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Objectives

- Long-term goals of the project.
- Project’s progress.
- Sampling design.
- Proposed sampling schedule.
Long-term goals

• Set up a network of 12 representative coral reef permanent monitoring sites in the Puerto Rican archipelago.

• Apply uniform sampling design and statistical methods.
Long-term goals

• Identify what early warning signals indicate ecological change in coral reefs.

• Incorporate documentation of additional parameters:
  – Coral vitality (*sensu* Dustan).
  – Disease/syndrome prevalence.
Long-term goals

• Incorporate monthly monitoring of water quality parameters at selected locations.

• Apply multivariate statistical approaches to document spatial and temporal variation patterns in benthic and fish community structure.
Long-term goals

• Apply alternative statistical approaches (e.g. Effect Size Statistic) to document spatial and temporal uncertainty.

  – Important to separate natural uncertainty from any variable effect:

    • Water quality effects.
    • Management effects.
Long-term goals

- Theoretical and practical training of DNER personnel.

- Have DNER taking control of the Long-Term Monitoring Program within approximately 2 to 3 years.
Initial Research Question

• **Spatial patterns.**

• Are there any significant site or regional spatial variation patterns in the ecological status of coral reef communities?
Original sampling design

- **Unbalanced hierarchical design.**

- Region (East, South – Year 1)
  - Sites (East, n=2); (South, n=5)
    - Reefs/Site (n=3) [N=21]
      - Depth (3-10 m; 10-20 m)
        » Transects (n=4)
Original sampling design

- **Unbalanced hierarchical design.**

- Region (Southwestern, West – Year 2)
  - Sites (Southwestern, n=3); (West, n=2)
  - Reefs/Site (n=3) [N=15]
    - Depth (3-10 m; 10-20 m)
      » Transects (n=4)
Suggested sampling design

• Balanced hierarchical design.

• Region (East, South – Year 1)
  – Sites (n=3)
    • Reefs (n=3) [N=18]
      – Depth (3-10 m; 10-20 m)
        » Transects (n=4)
Suggested sampling design

• Balanced hierarchical design.

• Region (Southwestern, West – Year 2)
  – Sites (n=3)
    • Reefs (n=3) [N=18]
      – Depth (3-10 m; 10-20 m)
        » Transects (n=4)
Benthic sampling

• Balanced hierarchical design.

• Time (every 2 years)

• Region
  – Sites (n=3)
    • Reefs (n=3) [N=18]
    – Depth (3-10 m; 10-20 m)
    » Transects (n=4)
Challenging questions

- Monitoring frequency

- Every 2 years: many sites, low temporal replication. Low resolution of short-term factors.

- Every 1 year: fewer sites, higher temporal replication. Higher resolution of short-term factors.
Challenging questions

- Site selection
- Confounding effects:
  - Structural coral reefs?
  - Hard grounds?
  - Highly degraded vs. “healthy”?
Challenging questions

• Management level

• Confounding effects:
  • Natural Reserve?
  • No-fishing reserve?
  • Control?
Challenging questions

- Environmental gradient effects
- Confounding effects:
  - Distance from pollution or stress sources?
  - Fishing pressure?
Challenging questions

• Keep it as it is

• Trade offs:
  • Does not respond any specific question.
  • Unbalanced statistical design.
  • Confounding temporal and spatial effects.
Challenging questions

• Are we having DNER collaboration?
• Personnel?
• Vessels?
• Water quality sampling equipment?

• If not:
• Limitation to sampling efforts.
• Not much to do regarding training DNER personnel.
Data collection

- Benthic sampling
- Fixed linear transects.
  - 10 m-long.
  - % cover.
  - H’n.
- Digital images.
Data collection

• Benthic sampling

• Fixed belt transects.

• 10 x 2 m.
• Coral vitality.
• Disease/syndromes.
• Damselfish.
• *Diadema antillarum*.
• Lobsters.

• Digital images.
Data collection

- Fish sampling
- Haphazard belt transects.
- 25 x 4 m.
- Whole fish community.
- Follow similar hierarchical design as benthic sampling.
Water quality sampling at selected sites

- Water transparency.
- Turbidity.
- Dissolved oxygen.
- Chlorophyll.
- Nutrients.

- 3 replicates/reef/month at Culebra and Cordillera sites.
Effects of water transparency

\[ y = 10.69 + 1.45x \]

\[ r = 0.7995 \]

\[ p < 0.0001 \]
<table>
<thead>
<tr>
<th>Factor</th>
<th>GL&lt;sup&gt;a&lt;/sup&gt;</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riqueza especies&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19,112</td>
<td>1.95</td>
<td>11.57</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Abundancia colonias&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19,112</td>
<td>10.28</td>
<td>8.67</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>% Coral&lt;sup&gt;c&lt;/sup&gt;</td>
<td>19,112</td>
<td>0.33</td>
<td>16.57</td>
<td>&lt;0.0001</td>
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<tr>
<td>% Algas&lt;sup&gt;c&lt;/sup&gt;</td>
<td>19,112</td>
<td>0.32</td>
<td>14.19</td>
<td>&lt;0.0001</td>
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<tr>
<td>% Esponjas&lt;sup&gt;c&lt;/sup&gt;</td>
<td>19,112</td>
<td>0.02</td>
<td>5.26</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>% Zoántidos&lt;sup&gt;c&lt;/sup&gt;</td>
<td>19,112</td>
<td>0.09</td>
<td>15.45</td>
<td>&lt;0.0001</td>
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<tr>
<td>H’n</td>
<td>19,112</td>
<td>1.45</td>
<td>11.33</td>
<td>&lt;0.0001</td>
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<tr>
<td>J’n</td>
<td>19,112</td>
<td>0.20</td>
<td>6.52</td>
<td>&lt;0.0001</td>
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<tr>
<td>H’c</td>
<td>17,109</td>
<td>1.23</td>
<td>8.83</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>J’c</td>
<td>17,109</td>
<td>0.04</td>
<td>4.88</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

<sup>a</sup> GL = grados de libertad (between, within).

<sup>b</sup> Datos transformados a la raíz cuadrada.

<sup>c</sup> Datos transformados al arcseno- (raíz cuadrada).
Spatial pattern analysis
<table>
<thead>
<tr>
<th>Factor</th>
<th>Global R statistic</th>
<th>Significancia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prueba Global (^a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tratamiento (^b)</td>
<td>0.329</td>
<td>0.4%</td>
</tr>
<tr>
<td>Pueba de pares de Tratamiento</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I vs. II</td>
<td>0.026</td>
<td>38.6% (NS)</td>
</tr>
<tr>
<td>I vs. III</td>
<td>0.484</td>
<td>0.7%</td>
</tr>
<tr>
<td>I vs. Bombardeo</td>
<td>-0.116</td>
<td>66.7% (NS)</td>
</tr>
<tr>
<td>II vs. III</td>
<td>0.306</td>
<td>4.8%</td>
</tr>
<tr>
<td>II vs. Bombardeo</td>
<td>0.679</td>
<td>6.7% (NS)</td>
</tr>
<tr>
<td>III vs. Bombardeo</td>
<td>1.000</td>
<td>3.6%</td>
</tr>
</tbody>
</table>

\(^a\) Prueba ANOSIM basada en 5,000 permutaciones. Datos transformados a la raíz cuadrada.

\(^b\) Tratamientos: I= <5 m, II= 5-15 m, III= >15 m, Bombardeo.
<table>
<thead>
<tr>
<th>Componente</th>
<th>Abundancia</th>
<th>% Contribución</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (&lt;5 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algas</td>
<td>0.79</td>
<td>64.01</td>
</tr>
<tr>
<td><em>Porites astreoides</em></td>
<td>0.02</td>
<td>6.83</td>
</tr>
<tr>
<td><em>Siderastrea radians</em></td>
<td>0.01</td>
<td>4.09</td>
</tr>
<tr>
<td>II (5-15 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algas</td>
<td>0.67</td>
<td>43.05</td>
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<tr>
<td><em>Erythropodium caribbaorum</em></td>
<td>0.04</td>
<td>10.34</td>
</tr>
<tr>
<td><em>Siderastrea siderea</em></td>
<td>0.04</td>
<td>6.23</td>
</tr>
<tr>
<td>III (&gt;15 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algas</td>
<td>0.54</td>
<td>31.54</td>
</tr>
<tr>
<td><em>Montastraea annularis</em></td>
<td>0.21</td>
<td>13.92</td>
</tr>
<tr>
<td><em>Porites astreoides</em></td>
<td>0.04</td>
<td>7.97</td>
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<tr>
<td>Bombardeo</td>
<td></td>
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<tr>
<td>Algas</td>
<td>0.86</td>
<td>86.46</td>
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<tr>
<td><em>Siderastrea radians</em></td>
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<td>8.19</td>
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<tr>
<td>Esponjas</td>
<td>0.01</td>
<td>2.82</td>
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</table>
Spatial patterns
(Dominance x Treatment)

Macroalgae

% Contribution

Treatment categories

<5 m  5-15 m  >15 m  Bomb
Spatial patterns (Dominance x Treatment)

Montastraea annularis spp. complex

% Contribution

Treatment categories

<5 m  5-15 m  >15 m  Bomb
Spatial patterns (Dominance x Treatment)
<table>
<thead>
<tr>
<th>Tratamientos</th>
<th>Componentes</th>
<th>A1</th>
<th>A2</th>
<th>% Contribución</th>
</tr>
</thead>
<tbody>
<tr>
<td>I vs. II</td>
<td>Montastraea annularis</td>
<td>0.02</td>
<td>0.08</td>
<td>11.76</td>
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<tr>
<td>I vs. III</td>
<td>Montastraea annularis</td>
<td>0.02</td>
<td>0.21</td>
<td>16.55</td>
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<tr>
<td>I vs. Bomb.</td>
<td>Zoántidos</td>
<td>0.04</td>
<td>0.10</td>
<td>17.09</td>
</tr>
<tr>
<td>II vs. III</td>
<td>Montastraea annularis</td>
<td>0.08</td>
<td>0.21</td>
<td>12.81</td>
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<tr>
<td>II vs. Bomb.</td>
<td>Zoántidos</td>
<td>&lt;0.01</td>
<td>0.10</td>
<td>12.51</td>
</tr>
<tr>
<td>III vs. Bomb.</td>
<td>Montastraea annularis</td>
<td>0.00</td>
<td>0.21</td>
<td>16.13</td>
</tr>
</tbody>
</table>
Effect Size (basado en BACIPS)

Coral species richness

Effect Size ($D_i - D_0$)

Treatment comparisons

-4 -3 -2 -1 0 1 2 3 4

I v II  I v III  I v Bomb  II v III  II v Bomb  III v Bomb
Effect Size (basado en BACIPS)

<table>
<thead>
<tr>
<th>Treatment comparisons</th>
<th>Effect Size ($D_i - D_c$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I v II</td>
<td>-0.20</td>
</tr>
<tr>
<td>I v III</td>
<td>-0.15</td>
</tr>
<tr>
<td>I v Bomb</td>
<td>-0.10</td>
</tr>
<tr>
<td>II v III</td>
<td>-0.05</td>
</tr>
<tr>
<td>II v Bomb</td>
<td>0.00</td>
</tr>
<tr>
<td>III v Bomb</td>
<td>0.05</td>
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</table>

% Coral cover

Treatment comparisons
Hypothesis development

Predator overfishing

Increased damselfish densities

Declining primary habitats of damselfishes (A. cervicornis)

Increased coralivorous snail and fireworm densities

Coral tissue predation

Invasion of secondary habitats (predation of new coral polyps)

Increased frequency of coral tissue lesions and susceptibility to pathogens

Localized increase in nitrogen fixation

Increased filamentous algal cover

Increased sediment trapping by algal turfs, decline in coral tissue regeneration and recruitment rates

Cyanobacterial bloom

Water transparency decline due to phytoplankton bloom, increased concentration of solid suspended material, increased sedimentation

Decline in nutrient-rich runoff pulses

Invasion by pathogenic microorganisms, induction of physiological stress, alteration of coral-associated microflora

Increase in highly concentrated dissolved nutrient pulses

Migration of herbivore fish schools as a behavioral response to spearfishing

Coral mortality as a result of recurrent disease/syndrome outbreaks

Declining herbivory

Increased macroalgal cover

Bleaching-related Erythropodium caribbaeorum mortality

Increased coral colony mortality

Substrate pre-occupation outcompeting of corals, inhibition of coral tissue regeneration and recruitment

Localised increase in nitrogen fixation

Increased filamentous algal cover

Increased coral colony mortality

Increased bioerosion rates

Increased sediment trapping by algal turfs, decline in coral tissue regeneration and recruitment rates

Decline in reef biodiversity, coral functional groups (i.e., Acroporids), engineer species (bioconstructors), essential fish habitats, shortening of food webs and declines in ecosystem processes

NET COMMUNITY PHASE SHIFT
¡Gracias! ¿Preguntas para papá?

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