>

*Life Expectancy=time until there is no water storage capacity remaining*
Application of a Structured Decision Process for Informing Watershed Management Options in Guánica Bay, Puerto Rico

(EPA 600/R-15/248, January 2016); EPA Science Inventory
https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NHEERL&dirEntryId=324903
Useful Decision Tools and Approaches

- **Stakeholder engagement** early and often to understand objectives, alternatives and the changing decision landscape
- **Structured Decision Approach** to accommodate both stakeholder objectives and scientific knowledge
- **Systems Framework** to provide transparency and to identify unintended consequences
- **Consequence comparisons** to characterize tradeoffs across multiple objectives
- **Value added scientific research** to provide information that directly influences a decision

Thank you

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R2 Coral Reef Protection Plan
Extended plan

Means objectives

- Foster sustainable practices
- Achieve regulatory compliance
- Build procedural capacity
- Learn and reduce uncertainties
- Improve coastal water quality

Fundamental objectives

- Increase environmental benefits
- Increase economic benefits
- Increase social benefits
- Increase human health benefits
- Increase governance benefits/Fulfill political commitments
- Increase learning benefits