Developing a Biological Condition Gradient (BCG) for the Protection of Coral Reefs in Guánica Bay

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December 2014

Process to Develop a Coral Reef BCG

- **Conduct coral reef assessments S. coast Puerto Rico with video documentation**
- **Establish expert panel of coral reef scientists**
- **Hold a series of workshops & webinars to elicit expert judgment and group deliberations**

1. **August 2012 – La Parguera, PR (conceptual & narrative)**
2. **March 2014 – El Yunque, PR (quantitative)**
3. **Spring 2015 – San Juan, PR (validation & calibration)**

2012 La Parguera, PR Workshop
Coral Reef BCG Conceptual Model

- Establish expert panel of coral reef scientists.

- ID key qualitative & semi-quantitative ecological attributes to determine coral reef condition using visual media & data from field studies.

- Use reef attributes to recommend categorical condition rankings for establishing BCG levels along a along a human stressor gradient.

- Develop expert-judgment-based rules for discerning condition levels.

- Discern through expert consensus reef attributes that characterize biological integrity (natural, fully-functioning system of reef organisms and communities) for coral reefs. Condition classes reflect continuum of environmental quality from pristine (left) to intermediate (middle), to severely degraded (right).

- Develop conceptual, narrative model to describe how biological attributes of coral reefs change along a gradient of increasing human-induced stress.

Narrative Coral Reef Attributes

- **Physical structure**: topographical heterogeneity

- **Corals**: species, shape, size, demographics

- **Sponges & Octocorals**: shape, size, habitat provision

- **Condition**: amount of tissue, disease, bleaching, tumors

- **Fish**: abundance, biomass and trophic interactions

- **Vertebrates**: charismatic megafauna

- **Other Invertebrates**: Diadema, conch, lobster, crabs

- **Algae/SAVs**: crustose coralline, calcareous, filamentous or fleshy algae

Coral Reef Attributes of Very Good Site

Condition Level	Corals	Fish
VERY GOOD to EXCELLENT (Approximate BCG Level 1)	Hi species diversity including rare, large old colonies with tissue coverage (*Montastraea*); balanced population structure (old & middle-aged colonies, recruits); *Acropora* thickets present, Low prevalence disease, tumors, mostly live tissue on colonies	Populations have balanced species abundance, sizes & trophic interactions

Coral Reef Attributes of Good Site

Condition Level	Corals	Fish
GOOD (Approximate BCG Level 3) 	Moderate coral diversity; large old colonies (*Montastraea*) with some tissue loss; varied population structure (usually old colonies, few middle aged & some recruits); *Acropora* thickets maybe present; rare species absent. Disease and tumor prevalence slightly above background level, more colonies have irregular tissue loss	Decline of large apex predators, groupers & snappers, noticeable; small reef fish more abundant

Coral Reef Attributes of Poor Site

Condition Level	Corals	Fish
POOR (Approximate BCG Level 6) 	Absence of colonies, those present are small, only highly tolerant species, little or no tissue. High incidence disease on small colonies of corals, sponges, & gorgonians, if present, low or no tissue coverage	No large fish, few tolerant species, lack of multiple trophic levels

Coral Reef Data Portal

- **Coral reef condition data available for partners and experts**

- **Pilot with EPA/NOAA data USVI & PR surveys**
  - **stony corals   fish   macroinvertebrates**

- **Taxonomy normalized ITIS (_www.itis.gov_)**

- **Data geo-referenced**

- **Standardized data files contain:**
  - Data in original format EPA or NOAA data
    Metadata
    X-walk of normalized data into standard metrics
    Final standardized data
    Data files in MS Excel 7

Application URL: http://www.epa.gov/storet/dw_home.html
or
http://www.waterqualitydata.us/

Coral Reef Species Sensitivity Database (CRSSD)

- **Document tolerance to anthropogenic stressors**

- **Taxa differ in their sensitivities to anthropogenic stressors**

- **Changes in species, abundance and diversity of taxa across human stressor gradients are important and useful indicators of adverse effects**

- **Tolerance information is not available for many coral reef taxa and human disturbances (temperature, nutrients, sediments, etc.)**

- **Alexandra M. Galindo 2014 Coral Reef Task Force Sunia Fellow, MS student UPR**

CRSSD for the Caribbean Stony Corals and Fish

- Encyclopedia of Life (http://eol.org): document min/max conditions (T, z, PO_4, NO_4 DO; life history Δ, reprod.)

- Created an EndNote^{TM} template for library citation, pdf & stressor database (species, stressor, intensity, duration & result)

- Web of Science (http://apps.webofknowledge.com): Reviewed the scientific literature for information about individual coral reef species' sensitivity/tolerance to stressors

- Downloaded relevant citation/abstract to EndNoteX7 into searchable database

- Develop MS Access database to summarize & analyze

Structured Decision-Making

BCG Contributions

1. Clarify the Decision Context

2. Define Objectives & Performance Measures

3. Develop Alternatives

4. Estimate Consequences

5. Evaluate Trade-offs & Select

6. Implement and Monitor

Iterate as required

Guánica Bay Watershed Management Plan
A Pilot Project for Watershed Planning in Puerto Rico
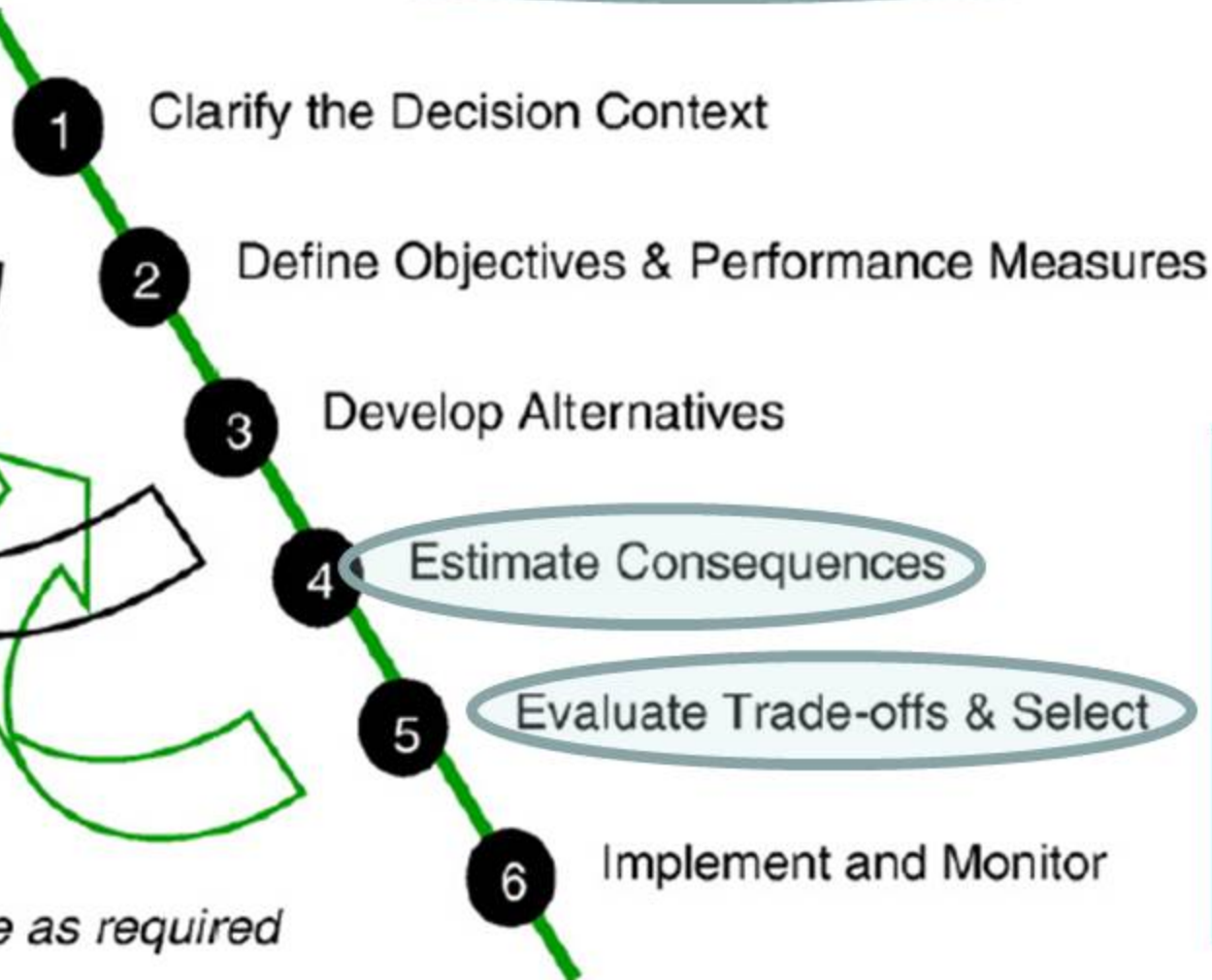
2014 El Yunque, PR Workshop
Semi-Quantitative Decision Model

- Begin to develop a quantitative Biological Condition Gradient (BCG)

- Consider different spatial scales and attributes associated with the entire reef ecosystem

- Consider tolerance of coral reef species to various anthropogenic stressors

- Develop preliminary multi-attribute narrative decision rules

Workshop Process
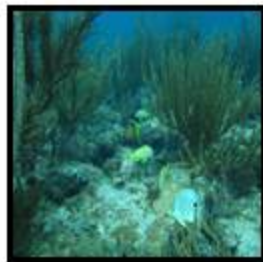
- **Expert groups: sessile organisms & mobile organisms**
    Expert judgment
    Group deliberations

- **Assign species to attribute levels I-VI (sensitivity to human stressors) & document rationale**
    Stony Coral stressors: Hi T & sediment
    Fish stressors: Fishing pressure & sediment

- **Use EPA survey data, assign stations to BCG condition levels**

- **Develop preliminary multi-attribute decision rules**

BCG Condition Levels

Biological Condition

1

2

3

4

5

6
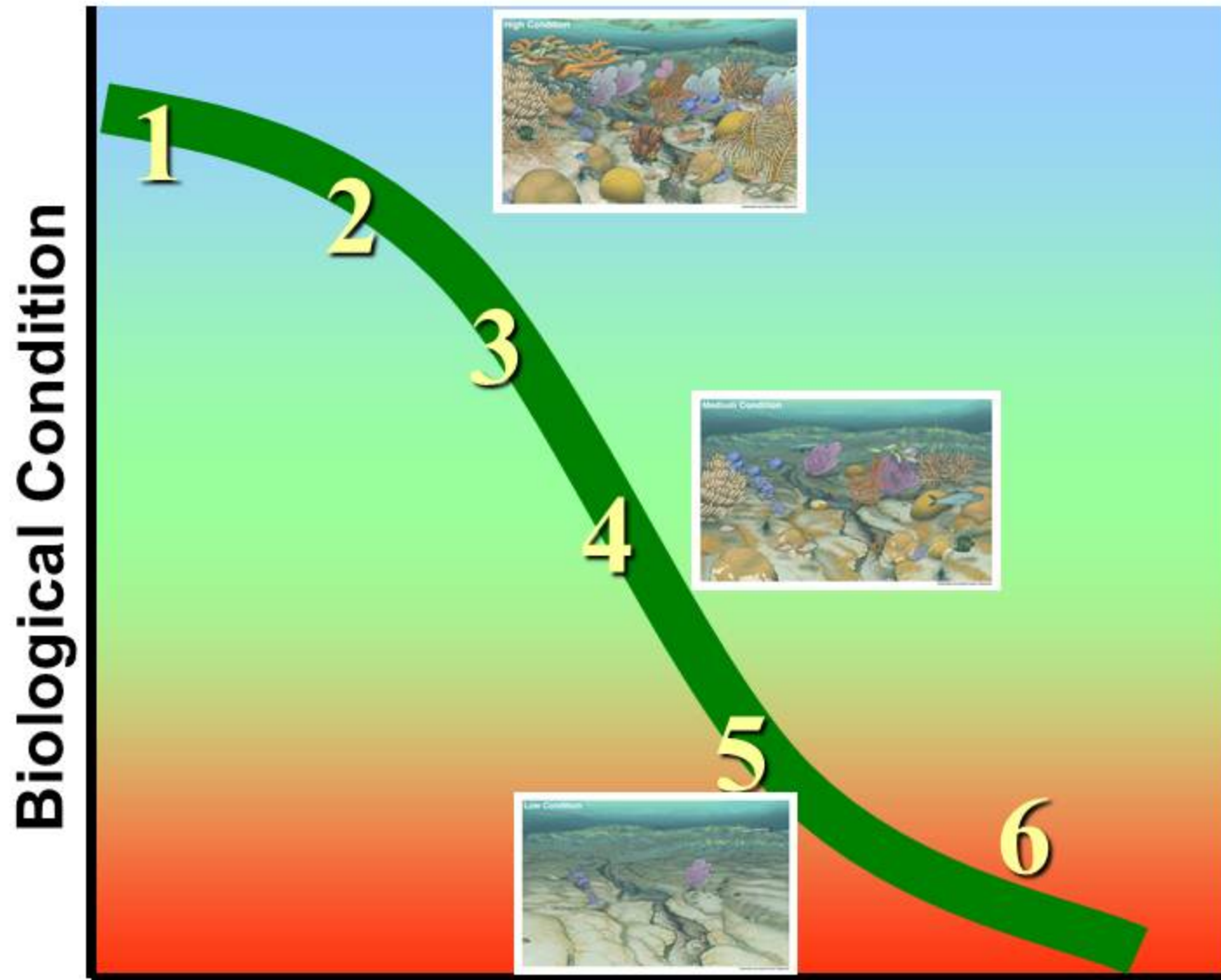
Increasing Effect of Human Activity

BCG Level Assignments

Sample	Location	Date				Habitat	Area	Count
Samp0007	Jobos	11/29/201	3	2	3	reef	160,710	21
Samp0020	Guanica	12/3/2011	3	3	3	hardbottom	46,299	17
Samp0040	Guanica	12/4/2010	4	4	4	hardbottom	27,183	13
Samp0046	La Parguera	12/2/2010	3	3+	3	reef	244,536	25
Samp0051	Guanica	12/4/2010	4	4	5	hardbottom	13,214	12
Samp0057	Guayanilla	12/2/2011	4	4+	5	reef	148,829	22
Samp0058	La Parguera	12/1/2010	3.5	4+	4	reef	100,602	18
Samp0059	Guayanilla/Jobos	11/29/201	3	3	4	hardbottom	34,070	16
Samp0060	Jobos	12/13/201	4	4	4-	hardbottom	14,877	17
Samp0071	Jobos	11/28/201	4	4	4	hardbottom	719,730	16
Samp0083	Guanica	12/2/2011	3	2-	3	hardbottom	94,739	24
Samp0090	Jobos	11/28/201	3	3+	3	reef	133,011	24
Samp0103	La Parguera	12/7/2011	5	5	5	hardbottom	2,346	5
Samp0106	Guayanilla	12/12/201	4	3	4	hardbottom	29,253	19
Samp0114	Guanica	12/4/2010	4	4	4-	hardbottom	44,264	10
Samp0116	Guayanilla	12/2/2011	4.5	4	5	hardbottom	11,198	11
Samp0124	Guayanilla/Jobos	11/27/201	5	5	5	hardbottom	9,655	7
Samp0125	Guanica	12/10/201	5	5	5	hardbottom	2,687	7
Samp0130	Guayanilla	12/11/201	4	4	4	reef	133,146	14
Samp0137	La Parguera	12/8/2011	3	2-	3	hardbottom	38,858	12
Samp0042	Jobos	12/13/201	3	3	3-	reef	36,918	20
Samp0063	Guanica	12/10/201	4	4	5	patch reef?	20,791	10
Samp0113	Guanica	12/9/2010	5	5	5	0	15,761	7
Samp0140	Jobos	11/28/201	4+	3-	4	0	167,494	15
Samp0070	Jobos	12/13/201	x	x	x	0	15,862	12
Samp0099	La Parguera	11/30/201	x	x	x	0	55,617	21
Samp0138	Guanica	12/2/2011	3	3	3	0	126,571	25
Samp0087	Jobos	12/13/201	x	x	x	0	23,634	9
SAMP0022	Guayanilla	12/6/2010	x	x	x	0	5,939	5
Samp0082	Guayanilla	12/11/201	6	6	6	0	821	2
Samp0131	Guayanilla	12/11/201	3	3	3	0	58,514	26

Site condition data provided

Distance (shore, km)	1.49
Distance (shelf, km)	1.66
Distance (disturbance)	6.150898
Sediment Threat	50%_100008
Rugosity Index (EPA) (m)	1.116
Diadema (100 m²)	0
Coral Density (m²)	1.76
Height_sd	21.86
Coral_2D_Cover_Live	0.264
Coral_Richness_Live_Transect_Area	9
CSA Total Live (3D)	14583.2
CSA Total Live (3D) m²	11714.1
Num Acroporids	0
Num massive colonies (Orbicella)	1
Sponge Density (m²)	4

STATION AND SAMPLE CHARACTERISTICS

StationID	1S1130
Region	Guunera
Latitude	Y/9367
Longitude	66.8266
ReefType	Linear Reef
Habitat	Coral Reef and Colonized Hardbottom
Depth (Coral, ft)	14
Distance (shore, km)	1.49
Distance (shelf, km)	1.66
Distance (disturbance)	6.150898
Sediment Threat	50%_100008
Rugosity Index (EPA) (m)	1.116
Diadema (100 m²)	0
Coral Density (m²)	1.76
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Coral_2D_Cover_Live	0.264
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CSA Total Live (3D)	14583.2
CSA Total Live (3D) m²	11714.1
Num Acroporids	0
Num massive colonies (Orbicella)	1
Sponge Density (m²)	4
Gorgonia Density (m²)	10.4
Sponge Morph Richness (5m²)	2
Gorgonia Morph Richness (5m²)	4
Fish, Richness (100-m²)	24
Fish, Density (100 m²)	407
Fish, Length (mean, cm)	9.1
Fish, Length (std dev, cm)	17.3
Fish, Total Biomass (kg/km²)	94738.5
Fish, Number of Schools	5
Acanthuridae(Tangs, Doctor and Surgeonfish)	6.9%
Scaridae & Sparosomids(Parrotfish both familie	11.8%
Chaetodontidae (Butterfly fish)	3.4%
Haemulidae (grunts)	14.7%
Pomacentridae (damsels)	12.5%
Labridae (wrasses)	43.2%
Lutjanidae & Carangidae (Snappers & Jacks)	6.1%
Serranidae (Groupers)	0.2%
Biomass, Herbivore	36763.9
Biomass, Piscivore, Small	4155.4
Biomass, Piscivore, Large	0.0

Species Attribute Level Assignments

BCG Attribute	Common Name	Scientific Name	Density (100-m²)	Biomass (kg/km²)
4	longspine squirrelfish	Holocentrus rufus	2	1,903.6
3	blackbar soldierfish	Myripristis jacobus	1	1,068.9
2	trumpet fish	Aulostomus maculatus	1	146.1
4	ocean surgeonfish	Acanthurus bahianus	21	9,588.2
2	blue tang	Acanthurus coeruleus	7	8,310.0
x	bar jack	Carangoides ruber	20	1,343.5
3	foureye butterflyfish	Chaetodon capistratus	10	1,495.5
3	banded butterflyfish	Chaetodon striatus	4	2,470.1
3	Caesar grunt	Haemulon carbonarium	15	15,431.1
2	smallmouth grunt	Haemulon chrysargyreum	30	10,111.7
4	french grunt	Haemulon flavolineatum	15	6,064.5
3	yellowhead wrasse	Halichoeres garnoti	1	815.2
3	clown wrasse	Halichoeres maculipinna	1	47.7
3	puddingwife	Halichoeres radiatus	4	682.6
3	bluehead wrasse	Thalassoma bifasciatum	170	6,984.8
3	schoolmaster	Lutjanus apodus	5	1,845.7
4	sergeant major	Abudefduf saxatilis	15	6,743.7
3	yellowtail damselfish	Microspathodon chrysurus	14	12,035.7
4	dusky damselfish	Stegastes adustus	11	1,318.5

Experts assign BCG Level to site

ParticipantAssignments

Participant	Score
Chris Jeffrey	2-
Lisamarie Carubba	3
Melanie McField	3
Michelle Scharer	3+
Richard Appeldoorn	3
Median	*3*

Station Rated Level 3

ExerciseID	Samp0083	Best Tier	2-	Assigned Tier	Reasoning
Collection Date	12/2/2011	Median Tier	3	3	
Collection Method	USEPA	Worst Tier	3	hardbottom	

TAXA'SUMMARY

BCG Attribute	Number of Taxa	Density (100-m²)	Biomass (kg/km²)	Pct Taxa	Pct Density	Pct Biomass
1	0	0	0.0	0%	0%	0%
2	3	38	18,567.7	13%	9%	20%
3	11	226	43,697.3	46%	56%	46%
4	9	123	31,130.0	38%	30%	33%
5	0	0	0.0	0%	0%	0%
6	0	0	0.0	0%	0%	0%
x	1	20	1,343.5	4%	5%	1%
Total	24	407	94,738.5	100%	100%	100%

Station Rated BCG Level 5

ExerciseID	Samp0082	Best Tier	6	Assigned Tier	Reasoning
Collection Date	12/11/2010	Median Tier	6	6	
Collection Method	USEPA	Worst Tier	6		

TAXA SUMMARY

BCG Attribute	Number of Taxa	Density (100-m²)	Biomass (kg/km²)	Pct Taxa	Pct Density	Pct Biomass
1	0	0	0.0	0%	0%	0%
2	0	0	0.0	0%	0%	0%
3	0	0	0.0	0%	0%	0%
4	2	7	821.0	100%	100%	100%
5	0	0	0.0	0%	0%	0%
6	0	0	0.0	0%	0%	0%
x	0	0	0.0	0%	0%	0%
Total	2	7	821.0	100%	100%	100%

TAXA LIST

BCG Attribute	Common Name	Scientific Name	Density (100-m²)	Biomass (kg/km²)	Family	TaxaMap
4	longfin damselfish	Stegastes diencaeu	6	719.2	Pomacentridae	map
4	beaugregory	tegastes leucosticti	1	101.8	Pomacentridae	map

Preliminary Multi-attribute Criteria for Fish at BCG Levels 2 & 3

➢ **BCG Level 2 (Very good)**
- Large groupers present
- Schools of snappers or piscivores
- Large predators present

➢ **BCG Level 3 (Good to fair)**
- High overall diversity
- High biomass
- Large body parrotfish
- Hi within-family diversity
- Groupers presences
- Presence of some (>1 spp) snappers and other piscivores

US Clean Water Act
(33 U.S.C. 1251 et seq.)

Objective: "To restore and maintain the chemical, physical and **biological integrity** of the Nation's waters".

Preliminary Multi-attribute Decision Criteria for Fish at BCG Levels 4 & 5

➢ **BCG Level 4 (Fair)**
- **Moderate to high diversity, but overall within-group diversity of snappers declined**
- **May be excesses of damselfish, wrasses**
- **At least one snapper, piscivore present**
- **Parrotfish present**

➢ **BCG Level 5**
- **More than 4-5 fish species**

Next Steps

- ## A series of webinars

   Coral Expert Group:
   - Reach consensus on reef classification
   - Do more station assignments
   - Attribute development for coral disease & bleaching

   Fish Expert Group:
   - Discuss attributes ecosystem function & connectivity; spatial & temporal scales of disturbance on biological

- ## Analyze & summarize 2nd workshop results

   - Establish the rules & evaluate how well they work
   - Initiate 1st draft of the BCG conceptual model for coral reefs
   - Consolidate narrative & semiquantitative rules from both workshops
   - Obtain additional results from more data & videos for other assemblages to compliment fish and coral species

Next Steps

- **Publications:**

  EPA report on 1st workshop

  Journal article(s) on workshops and results thus far

- **Calibration and Validation of Numeric Criteria for Corals and Fish 3rd Workshop (Spring 2015)**

- **Work on the Generalized Stressor Gradient (land-based threats, sea temperature, ocean acidification, fishing pressure combined somehow)**

- **Attribute VII – coral disease IAG with USGS**

Workshop Participants

Richard Appeldoorn, CCRI, UPR

Jerry Ault, U of Miami, RSMAS

David Ballantine, CCRI

Jorge Bauzá, San Juan Bay Estuary Program

Miguel Canals, Puerto Rico DNER

Lisa Marie Carrubba, NOAA

David Cuevas, US EPA/ Region 2

Ernesto Diaz, Puerto Rico DNER

William Fisher, US EPA/ORD

Edwin A. Hernández, UPR

Aaron Hutchins, TNC

Evelyn Huertas, US EPA/ Region 2

Chris Jeffrey, NOAA

Melanie McField, Smithsonian Institution

Jeiger Medina, Protectores de Cuencas

Jeff Miller, NPS, USVI NP

Francisco Pagan, CCRI, UPR

Simon Pittman, NOAA

Antares Ramos, NOAA

Loretta Roberson, UPR

Hector Ruiz, CCRI , UPR

Carolyn Rogers, USGS, U

Alberto Sabat, UPR

Lisbeth San Miguel-Rivera, EQB

Michelle Sharer, NOAA

Tyler Smith, UVI, St. Thomas

Alina Szmant, UNC Wilmington

Brandi Todd, US EPA/Region 6

Vance Vincente, Vincente & Associates

Ernesto Weil, CCRI, UPR

Paul Yoshioka, CCRI , UPR

Roberto Viquiera, Protectores de Cuencas
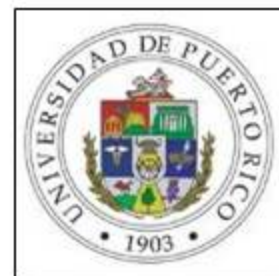
Biological Integrity

The capacity of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitats within a region.

QUANTITATIVE MEASURES

REFERENCE

CLASSIFICATION

(As modified from Karr and Dudley, 1981)
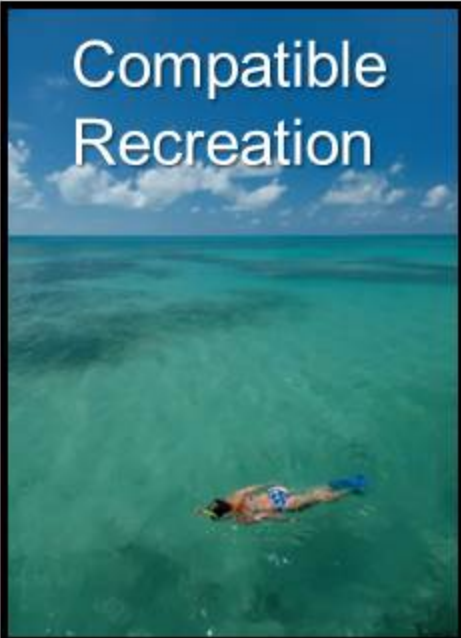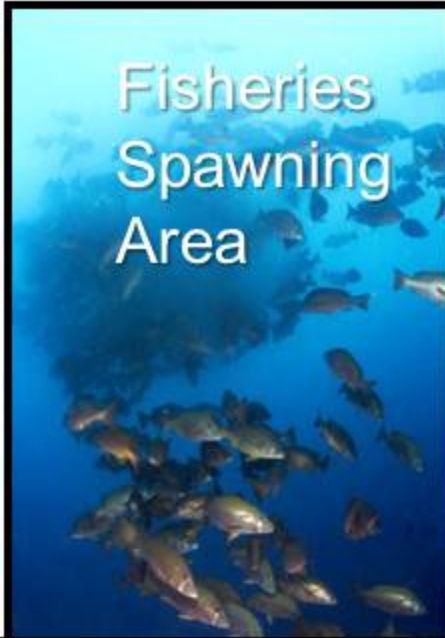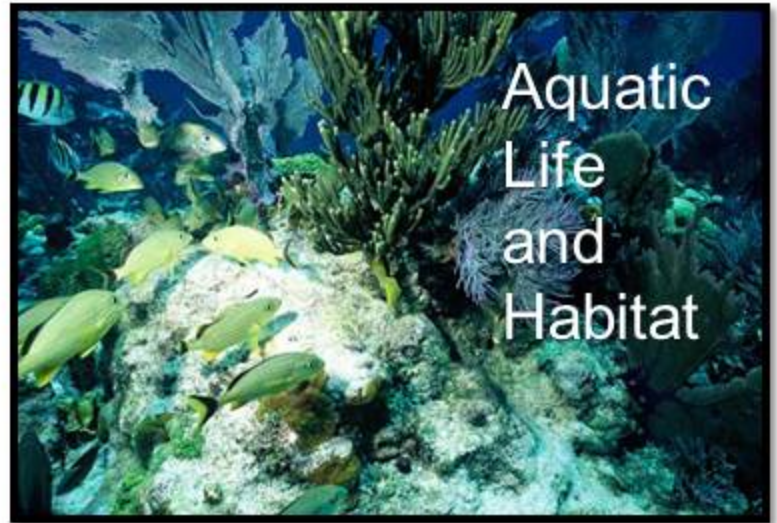
Designated Uses of Coral Reefs

Compatible Recreation

Fisheries Spawning Area

Aquatic Life and Habitat

Recreational

Scientific Investigations

5

Biological Condition Gradient

Natural structure & function of biotic community maintained

1

2 — **Minimal changes in structure & function**

3 — **Evident changes in structure and minimal changes in function**

4 — **Moderate changes in structure & minimal changes in function**

Major changes in structure & moderate changes in function — 5

Severe changes in structure & function — 6

Biological Condition

Increasing Effect of Human Activity ⟶

6
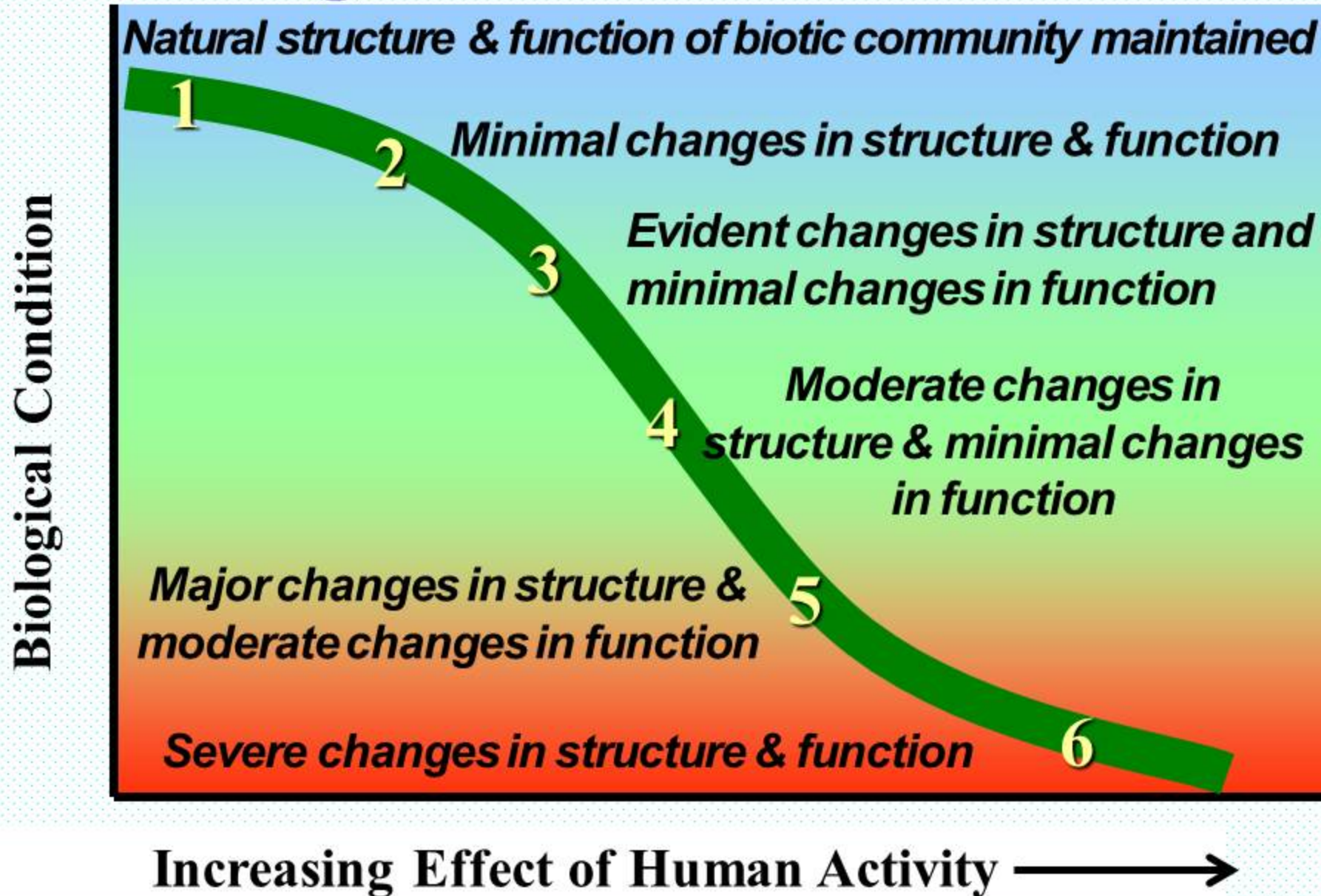
(Modified from Davies and Jackson 2006)

Key Concepts

The Biological Condition Gradient (BCG) has two key concepts that are often confused – Attributes and Levels.

- **Attributes** are measurable components of a biological system (Roman numerals)

  species composition

- **Levels** are the discrete levels of biological condition across a stressor-response curve (Integers)

  BCG level 1 high quality to level 6 is completely degraded

(Karr and Chu 1999)

Stream BCG Attributes

I. Historically documented, sensitive, long-lived regionally endemic taxa

II. Sensitive, rare or specialist taxa

III. Sensitive, ubiquitous taxa

IV. Taxa of intermediate tolerance

V. Tolerant taxa

VI. Non-native taxa

VII. Organism condition

VIII. Ecosystem function

IX. Influence of spatial and temporal scale of disturbance on biological response and recovery potential

X. Ecosystem connectivity

Reef Assessment
Stony corals, Fish, Octocorals, Sponges, & Macroinvertebrates