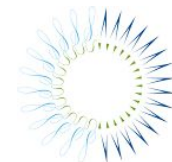


Seventh Meeting of the Scientific Coordination Committee (SCS7)  
Sitka, Alaska: August 15-17

# Multivariate approaches for EBFM implementation in the U.S. Caribbean

**Juan J. Cruz-Motta**, Stacey Williams, Tarsila Seara, William Arnold, Graciela Garcia-Moliner, Orian Tzadik, Tauna Rankin, Alida Ortiz, Kevin McCarthy, Maria Lopez-Mercer, Sarah Stephenson, Sennai Habtes, Edwin Cruz-Rivera, Liajay Rivera-Garcia.



THE  
**PEW**  
CHARITABLE TRUSTS



# EBFM (NMFS, 2016)

*“A systematic approach to fisheries management in a geographically specified area that contributes to the resilience and sustainability of the ecosystem; recognizes the physical, biological, economic, and social interactions among the affected fishery-related components of the ecosystem, including humans; and seeks to optimize benefits among a diverse set of societal goals”*

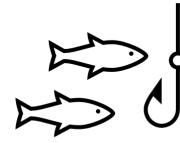
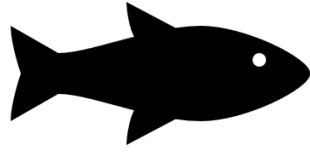


Different meanings (8) and **different principles** (at least 10) (Link and Markshak, 2021)



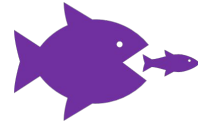
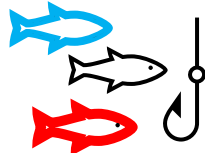
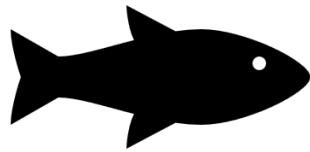
***Moving beyond a single species approach***

SSF



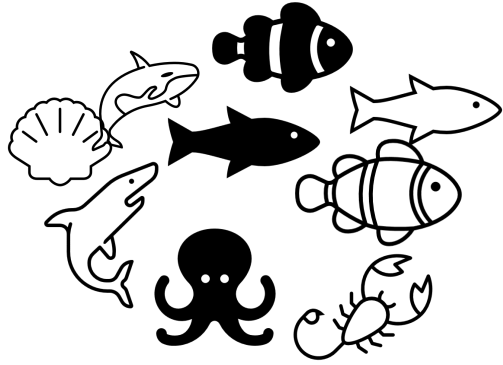
DF

EAF



DF

EBFM



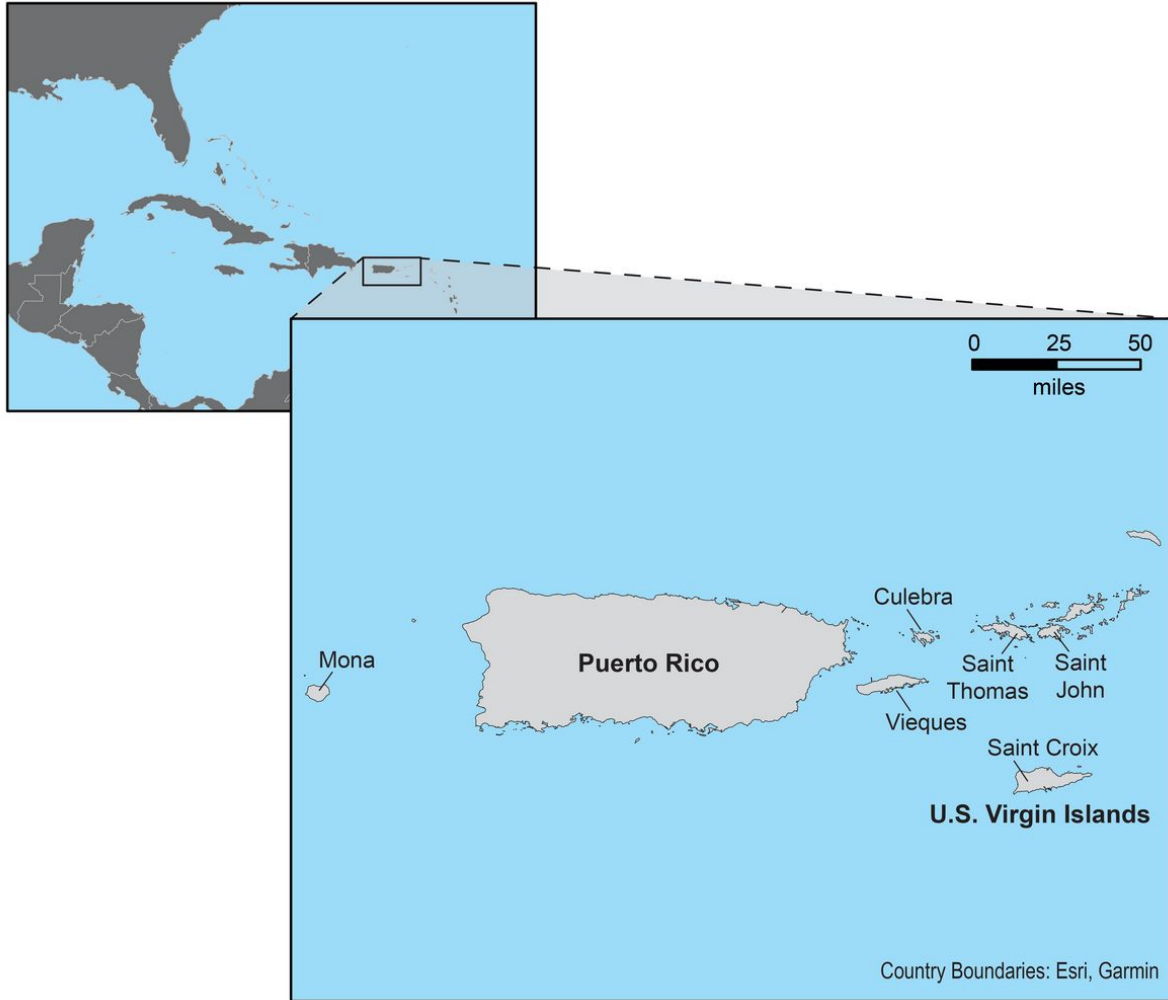
EFP



**BUT**

- Disagreement on terminology and principles
- Develop appropriate analytical and modelling tools
- Changing governance structures (interagency approach)
- Copious data is needed
- Too conservative and restrictive advice
- Too expensive

# U.S. Caribbean



Lowest landings

Lowest total revenue

Limited shelf area

One of deepest EEZ

Low congressional representation

Lowest Absolute Population

Data poor

Fully artisanal fishery

## WHY BOTHER???



# HOWEVER

- Highest number of managed species
- Highest ecological diversity
- $\approx 80\%$  Fisheries depends on Coral Reefs
- Relatively high productivity / shelf area
- High Stakeholder involvement

# ALSO

- Important Habitat loss
- High temperature increase
- Second Highest population density in US fishing regions



Multi-specific, Multi-driver, Multi-gear,  
Multi-objectives SYSTEM

Ideal system to implement EBFM

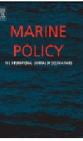
Perhaps EBFM the only option?



**AIM**

To develop an **FEP** for the US Caribbean in order to guide  
the implementation of an **EBFM**





# Development of FEPs

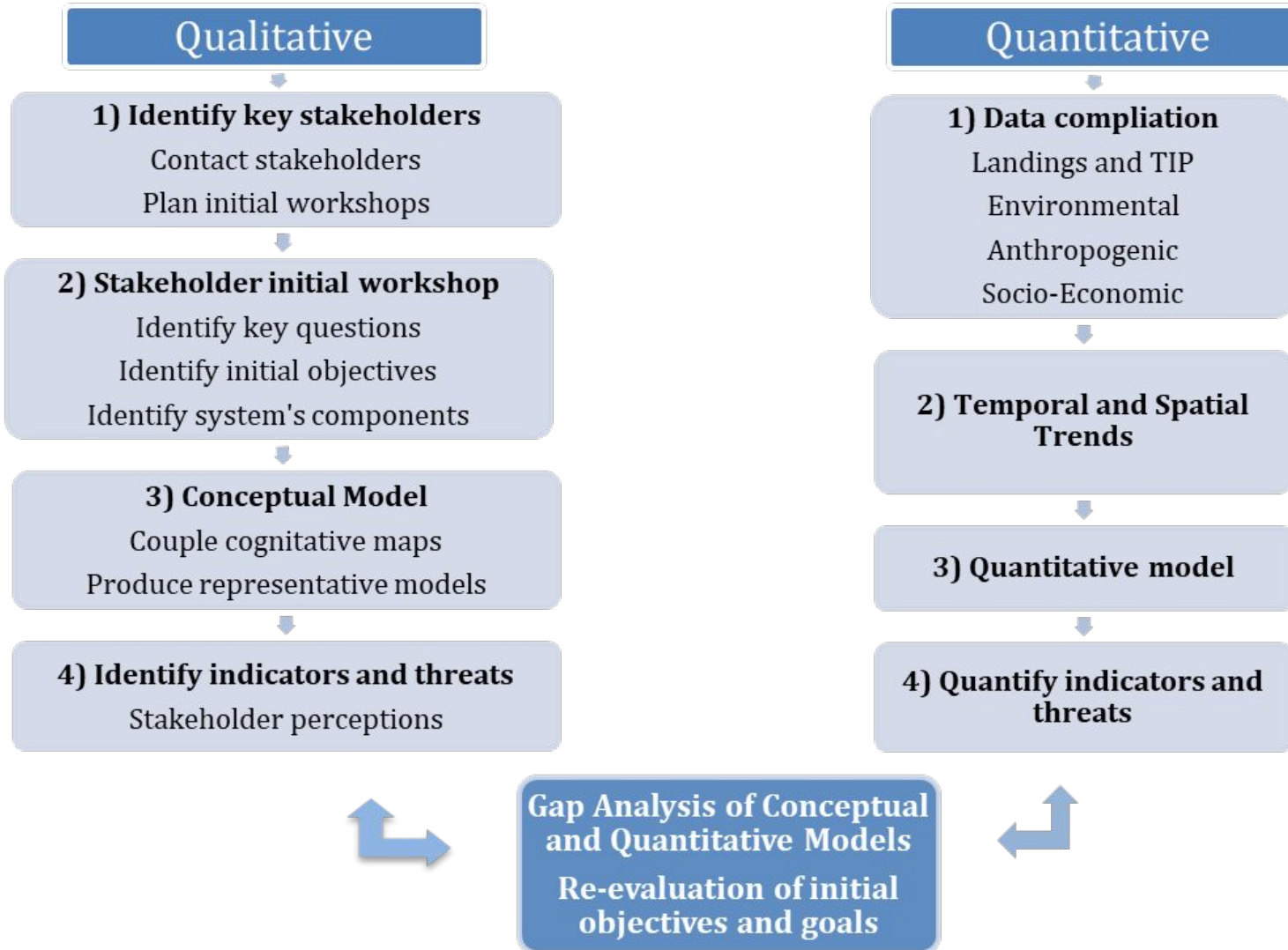


## Building effective fishery ecosystem plans

Phillip S. Levin<sup>a,\*</sup>, Timothy E. Essington<sup>b</sup>, Kristin N. Marshall<sup>c</sup>, Laura E. Koehn<sup>b</sup>, Lee G. Anderson<sup>d</sup>, Alida Bundy<sup>e</sup>, Courtney Carothers<sup>f</sup>, Felicia Coleman<sup>g</sup>, Leah R. Gerber<sup>h</sup>, Jonathan H. Grabowski<sup>i</sup>, Edward Houde<sup>j</sup>, Olaf P. Jensen<sup>k</sup>, Christian Möllmann<sup>l</sup>, Kenneth Rose<sup>m</sup>, James N. Sanchirico<sup>n</sup>, Anthony D.M. Smith<sup>o</sup>



# Where are We Now?: Description of the Fisheries System

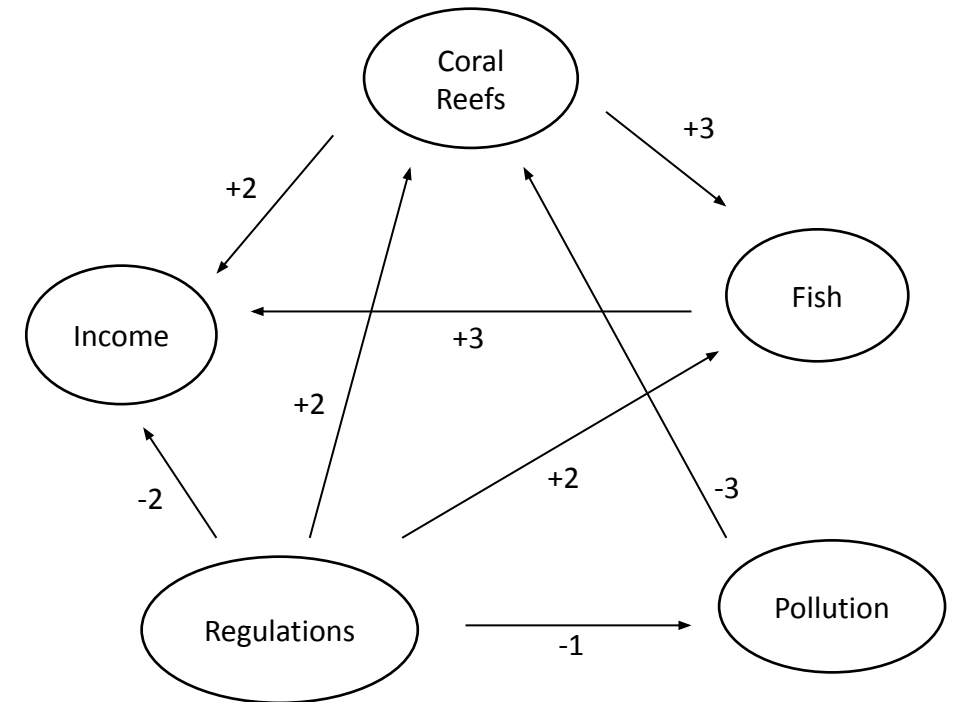


# Qualitative

## (Based on stakeholder perception)

### Conceptual Models (Fuzzy Cognitive Maps):

- DAPs = 3 (38)
- SSC = 1 (11)
- PEW (CFCM):
  - Business = 3 (17)
  - NGOs = 3 (20)
- Lenfest Project:
  - Experts = 4 (24)
  - Managers = 3 (9)
  - Fishers = 12 (117)



# Conceptual Models Goals

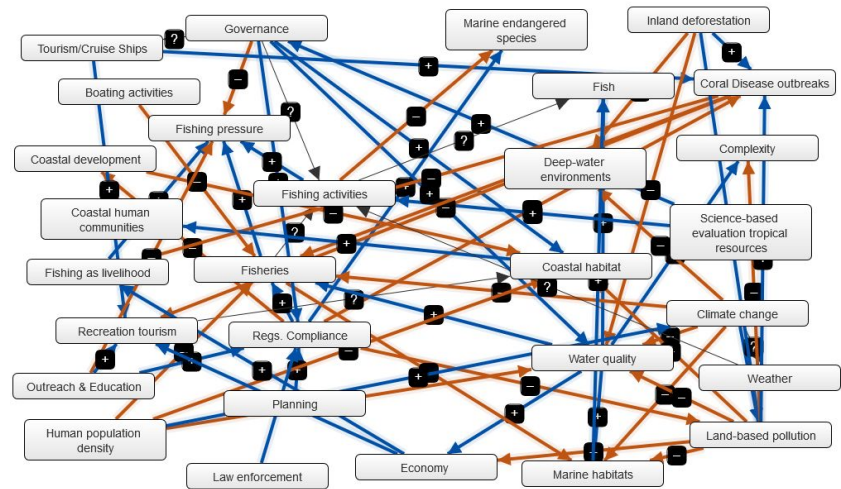
- Allow visualization and in-depth analyses of stakeholder perceptions (e.g., using graph theoretical approach).
- Help identify priorities and risk factors to guide management decisions.
- Identify data gaps.
- Guide the development of hypotheses to be tested using the quantitative approach.





Dra. Alida Ortiz  
 Chair Outreach and Education Advisory Panel  
 CFMC

?????????  
 “Spaghetti Salad”



mentalmodeler.com/scenario/

MentalModeler

Files Model Matrix Preferred Slate & Metrics Scenario Info

	commercial fisheries	environmental/oceanographic variables	MPA	fishing gear types	habitat	marine disease	coastal development	non-point source pollution	nurseries	biomass	marine biodiversity	coral disease	fishing grounds	disturbances	climate change	recruitment	connectivity	coastal erosion
commercial fisheries	-	-	-	-	-	-	-	-	-	-1	-	-	-	-	-	-	-	-
environmental/oceanographic variables	-	-	-	-	-	-	-	-	-	0	0	-	-	-	-	0	0	-
MPA	-	-	-	-	1	-	1	-	1	-	-	-	1	-	-	-	-	-
fishing gear types	-	-	-	-	-1	-	-	-	-	0	-	-	-	-	-	-	-	-
habitat	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
marine disease	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
coastal development	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
non-point source pollution	-	-	-	-	-1	-	-	-	-1	-	-	-	-	-	-	-	-	-
nurseries	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-
biomass	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
marine biodiversity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
coral disease	-	-	-	-	1	-	-	-	-	1	1	-	-	-	-	-	-	-
fishing grounds	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
disturbances	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-
climate change	-	-	-	-	-1	-	-	-	-	-	-	-	-	-	-	-	-	-
recruitment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-



## 3 workshops for managers

June 28 2021		Abiotic	
June 30 2021	Oceanic Waters	Water Quality (10)	Water Quality (10) (19)
July 1 2021	Rain		
	River		
		Bathymetry Shifts	Environmental/Oceanographic Variables (1)
		Marine Currents	
		Nutrients	
		Sea Surface Temperature (15)	
	Coastal Waters		
		Fisheries	
	Recreational Fisheries		
	Commercial Catch	Fishery Catch	
			Bait Fish (3)
			Biomass (A)
		Commercial Fishers	Comercial Fishers
			Fishing Eligibility (D)
			Fishing Gear Types
		Fishing Grounds	Fishing Grounds
			Fishing Interest (D)
		Recreational Fishers (16) (17)	Sports Fishing (16)
			Subsistence Fishing (17)
		Economic	
	Consumer		Fish Market Demand
	Imported Marine Species		
	Restaurants		
			Funding & Capacity
		Tourism (8)	
			Marine Recreation (Boating & Touring)
		User Behavior	
	Tourism		

- Synonyms across groups, stakeholder and islands

- Groupings of components

Habitat, ecological components, Management/Governance, Science, Disturbances, Anthropogenic Impacts, Education, Social/Economic



Each vector (relationship) is considered a variable

	ST MA1	PR MA2	PR MA3	ST FI1	ST FI2	PR FI1	PR FI2	EX PR1	EX PR2	EX ST1	
Fisheries to Fish assemblages	-1	-1	-1	0	0	0	0	0	-1	0	1
Fish assemblages to Fisheries	1	1	1	1	1	1	1	1	0	1	1
Regulations to fisheries	1	1	1	-1	-1	-1	-1	1	1	1	1
Fisheries to regulations	1	1	1	0	0	0	0	1	0	1	1
Contamination to fish assemblages	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0
Habitat to fish assemblages	1	1	1	1	1	1	1	1	1	1	0
Tourism to fisheries	1	0	-1	1	1	0	0	-1	-1	-1	-1
Fisheries to tourism	1	1	0	1	1	1	1	0	0	0	1
<b>Island</b>	STT	PR	PR	STT	STT	PR	PR	PR	PR	STT	
<b>Stakeholder</b>	MAN	MAN	MAN	FISH	FISH	FISH	FISH	EXP	EXP	EXP	

## MULTIVARIATE DATA SET

	ST MA1	PR MA2	PR MA3	ST FI1	ST FI2	PR FI1	PR FI2	EX PR1	EX PR2	EX ST1	
Fisheries to Fish assemblages	-1	-1	-1	0	0	0	0	0	-1	0	1
Fish assemblages to Fisheries	1	1	1	1	1	1	1	1	0	1	1
Regulations to fisheries	1	1	1	-1	-1	-1	-1	-1	1	1	1
Fisheries to regulations	1	1	1	0	0	0	0	0	1	0	1
Contamination to fish assemblages	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0
Habitat to fish assemblages	1	1	1	1	1	1	1	1	1	1	0
Tourism to fisheries	1	0	-1	1	1	0	0	0	-1	-1	-1
Fisheries to tourism	1	1	0	1	1	1	1	1	0	0	1
<b>Island</b>	STT	PR	PR	STT	STT	PR	PR	PR	PR	STT	
<b>Stakeholder</b>	MAN	MAN	MAN	FISH	FISH	FISH	FISH	EXP	EXP	EXP	



	ST MA1	PR MA2	PR MA3	ST FI1	ST FI2	PR FI1	PR FI2	EX PR1	EX PR2	EX ST1
ST MA1										
PR MA2	93.75									
PR MA3	75	81.25								
ST FI1	68.75	62.5	43.75							
ST FI2	68.75	62.5	43.75	100						
PR FI1	62.5	68.75	50	93.75	93.75					
PR FI2	62.5	68.75	50	93.75	93.75	100				
EX PR1	62.5	68.75	87.5	31.25	31.25	37.5	37.5			
EX PR2	56.25	62.5	81.25	62.5	62.5	68.75	68.75	68.75		
EX ST1	50	56.25	50	31.25	31.25	37.5	37.5	37.5	43.75	
<b>Island</b>	STT	PR	PR	STT	STT	PR	PR	PR	PR	STT
<b>Stakeholder</b>	MAN	MAN	MAN	FISH	FISH	FISH	FISH	EXP	EXP	EXP

## Resemblance Matrix (Gower)

# Non-metric MDS

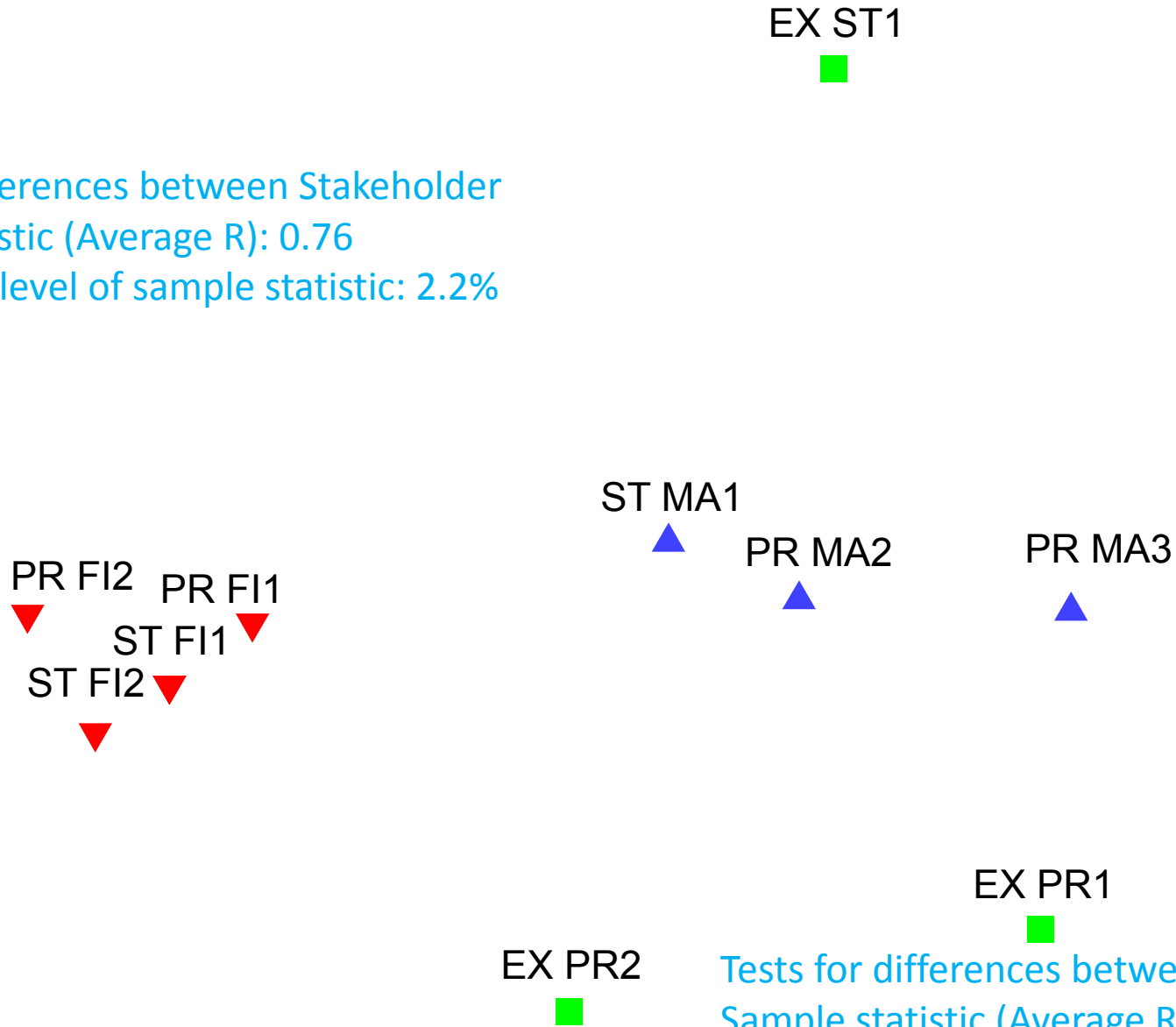
Resemblance: S15 Gower

2D Stress: 0.02

## Stakeholder

- ▲ MAN
- ▼ FISH
- EXP

Tests for differences between Stakeholder  
Sample statistic (Average R): 0.76  
Significance level of sample statistic: 2.2%

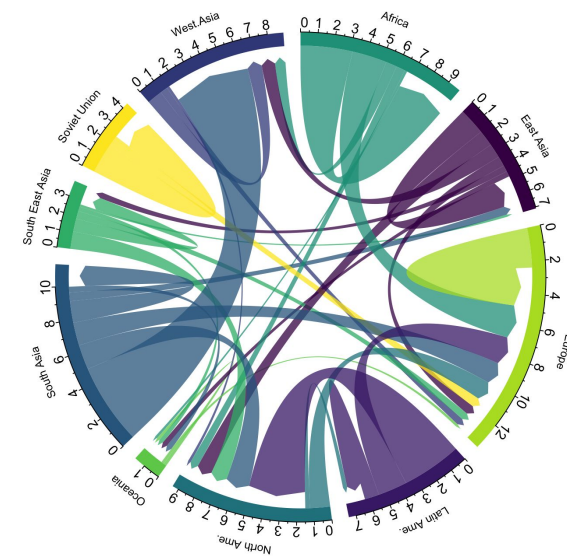
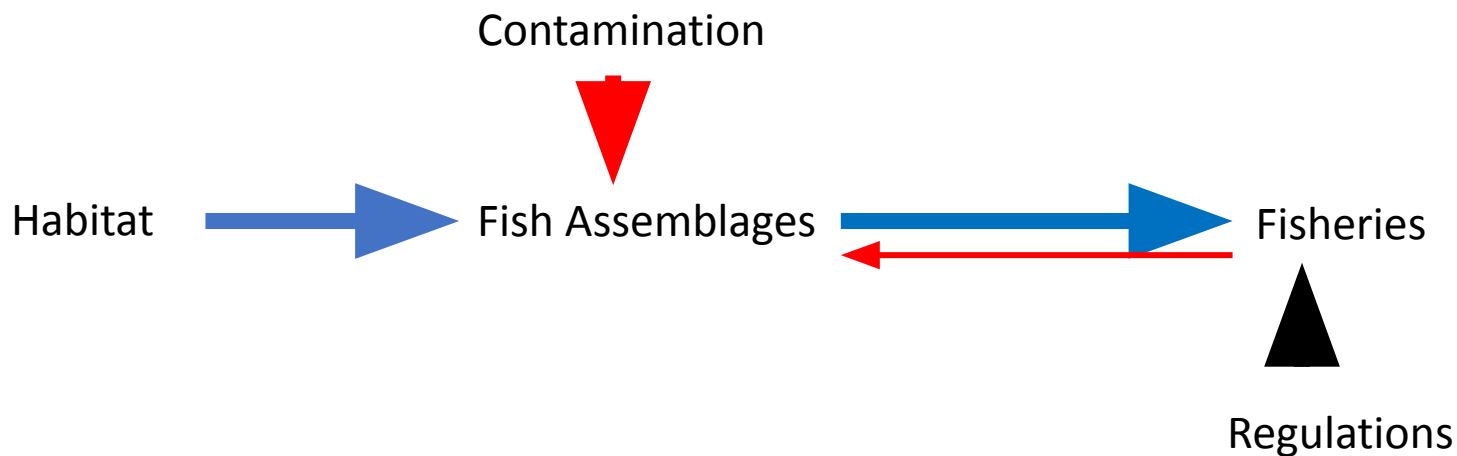


Tests for differences between Islands  
Sample statistic (Average R): 0.34  
Significance level of sample statistic: 11.1%



# Example Melded/Simplified Model

	ST MA1	PR MA2	PR MA3	ST EI1	ST EI2	PR EI1	PR EI2	EX PR1	EX PR2	EX ST1		Frequency	Absolute
Eisheries to Fish assemblages	-1	-1	-1	0	0	0	0	0	-1	0	1	-3	5
Fish assemblages to Fisheries	1	1	1	1	1	1	1	1	0	1	1	9	9
Regulations to fisheries	1	1	1	-1	-1	-1	-1	-1	1	1	1	2	10
Fisheries to regulations	1	1	1	0	0	0	0	0	1	0	1	5	5
Contamination to fish assemblages	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-9	9
Habitat to fish assemblages	1	1	1	1	1	1	1	1	1	1	0	9	9
Tourism to fisheries	1	0	-1	1	1	0	0	0	-1	-1	-1	-1	7
Fisheries to tourism	1	1	0	1	1	1	1	1	0	0	1	7	7
<b>Island</b>	STT	PR	PR	STT	STT	PR	PR	PR	PR	STT			
<b>Stakeholder</b>	MAN	MAN	MAN	FISH	FISH	FISH	FISH	EXP	EXP	EXP			

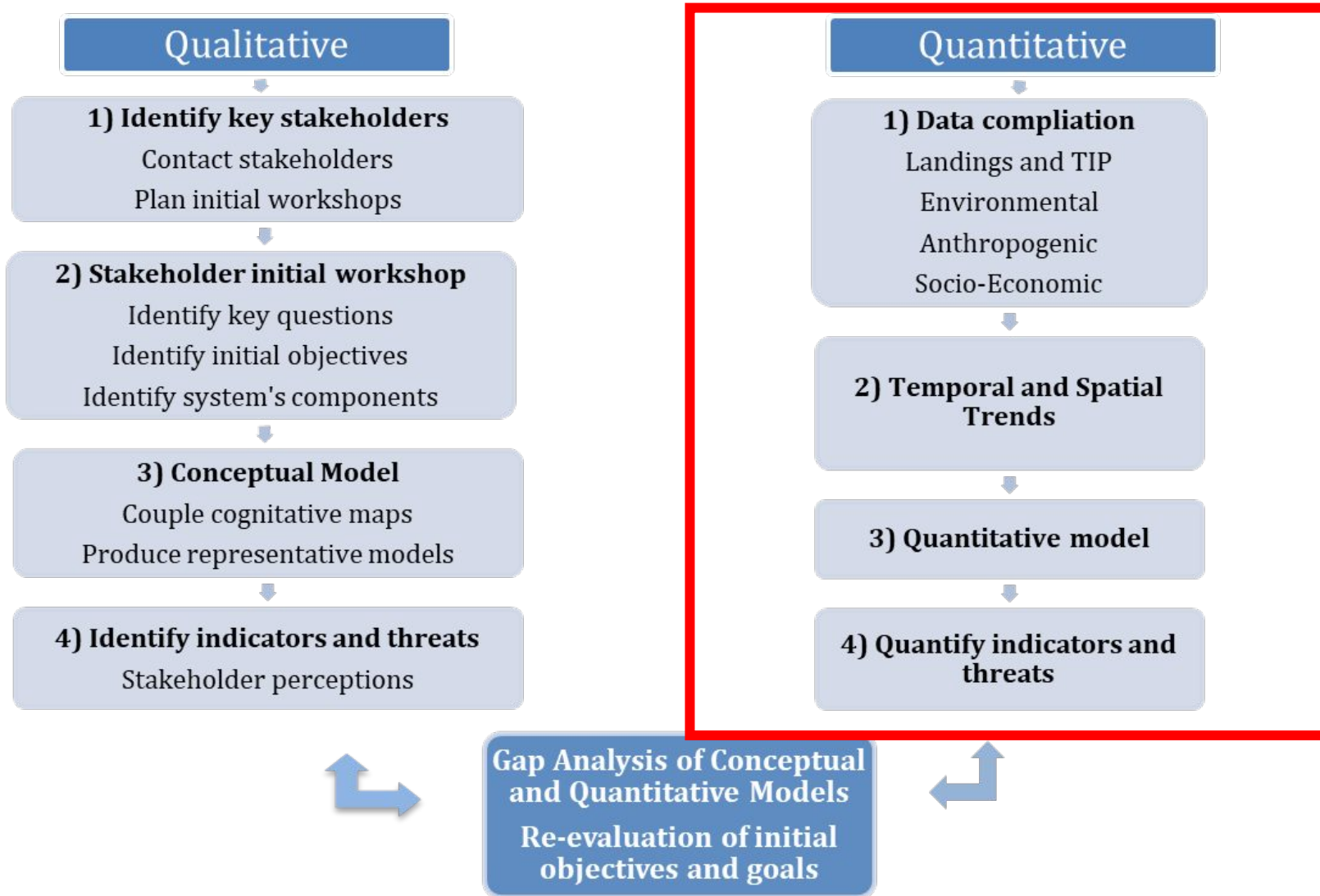


# Highlights:

## U.S. Caribbean Conceptual Models

- 1) Analysis of the entire socio-ecological system. Not only a single the targeted species.
- 1) Comprehensive stakeholder involvement
- 1) Stakeholders were interviewed separately. Workshops not “lead” by a specific group or stake holder
- 1) Quantitative analyses of conceptual models (perceptions) that will allow to:
  - 1) Estimate Similarities/Differences within/between stakeholders and islands/regions
  - 1) Identify main components and connections to be used on a melded/simplified model
- 2) Preliminary analyses are showing emerging components not currently considered =  
Recreational Fisheries

# Where are We Now?: Description of the Fisheries System



# Quantitative Approach

## Data Collection

### Fishery Independent

NCRMP

PRCRMP

USVI CRMP

SEAMAP

CRES

### Fishery Dependent

PR DRNA

USVI DPNR

SEFSC

TIP

### Env/Anthrop

Oceanographic features

Disturbances

Rainfall

Connectivity

Habitat features

Anthropogenic

### Socio-Economic

CSVI

\*Fishery Engagement and Reliance

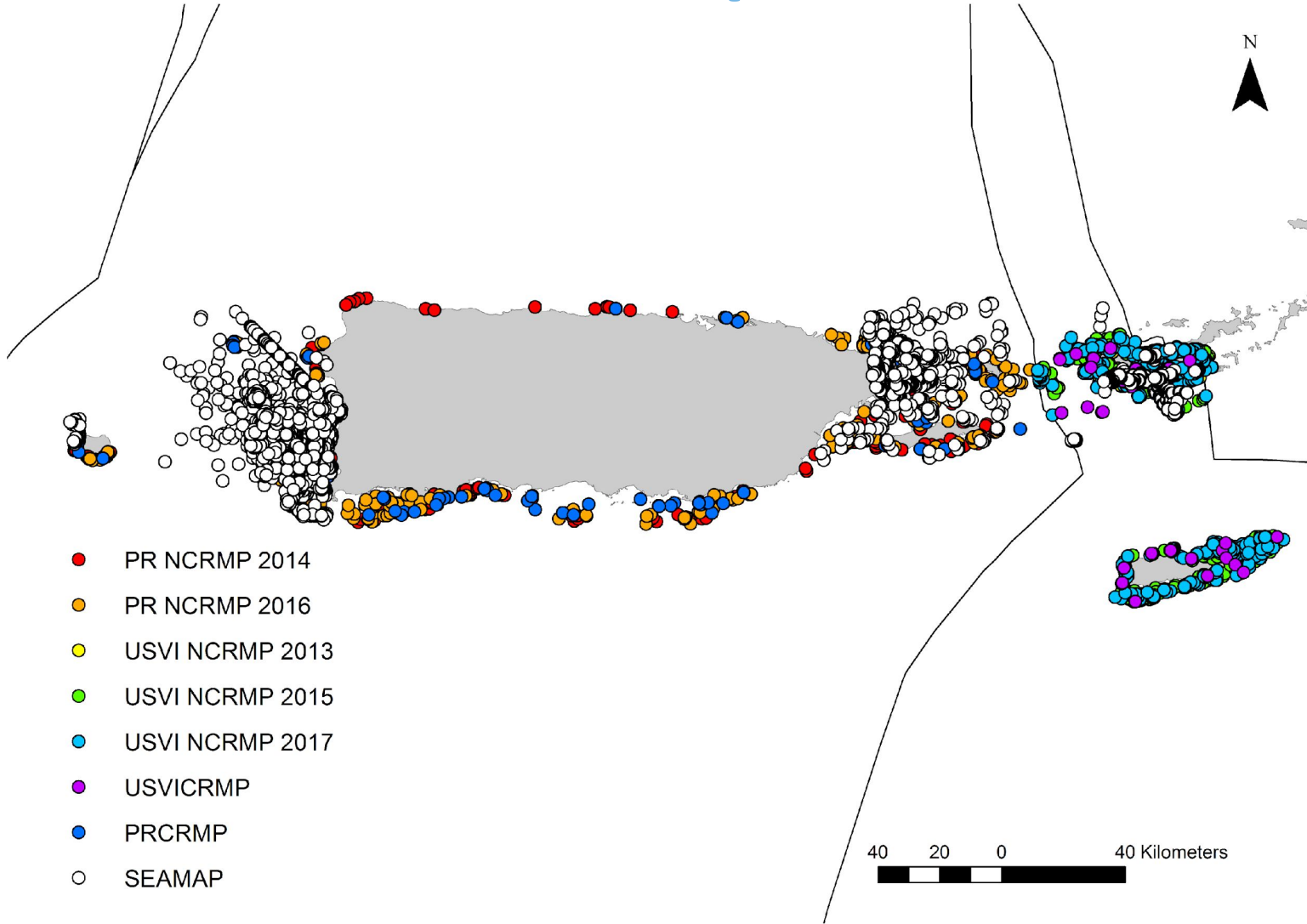
\*Social Vulnerability

Post disturbance assessments

Coral reef dependency

Fishery Census Data

# Fisheries Independent and Habitat Data



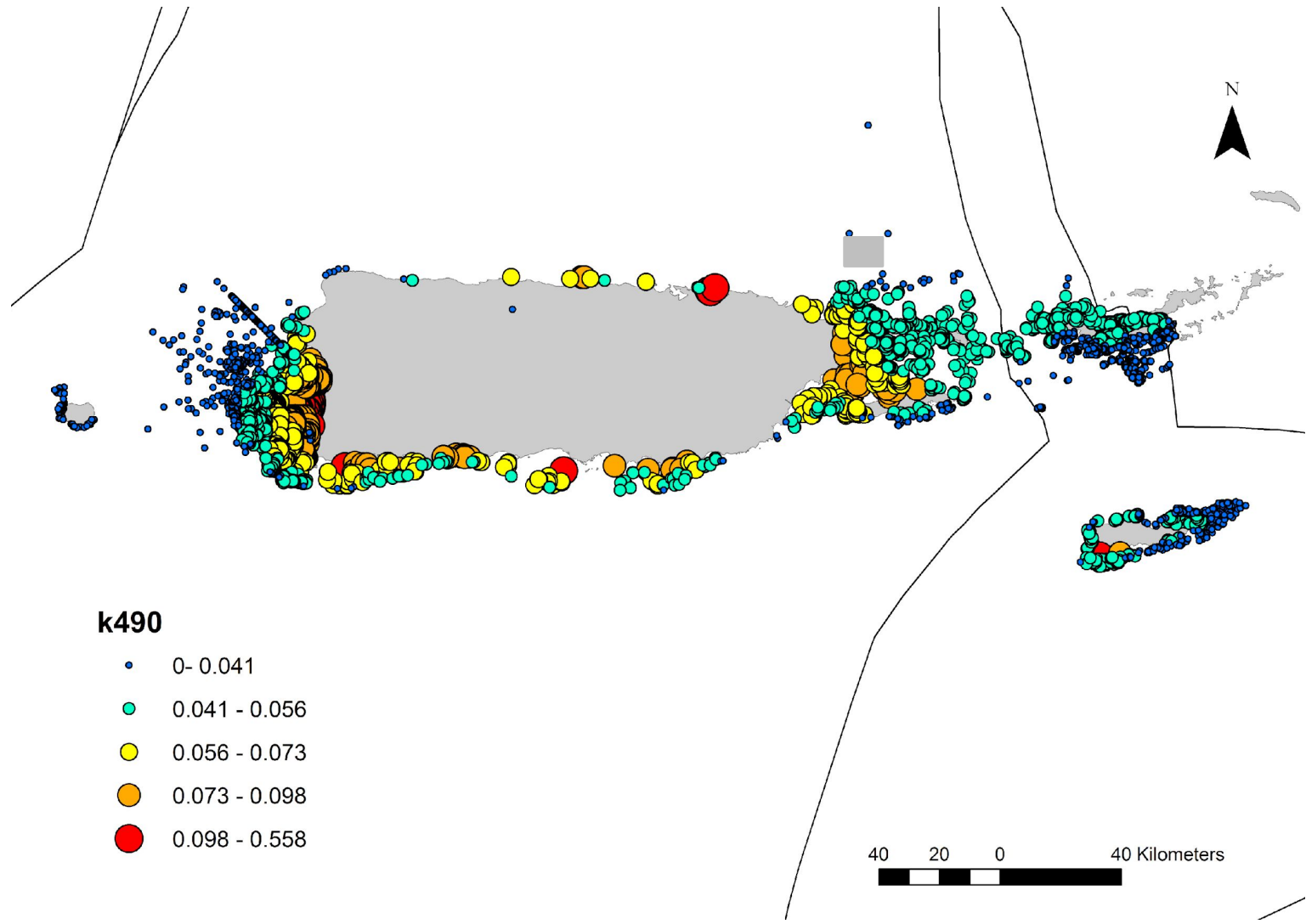
## Habitat:

- Type
- Heterogeneity
- Relative cover of coral species
- Relative cover of benthic groups
- Rugosity
- Abundance of invertebrates of interest (e.g. Lobsters, *Diadema*)

## Fish Assemblages:

- Abundance per species
- Biomass per species
- Size Class Frequencies per species

# Environmental/Anthropogenic Data



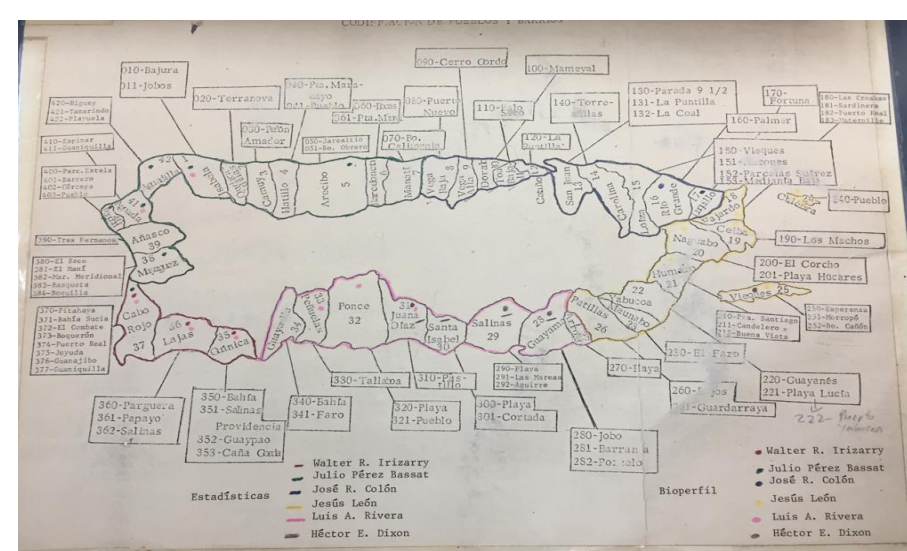
**k490**

- 0 - 0.041
- 0.041 - 0.056
- 0.056 - 0.073
- 0.073 - 0.098
- 0.098 - 0.558

Variable	Data source
Wave exposure	Significant Wave Height
Currents	Current speed
Rainfall	Rainfall
Hurricanes	Hurricane tracks
Distance from port	Port location
Depth	Bathymetry
Proximity to closest MPA	MPA location
Proximity to spawning aggregation	Location of fish spawning aggregation sites
Reef area	Habitat map
Habitat type	Habitat map
Habitat heterogeneity	Habitat map
Nursery habitat	Habitat map
Connectivity	Larval connectivity data
Human population density	Human population data
Human population density	Gravity of human impacts
Distance from shelf break	Continental margin
Sea surface temperature anomalies (DHW)	Sea Surface Temperature
Slope	Bathymetry
Turbidity	Diffuse attenuation K490
discharge	Hydrography
Productivity	Net primary production
Water Pollution	Reef at Risk
Inorganic Pollution	Halpern Model
Proximity to MPA	MPA location

<https://oceancolor.gsfc.nasa.gov/I3/order/>

Landings data (SEFSC):  
Response variable (Biomass)  
1983 -2020  
NCE = 28%

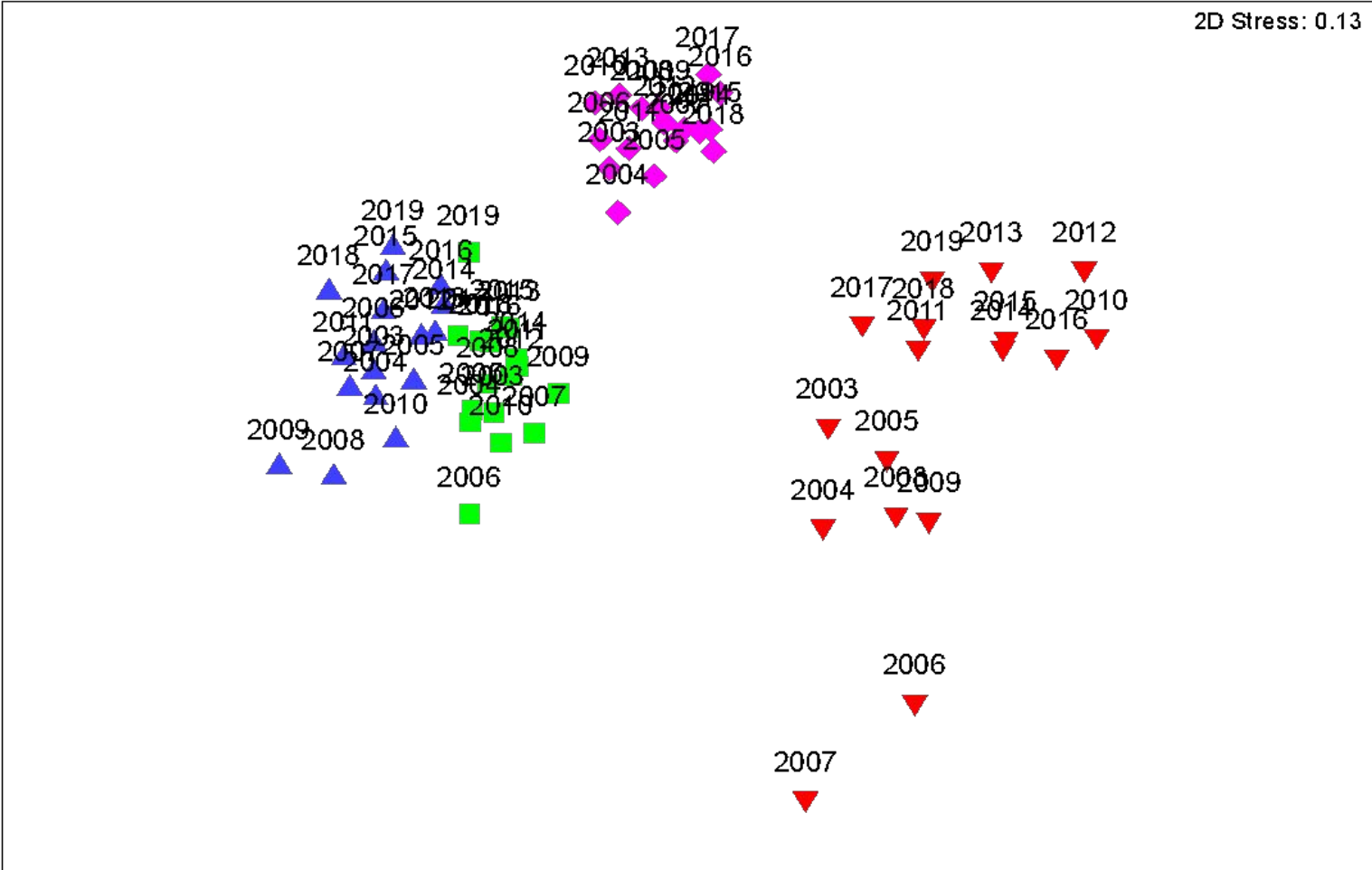


	MACKEREL, PORGY,			TUNA AND			SNAPPER,			YEAR	REGION	LOCATION	GEAR			
	BARRACUDA	JACKS	KING	MACKERELS,	GROUPER,	SNAPPER,	SNAPPER,	SNAPPER,	SNAPPER,							
				UNSPECIFI	UNSPECIFIED	LANE	MUTTON	SILK	L	SPINY	UNSPECIFIED					
\$1		0	0	0	0	0	0	0	0	0	2359.01639	0	1983 PR-East CEIBA BY HAND, DIVING GEAR			
\$2		0	0	0	0	0	0	0	0	0	0	0	1983 PR-East CEIBA HAUL SEINES			
\$3		0	0	0	906.557377	0	1732.786885	627.868852	88.5245902	0	1345.90164	0	1983 PR-East CEIBA HOOK AND LINE, BOTTOM			
\$4		0	0	0	1909.836066	0	3455.737705	9993.44262	724.590164	0	1422.95082	301.639344	1983 PR-East CEIBA POTS AND TRAPS, FISH			
\$5		0	0	108.196721	0	0	0	0	0	0	0	0	1983 PR-East CEIBA TROLL LINES			
\$6		0	0	0	0	0	0	0	0	0	2498.36066	0	1983 PR-East CULEBRA BY HAND, DIVING GEAR			
\$7		0	0	195.081967	0	0	3906.557377	0	0	0	2419.67213	0	1983 PR-East CULEBRA HOOK AND LINE, BOTTOM			
\$8		0	0	0	0	0	1632.786885	122.95082	106.557377	0	1062.29508	0	1983 PR-East CULEBRA POTS AND TRAPS, FISH			
\$9		0	0	0	0	0	0	0	0	0	1677.04918	0	1983 PR-East CULEBRA POTS AND TRAPS, SPINY LOBSTER			
\$10		0	0	1139.34426	0	0	60.65573771	0	0	0	0	0	1983 PR-East CULEBRA TROLL LINES			
\$11		0	0	0	0	0	0	0	0	0	7829.5082	0	1983 PR-East FAJARDO BY HAND, DIVING GEAR			
\$12		0	0	0	0	0	73.7704918	118.032787	0	0	36.0655738	0	1983 PR-East FAJARDO GILL NETS, OTHER			
\$13	1290.163934		0	278.688525	0	0	0	19.6721311	0	647.540984	0	0	1983 PR-East FAJARDO HAUL SEINES			
\$14		0	0	2800	19.67213115	0	2318.032787	1308.19672	929.508197	788.52459	28239.3443	0	1983 PR-East FAJARDO HOOK AND LINE, BOTTOM			
\$15		0	0	0	0	0	62.29508197	103.278689	65.5737705	0	50.8196721	0	1983 PR-East FAJARDO LONG LINES, BOTTOM			
\$16	42.62295082		0	155.737705	1496.721311	0	9913.114754	2221.31148	1583.60656	0	2675.40984	859.016393	32.78688525	1983 PR-East FAJARDO POTS AND TRAPS, FISH		
\$17		0	0	25301.6393	0	0	204.9180328	0	0	0	0	0	0	1983 PR-East FAJARDO TROLL LINES		
\$18		0	0	0	0	0	18.03278689	0	0	0	2467.21311	0	0	1983 PR-East HUMACAO BY HAND, DIVING GEAR		
\$19		0	0	0	0	0	0	0	0	0	0	0	0	1983 PR-East HUMACAO CAST NETS		
\$20		0	0	0	0	0	0	386.885246	0	0	0	0	0	1983 PR-East HUMACAO GILL NETS, OTHER		
\$21		0	0	0	0	0	0	0	0	0	0	0	0	1983 PR-East HUMACAO HAUL SEINES		
Indicators	Barracuda	Jacks	Scomb	Porgy	Scomb	Groupers	Snapper	Snapper	Snapper	Snapper	Lobster	Snapper				

# Description of Temporal Trends and Spatial patterns Landings 2003-2019

Non-metric MDS

Standardise Samples by Total  
Transform: Square root  
Resemblance: S17 Bray-Curtis similarity



**REGION**

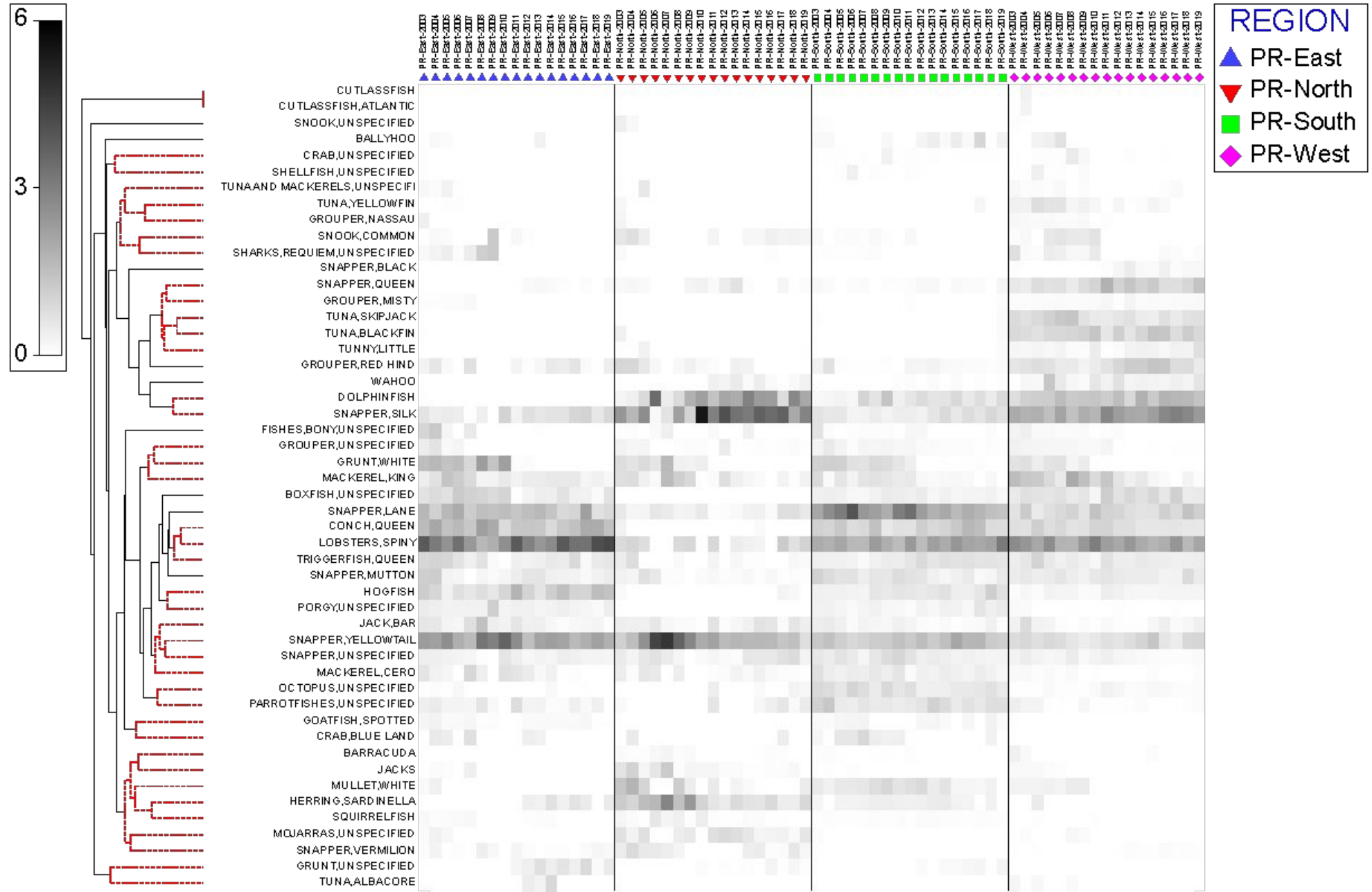
- ▲ PR-East
- ▼ PR-North
- PR-South
- ◆ PR-West

## Analysis of similarities

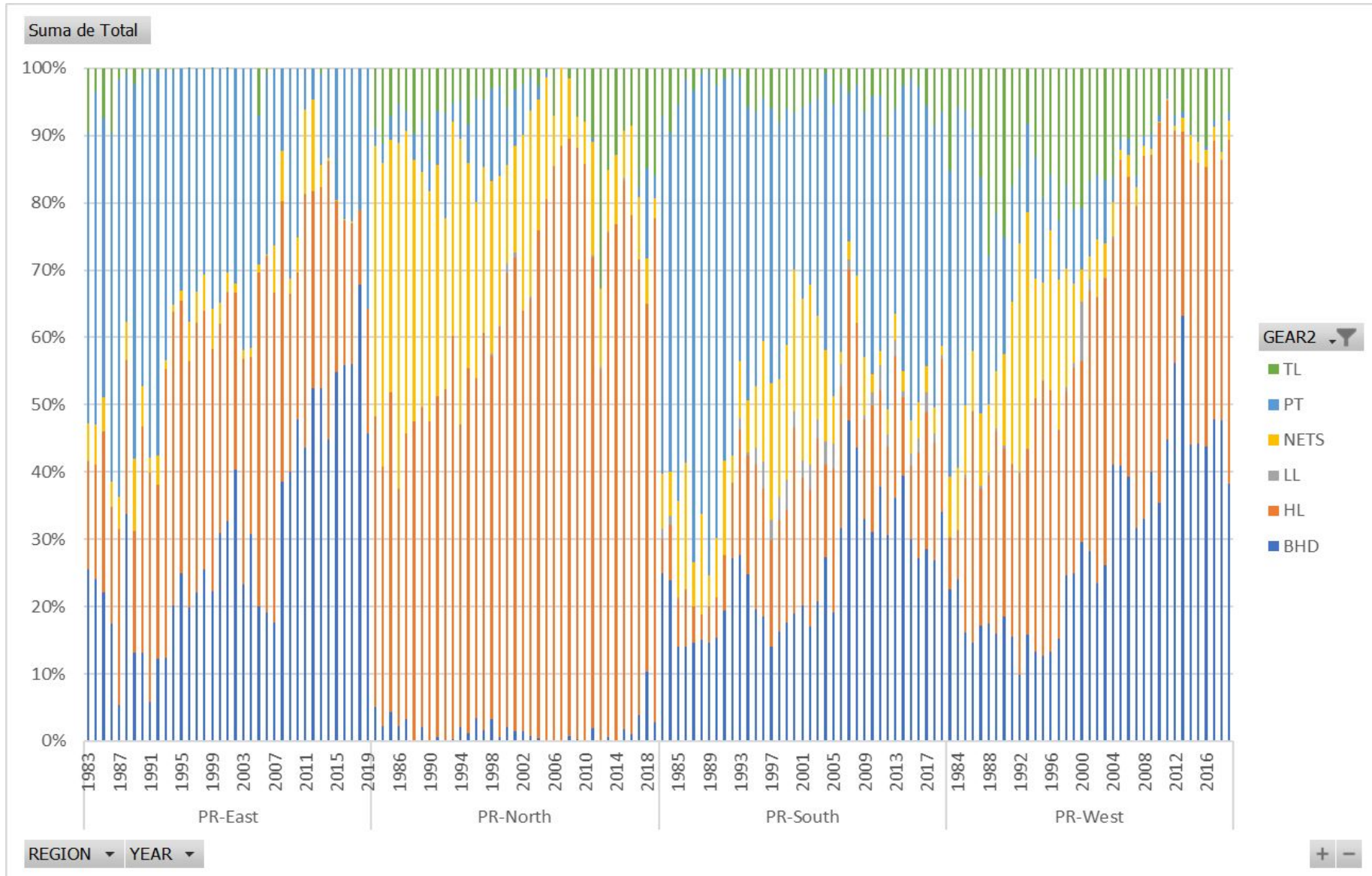
Tests for differences between unordered REGION  
Global Test  
Sample statistic (Average R): 0.742  
Significance level of sample statistic: 0.1%

Tests for differences between ordered YEAR  
Global Test  
Sample statistic (Average R): 0.646  
Significance level of sample statistic: 0.1%

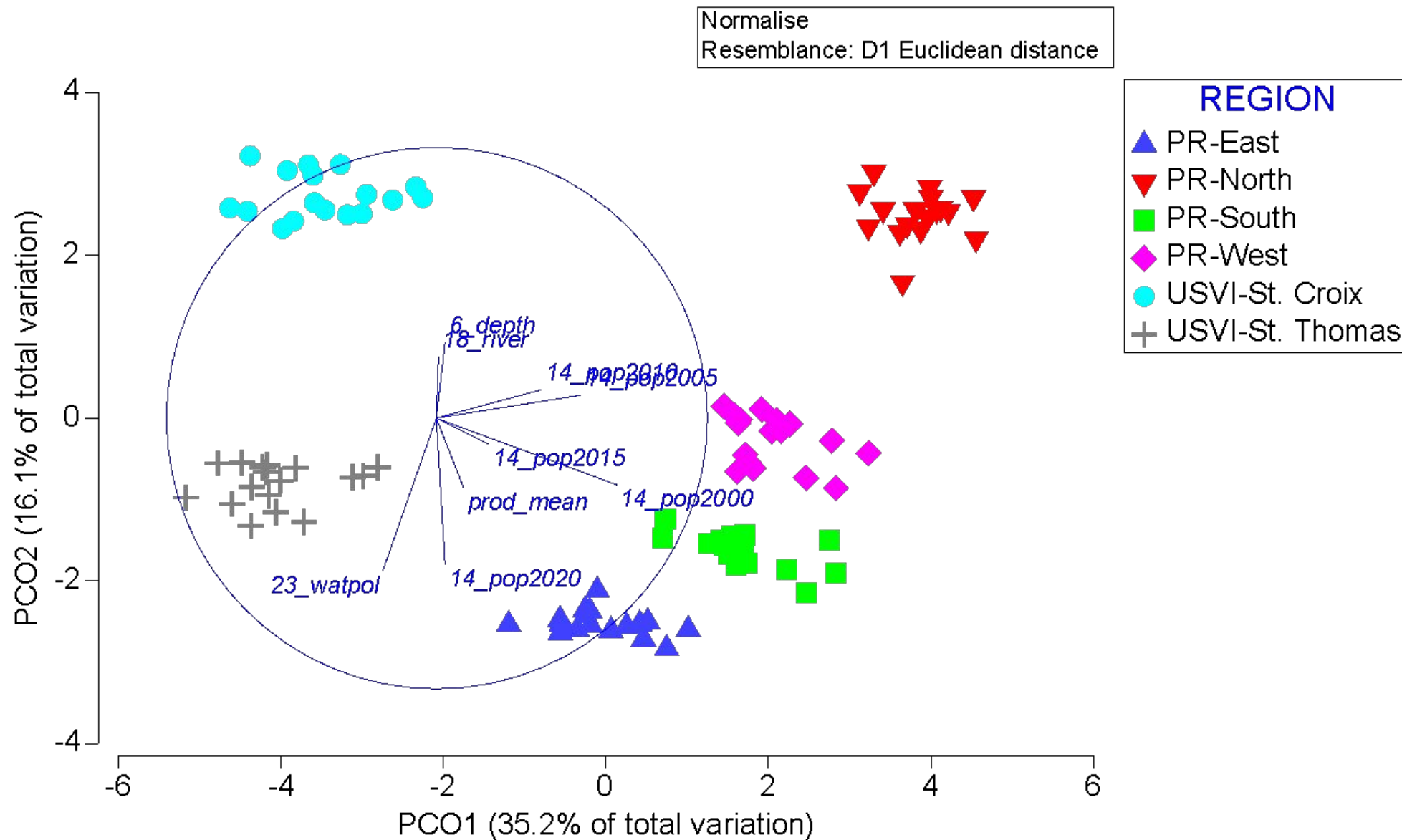
# Relative contribution of groups to spatial/temporal patterns



# Relative Landings per gear/region/year

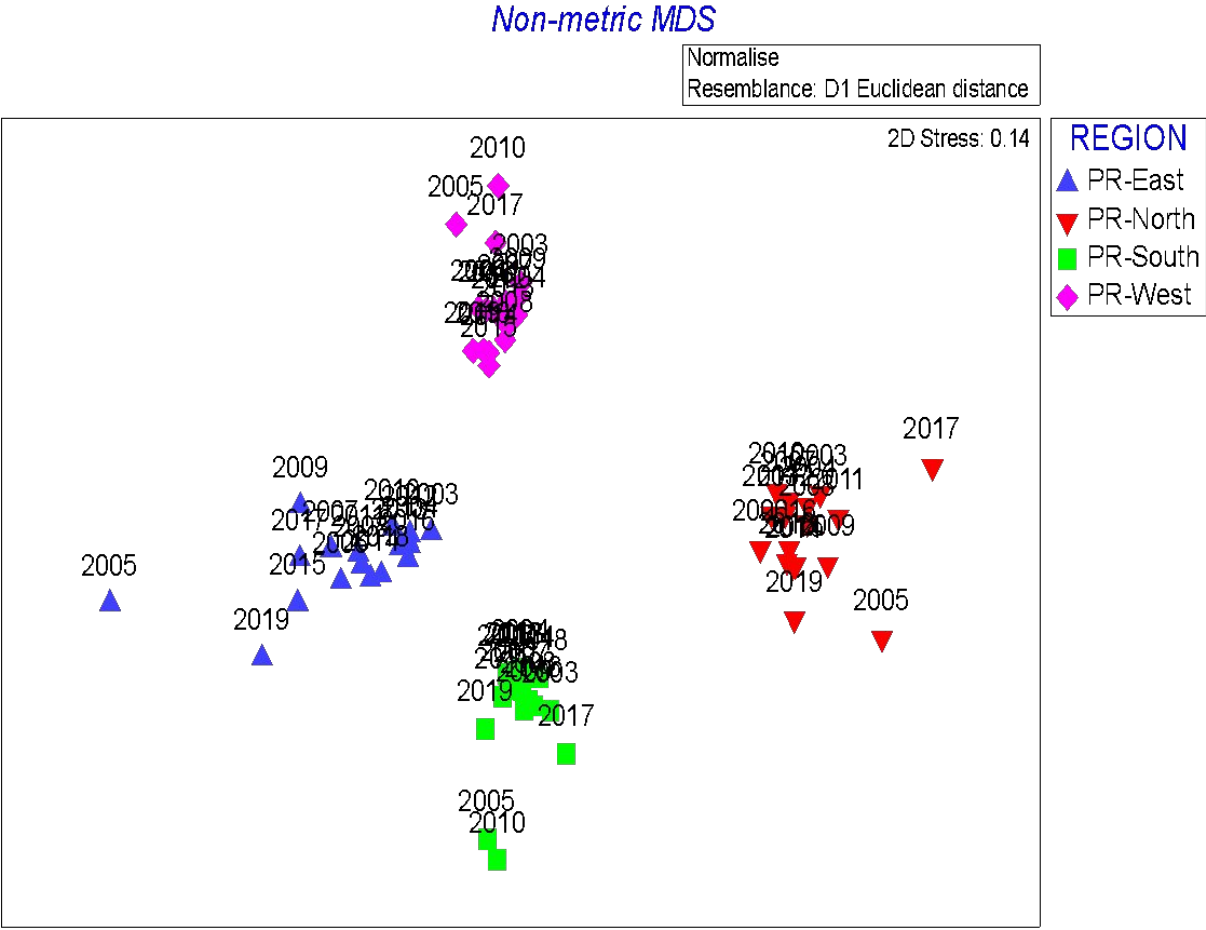
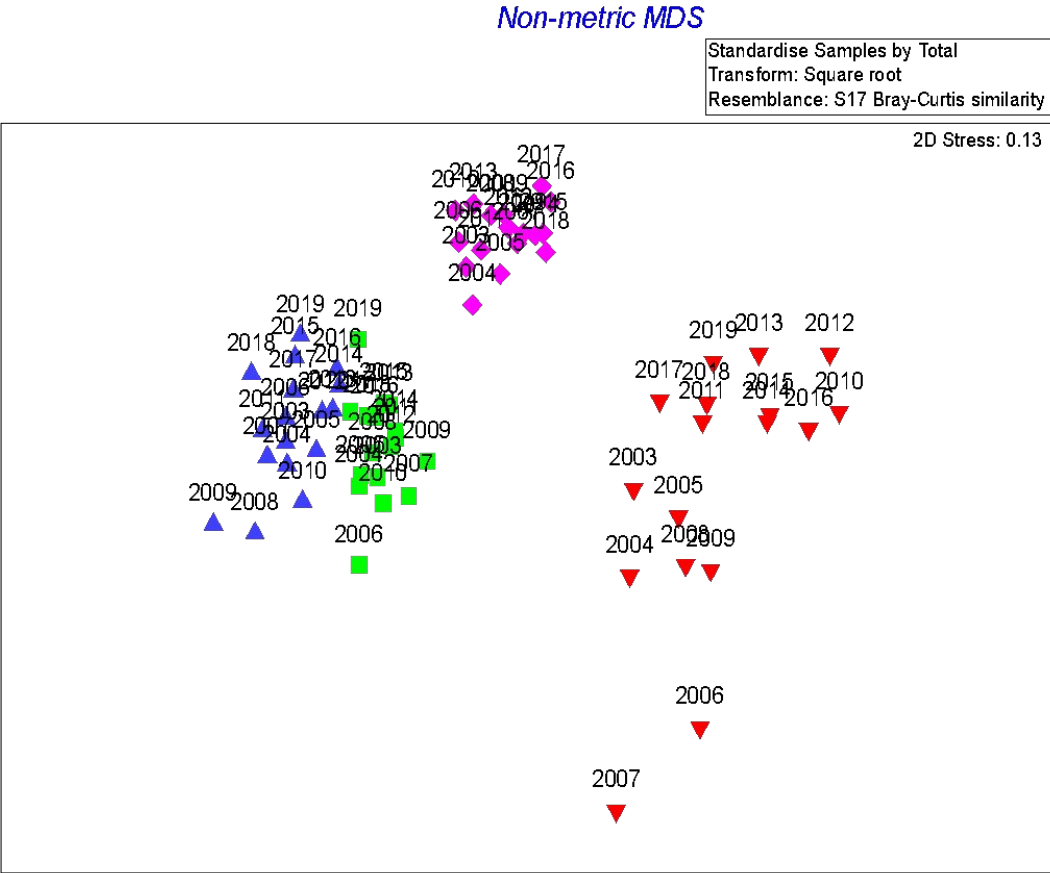


# Description of Temporal Trends and Spatial patterns Environmental Data 2003-2019



# Landings 2003-2019

# Environmental 2003 – 2019



**RELATE (Rho)**



## BIO-ENV Results (Rho)

*Best result for each number of variables*

### **No. Vars    Corr. Selections**

<b>1</b>	<b>0.790 MARG</b>
<b>2</b>	<b>0.846 MARG, I-POLL</b>
<b>3</b>	<b>0.847 MARG, I-POLL, RIVER</b>
<b>4</b>	<b>0.845 NUR, MARG, I-POLL, RIVER</b>
<b>5</b>	<b>0.844 NUR, MARG, I-POLL, RIVER, MPA</b>

MARG = Distance to margin (Beril)

I-POLL = Inorganic Pollution (Halpern Model)

RIVER = Distance to River Mouth

NUR = Nursery

MPA = Distance to Marine Protected Area

# Landings temporal trends 2003-2019

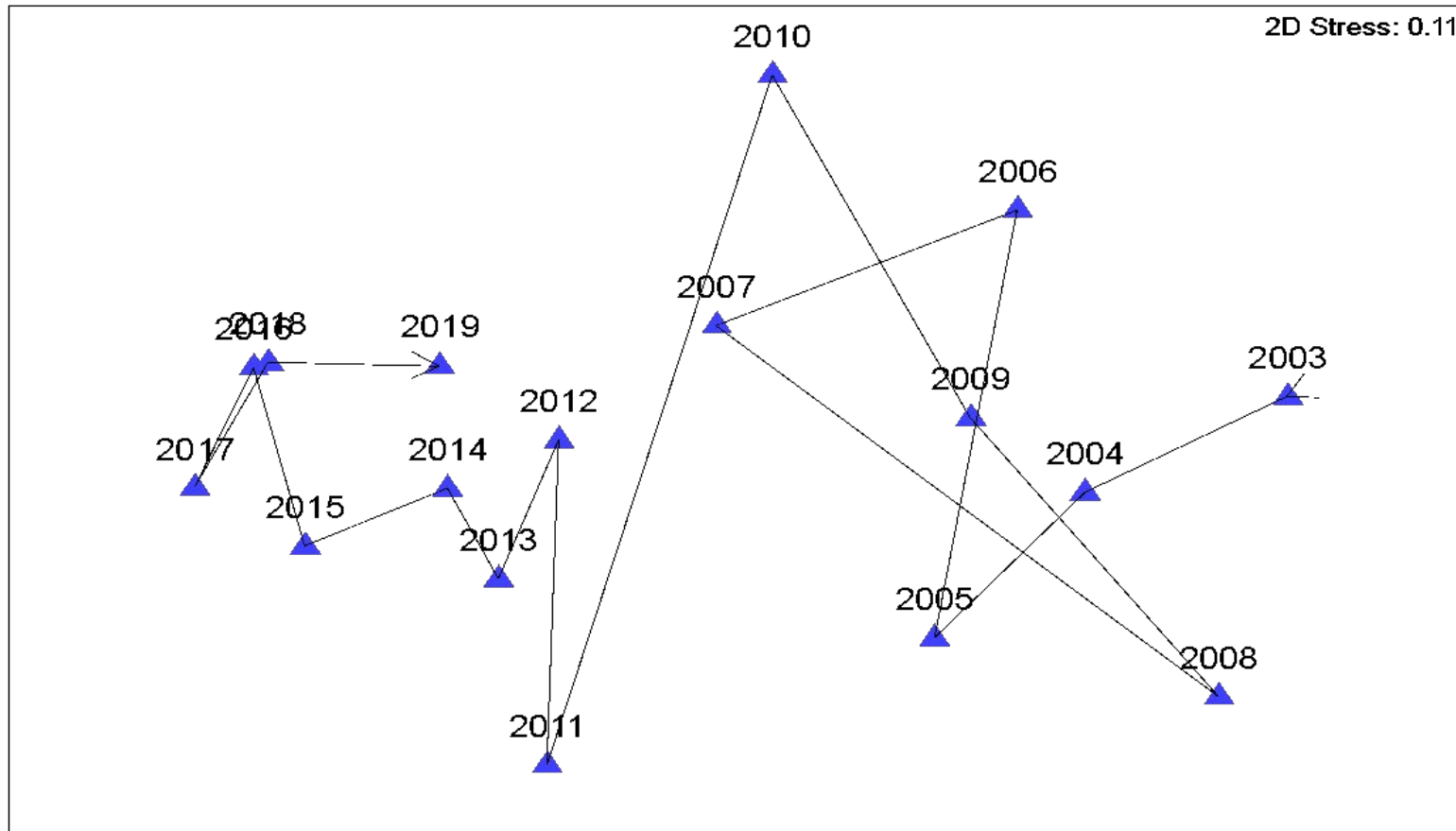
## West coast PR (EXAMPLE)

*Non-metric MDS*

Standardise Samples by Total  
Transform: Square root  
Resemblance: S17 Bray-Curtis similarity

2D Stress: 0.11

REGION  
▲ PR-West





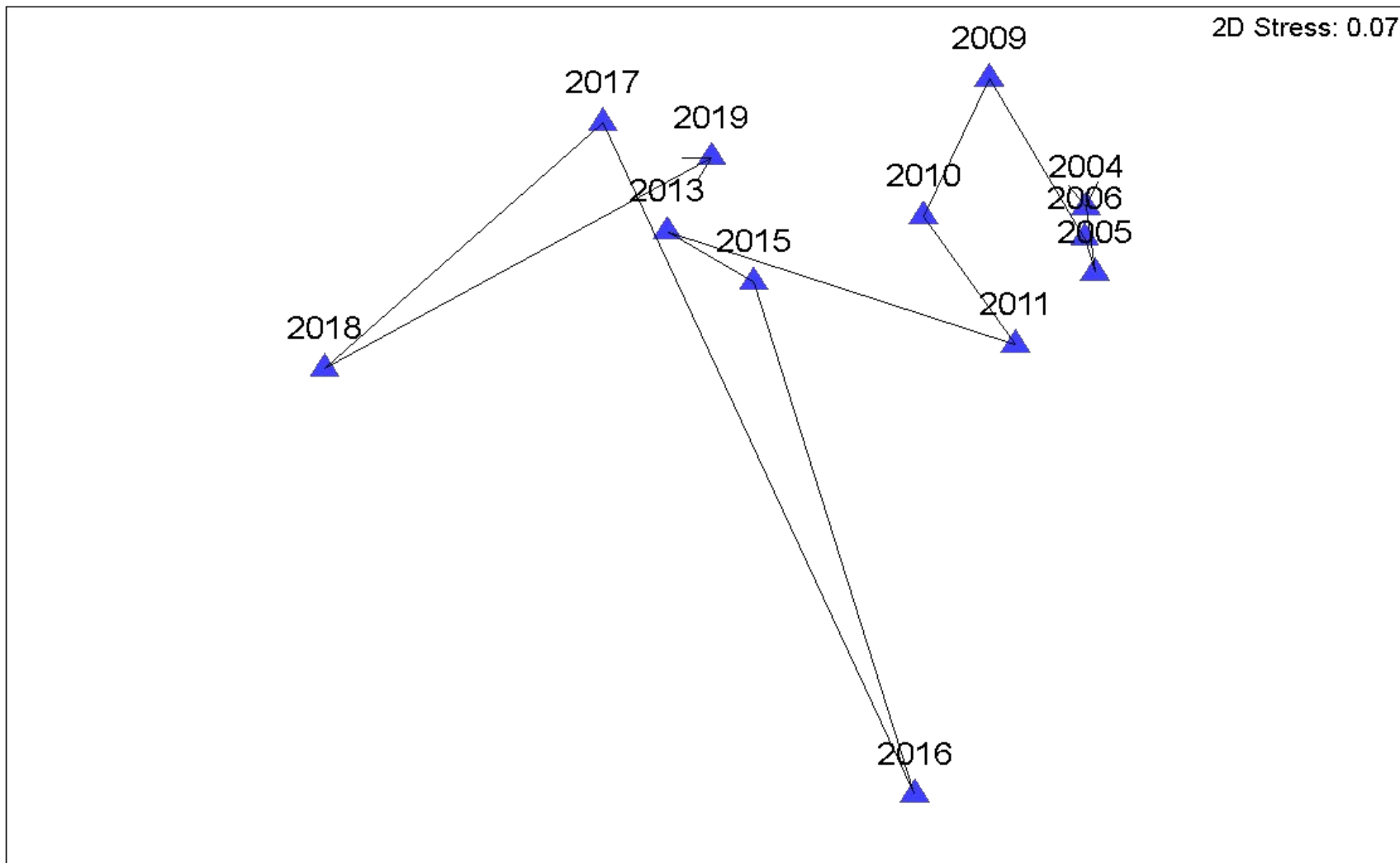
# Fisheries independent data (PRCRMP): Fish Abundance West Coast 2004-2019

*Non-metric MDS*

Resemblance: S17 Bray-Curtis similarity

2D Stress: 0.07

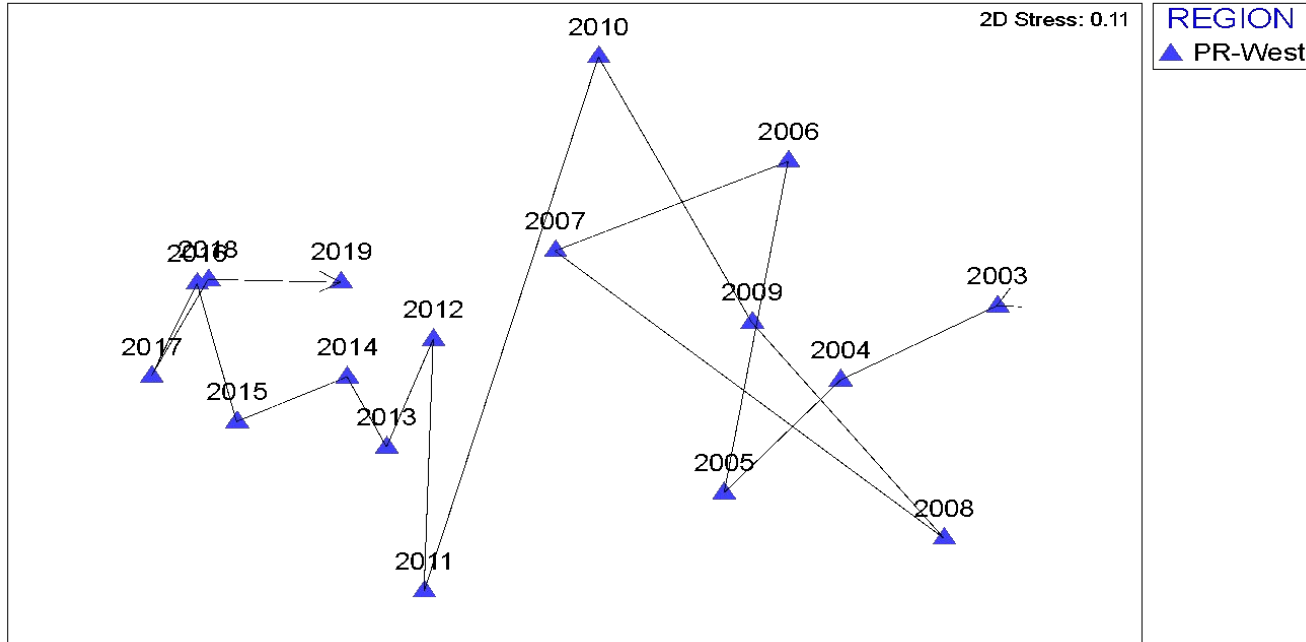
**REGION**  
▲ West



# Landings

Non-metric MDS

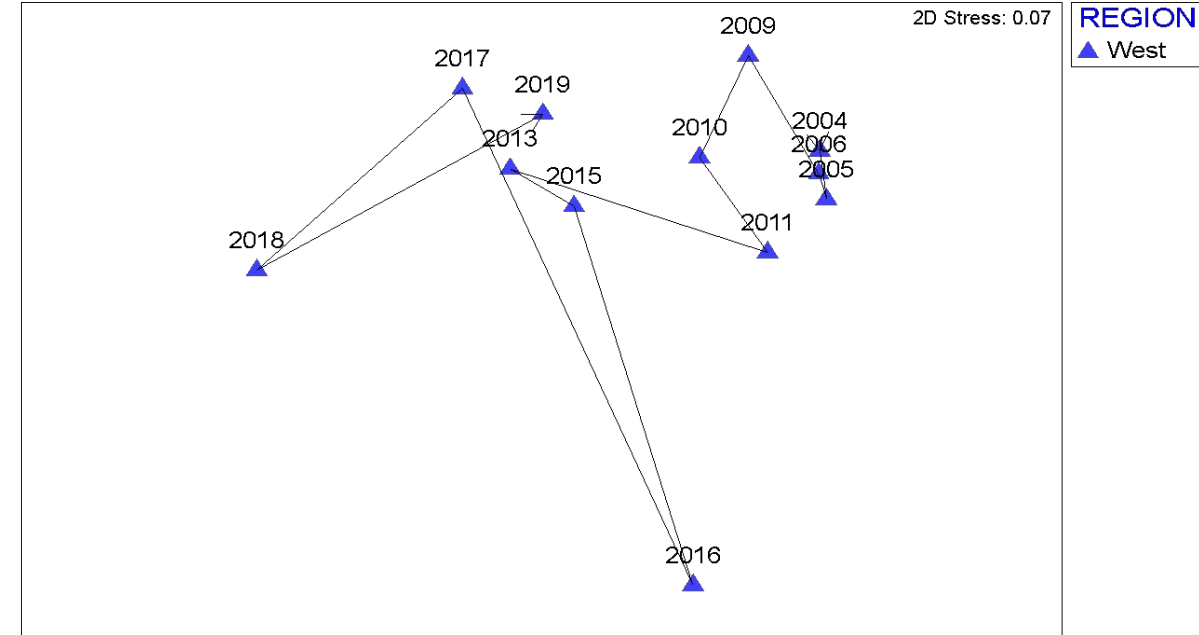
Standardise Samples by Total  
Transform: Square root  
Resemblance: S17 Bray-Curtis similarity



# Fisheries Independent

Non-metric MDS

Resemblance: S17 Bray-Curtis similarity



## RELATE (Rho)



Sample statistic (Rho): 0.473

Significance level of sample statistic: 0.009

Number of permutations: 9999

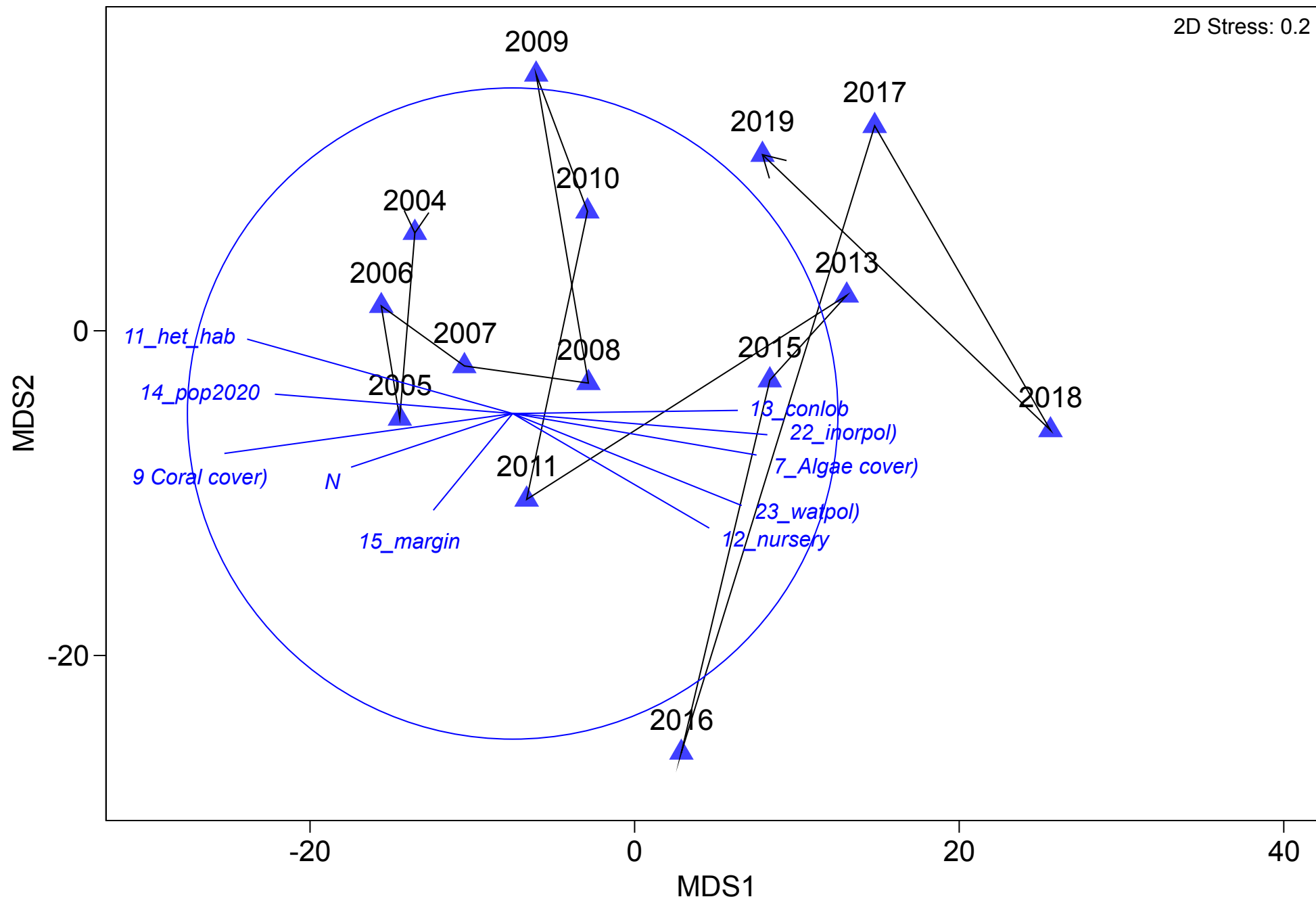
# Metric MDS

Resemblance: S17 Bray-Curtis similarity

2D Stress: 0.2

**REGION**

▲ West



## BIO-ENV Results (Rho)

*Best result for each number of variables*

### **No. Vars    Corr. Selections**

**1    0.469 Coral Cover (CC)**

**2    0.471 CC, Inorganic Pollution (IP)**

**3    0.478 CC, IP, Water Pollution (WP)**

**4    0.473 CC, IP, WP, Population 2020**

**5    0.474 CC, IP, WP, Population 2020, N**

# FINAL MESSAGE:

(For the Caribbean case)

- Description of temporal trend using a **multispecific** approach:  
Fisheries, Fish Assemblages and Drivers



- Identify alternative (potential) **drivers**:  
Indicators and Threats



However

- Need to Manage Fisheries outside CFCM jurisdiction:  
emerging and novel cross-mandate policymaking process?

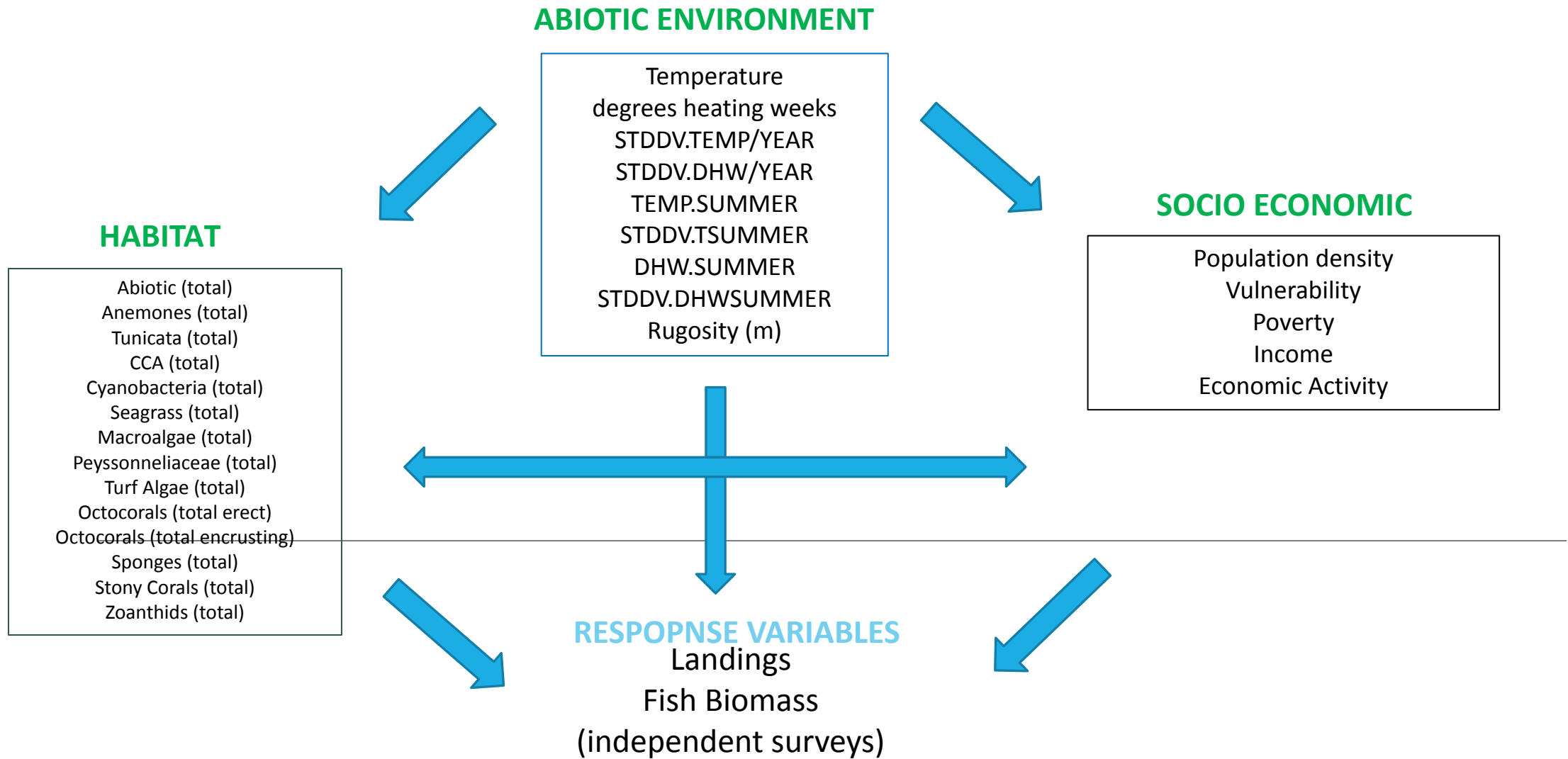
Thanks to:

- Lenfest Ocean Program: Funding
- CFMC: Funding
- All stakeholders that participated in the workshops



Questions???

# SOME variables available for analysis

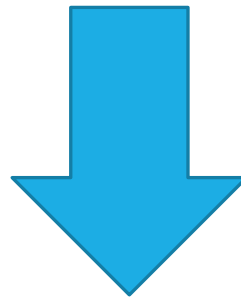


# Analitical tool: Structural Equation Modelling (SEM)

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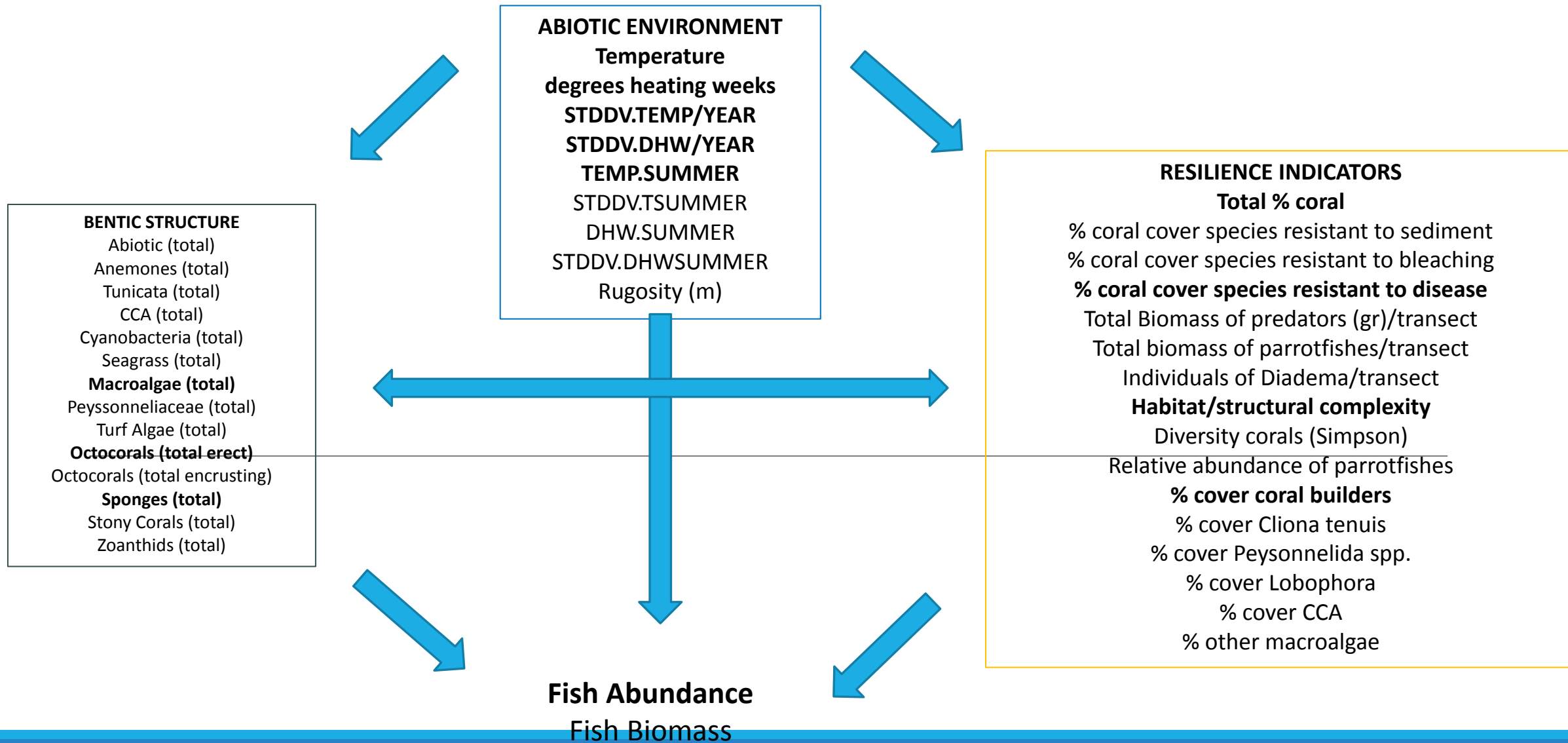
The spatiotemporal resolution of variables differ, but can (and should) be matched by time (e.g. year/season) and space (e.g. Location/reef/region) .

Too many variables, too many potential paths (causal relation or covariation): We need specific models with causal relationships to avoid overparameterization.

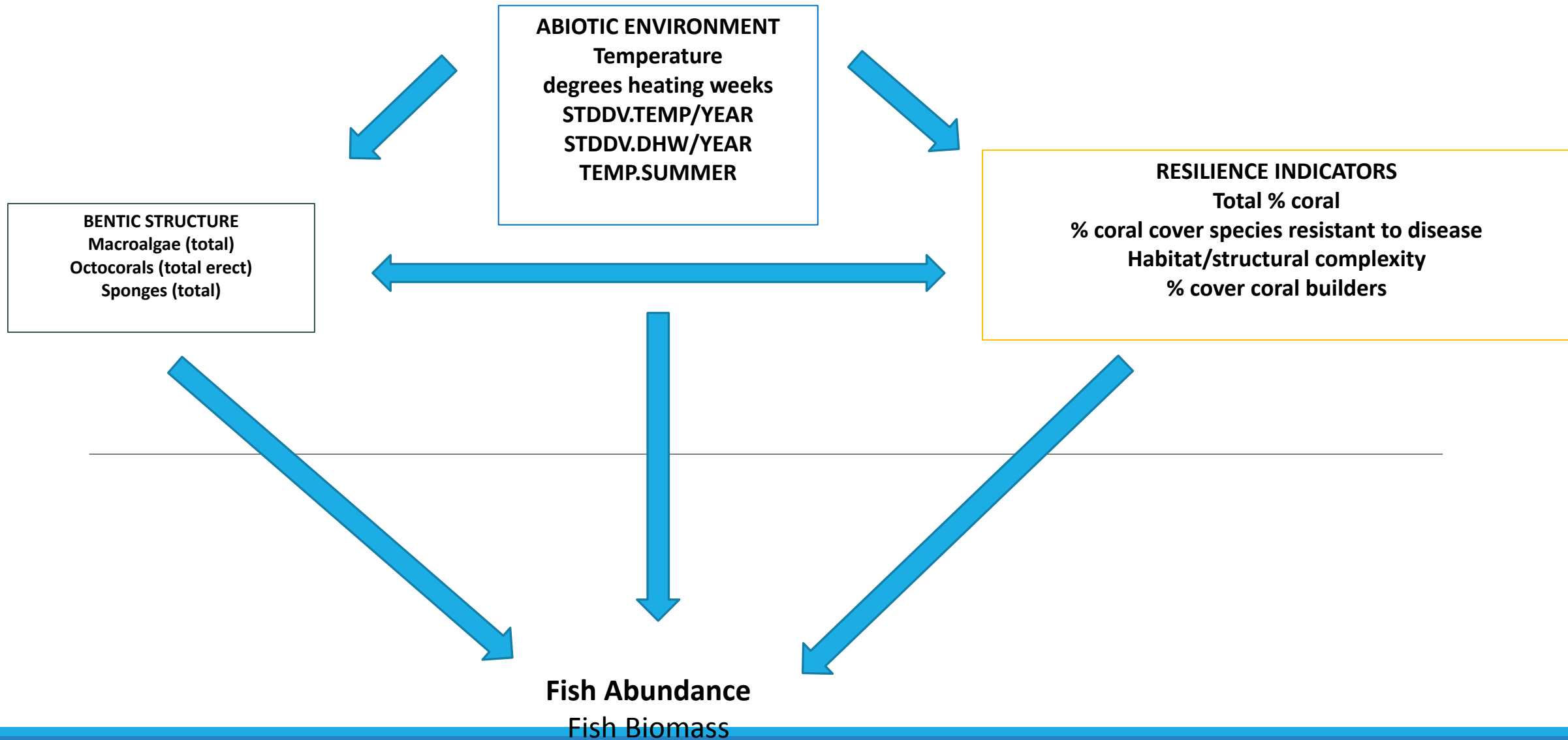


CONCEPTUAL MODELS

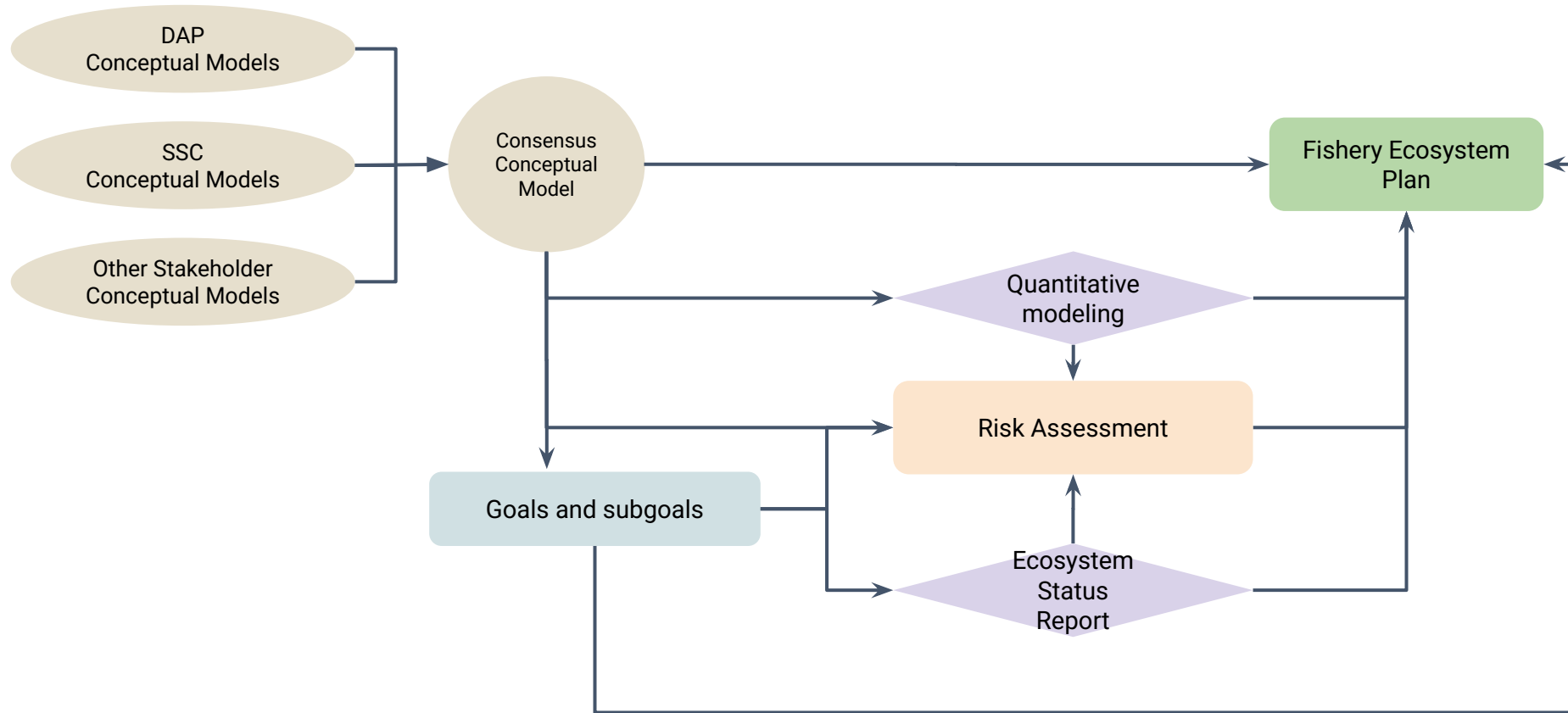
# EXAMPLES OF SOME variables available for analysis



# SELECTION of variables using Conceptual Model(s)



# EBFM-TAP U.S. Caribbean





The ecosystem-based fisheries management (EBFM) framework has a solid theoretical justification and has been embraced in principle by many regions; yet, systematic implementation remains a challenge. Taken from Karnauskas et al 2020.

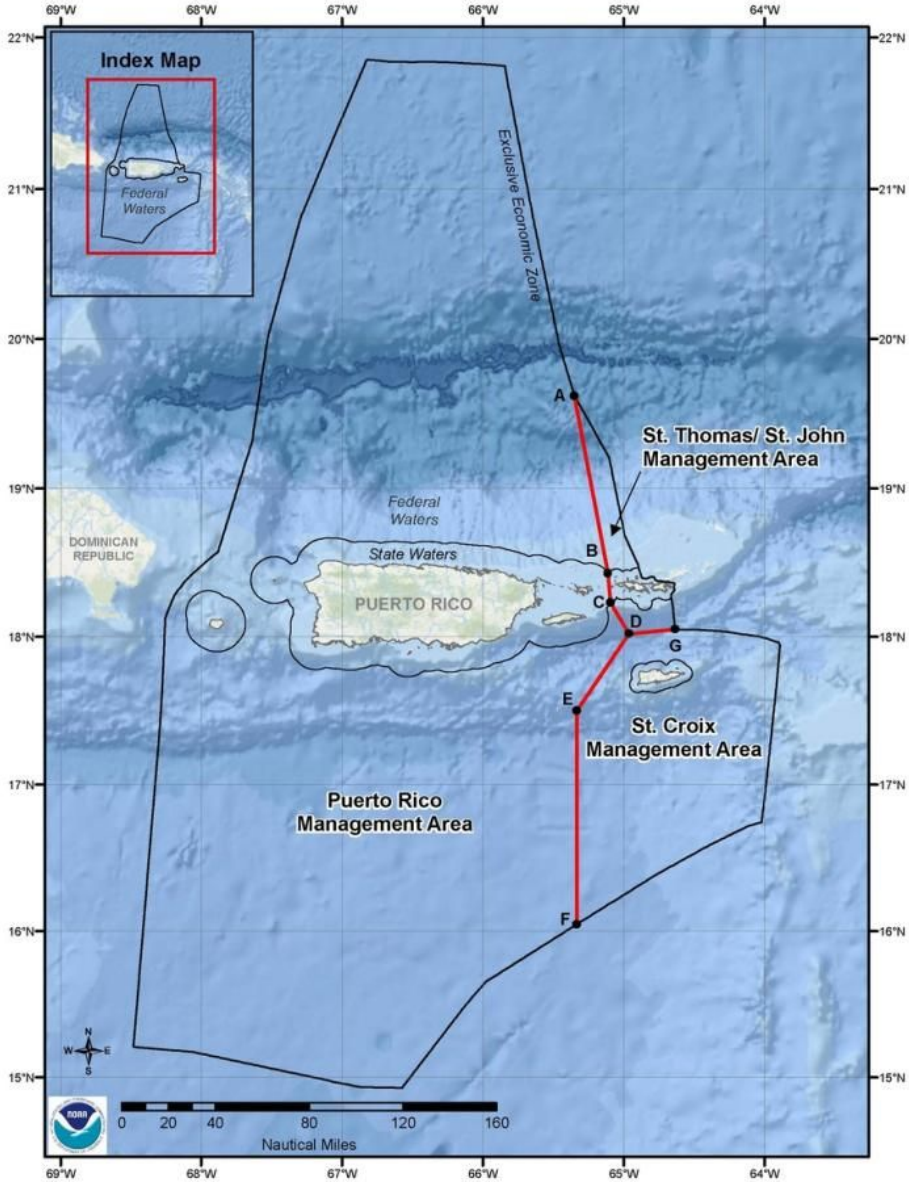
In the US it is claim that most stocks are not overfished (NOAA), however in the Caribbean things seems to go bad (

Check 2020 SOS Stock Status Tables for fisheries in the US Caribbean...most of them we don't know.  
We can not use a Single Species approach.

Please note that the ecosystem response papers I have found are actually univariate since they group all the species in a singles or few indicators.

Plea to move from the industrial thinking to artisanal thinking (see papaers idea to see what I mean)

# Caribbean Island/Island Group Management Areas



Ocean Basemap from ArcGIS.com  
Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors