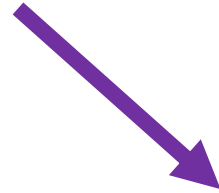


Structure and Logical framework behind an FEP: The Caribbean case

Juan J. Cruz-Motta; Tarsila Seara; Stacey Williams

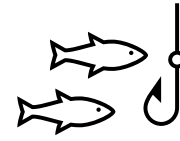
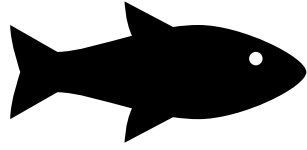
What is an FEP?

- Tool to assist in the process of implementing EBFM.
- Consolidate information to better understand linkages and tradeoffs between environmental, economic, and social aspects of fisheries ecosystems.
- Translating FEP goals into action



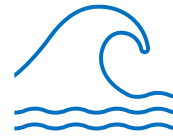
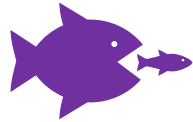
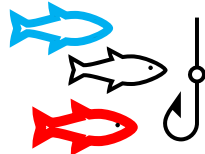
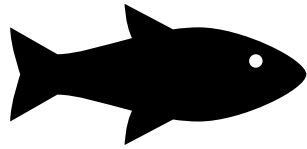
Lenfest Loop

SSF



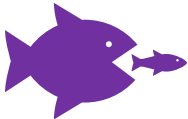
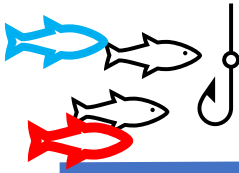
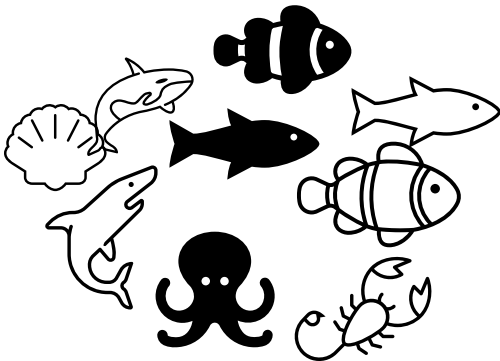
FMP

EAFM



FMP

EBFM



FEP

1. Where are we now?

- a) Defining the fishery system by identifying its key components and how they interact
- b) Quantifying the status and trends of the fishery system using indicators, and
- c) Identifying threats to the system.

1.a) Defining the fishery system

1) Conceptual Models

A. To guide management strategies

B. *“A conceptual model can be considered complete when consensus is reached among those constructing the model. In cases where consensus cannot be reached, the FEP can proceed with alternative conceptualizations”*

2) Ecosystem Status Report

US Caribbean



Non-metric MDS

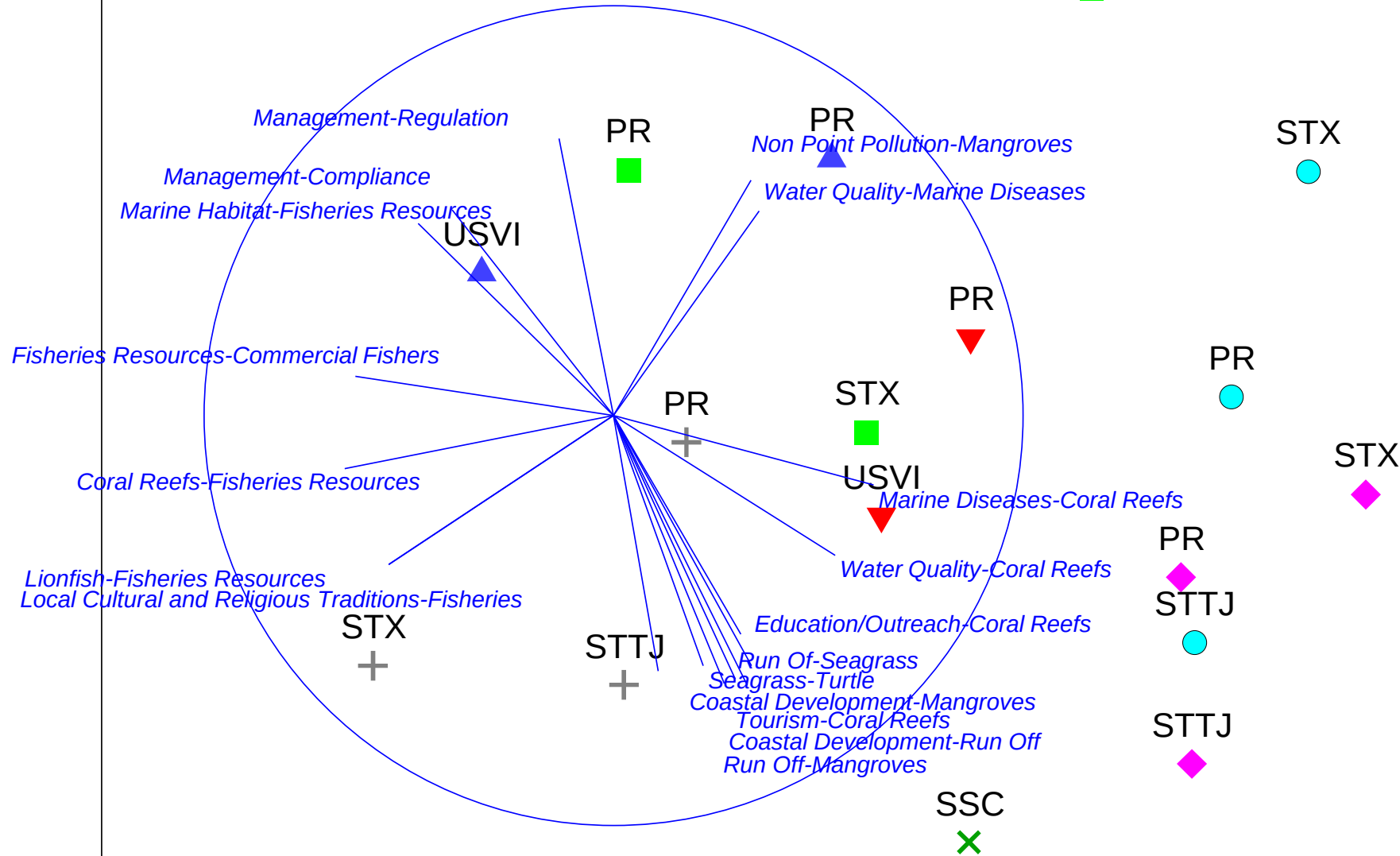
At 60 %

Resemblance: S8 Sorensen

2D Stress: 0.2

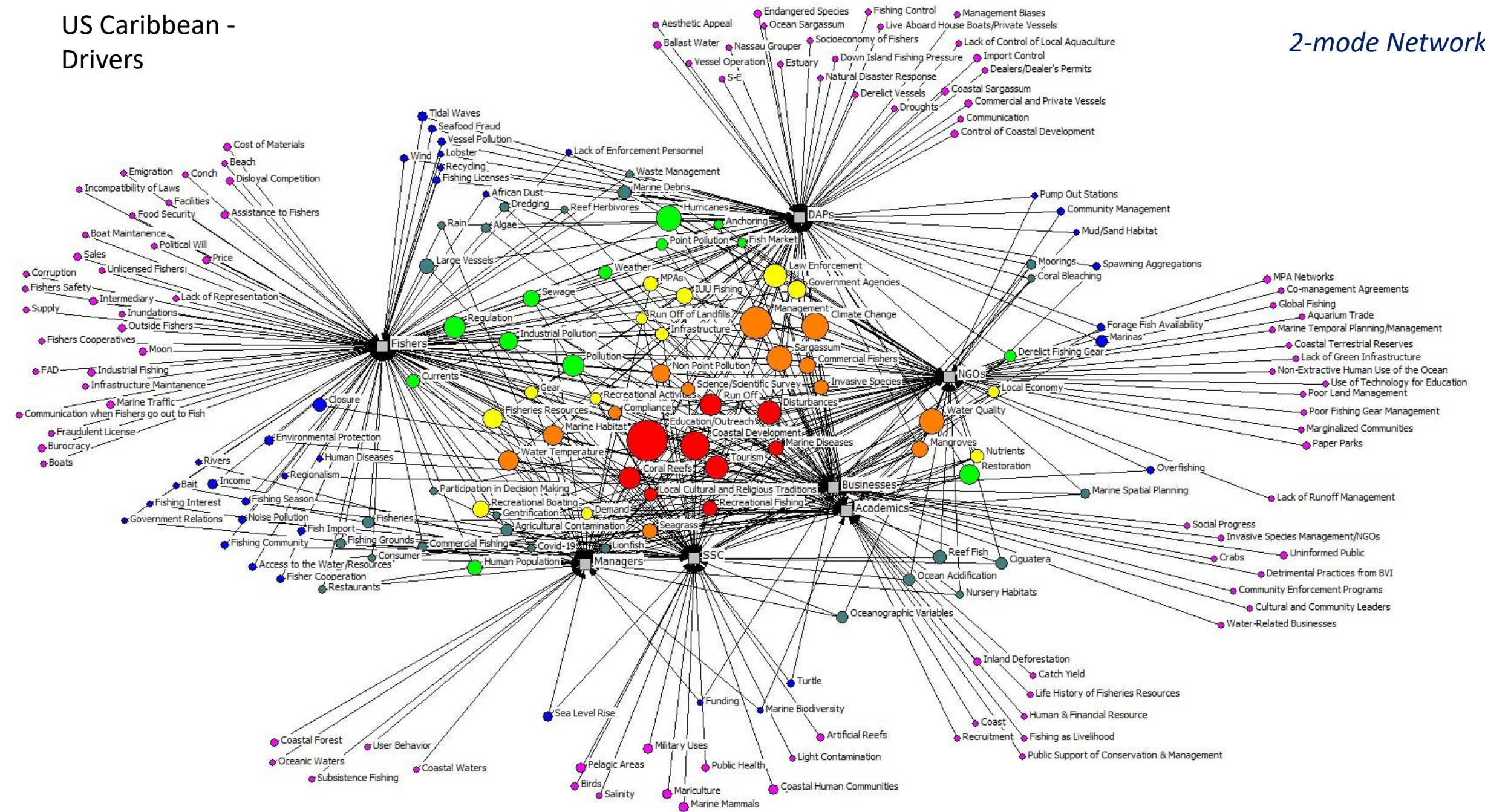
Stakeholder

- MAN
- EXP
- DAP
- BUS
- NGO
- FISH
- SSC



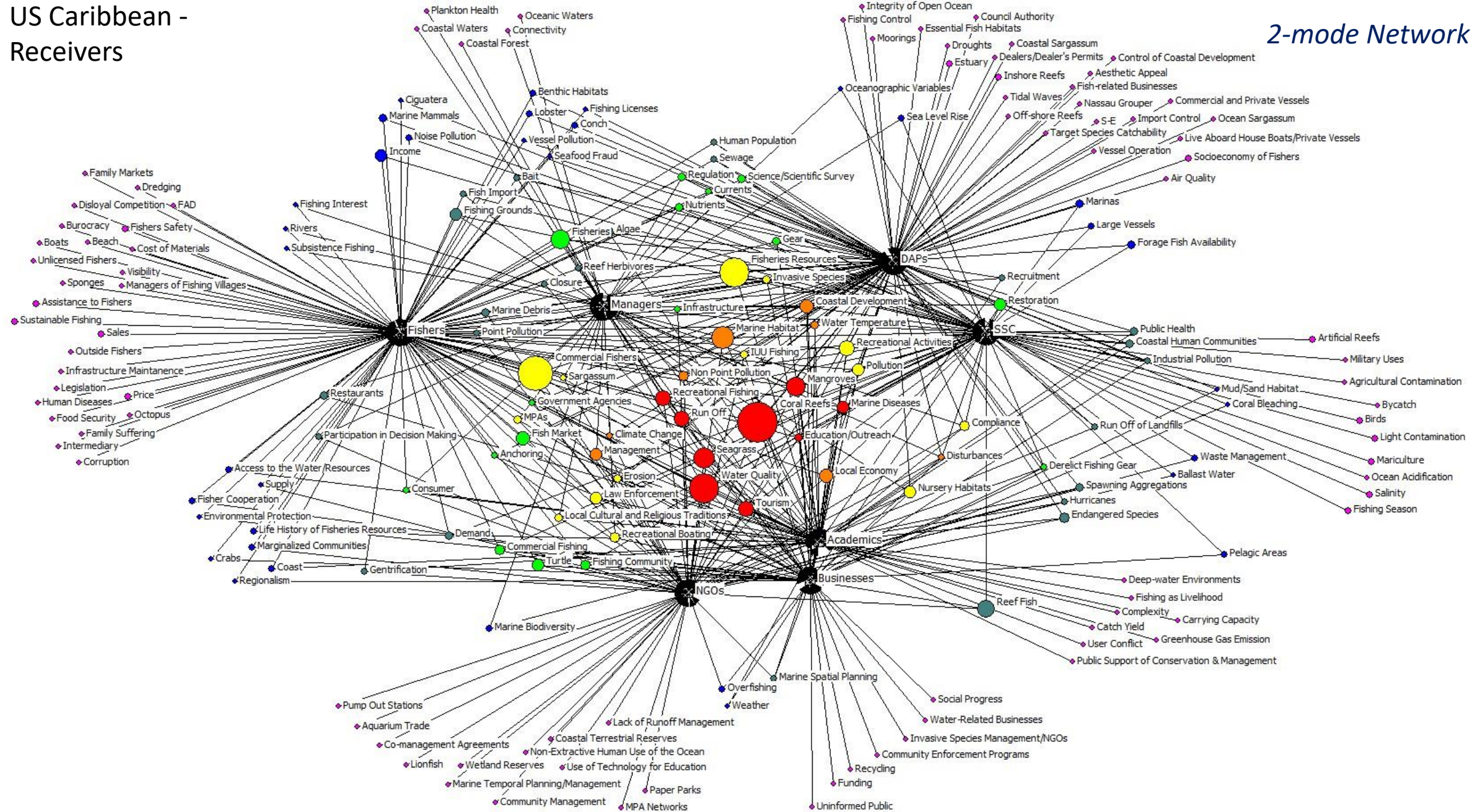
US Caribbean - Drivers

2-mode Network



US Caribbean - Receivers

2-mode Network



Ecosystem Components identified by all 7 stakeholder groups as important drivers and receivers:

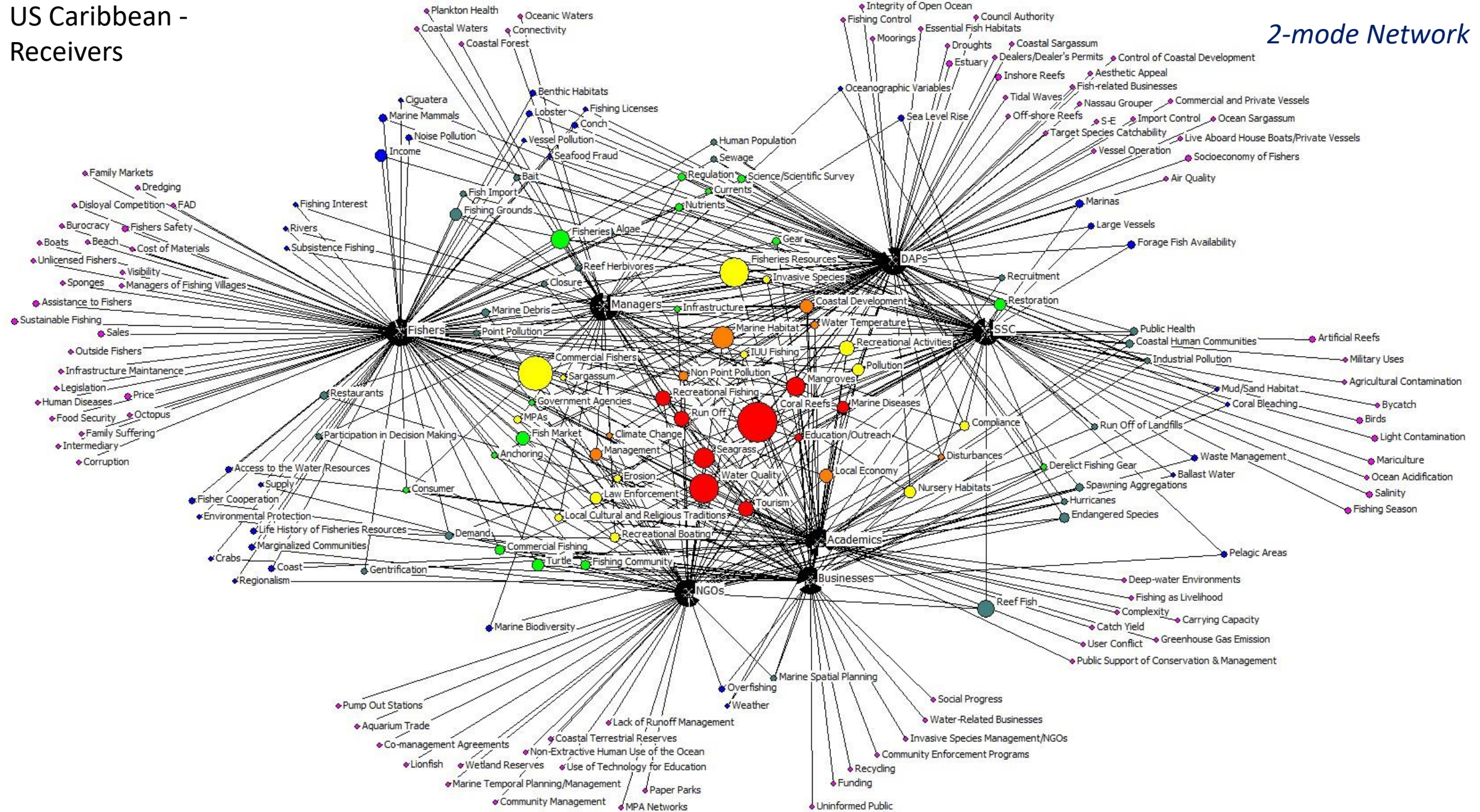
Drivers	Receivers
Recreational Fishing	Recreational Fishing
Coral Reefs	Coral Reefs
Run-off	Run-off
Tourism	Tourism
Education/Outreach	Education/Outreach
Marine Diseases	Marine Diseases
Disturbances	Water Quality
Coastal Development	Mangroves
Local Cultural and Religious Traditions	Seagrass

1.b) Select and calculate indicators

- 1) To evaluate:
 - 1) The status of the fishery system. Baseline.
 - 2) How it respond to environmental and anthropogenic drivers
 - 3) How has the fishery system changed through time
- 2) First step is to translate components into “attributes”
 - 1) Attribute = characteristic that describe the sate of the component.
 - 1) Example: Component = coral reefs. Attribute = total coral cover.
 - 2) Example: Component = Recreational fishing. Attribute = Total biomass

US Caribbean - Receivers

2-mode Network

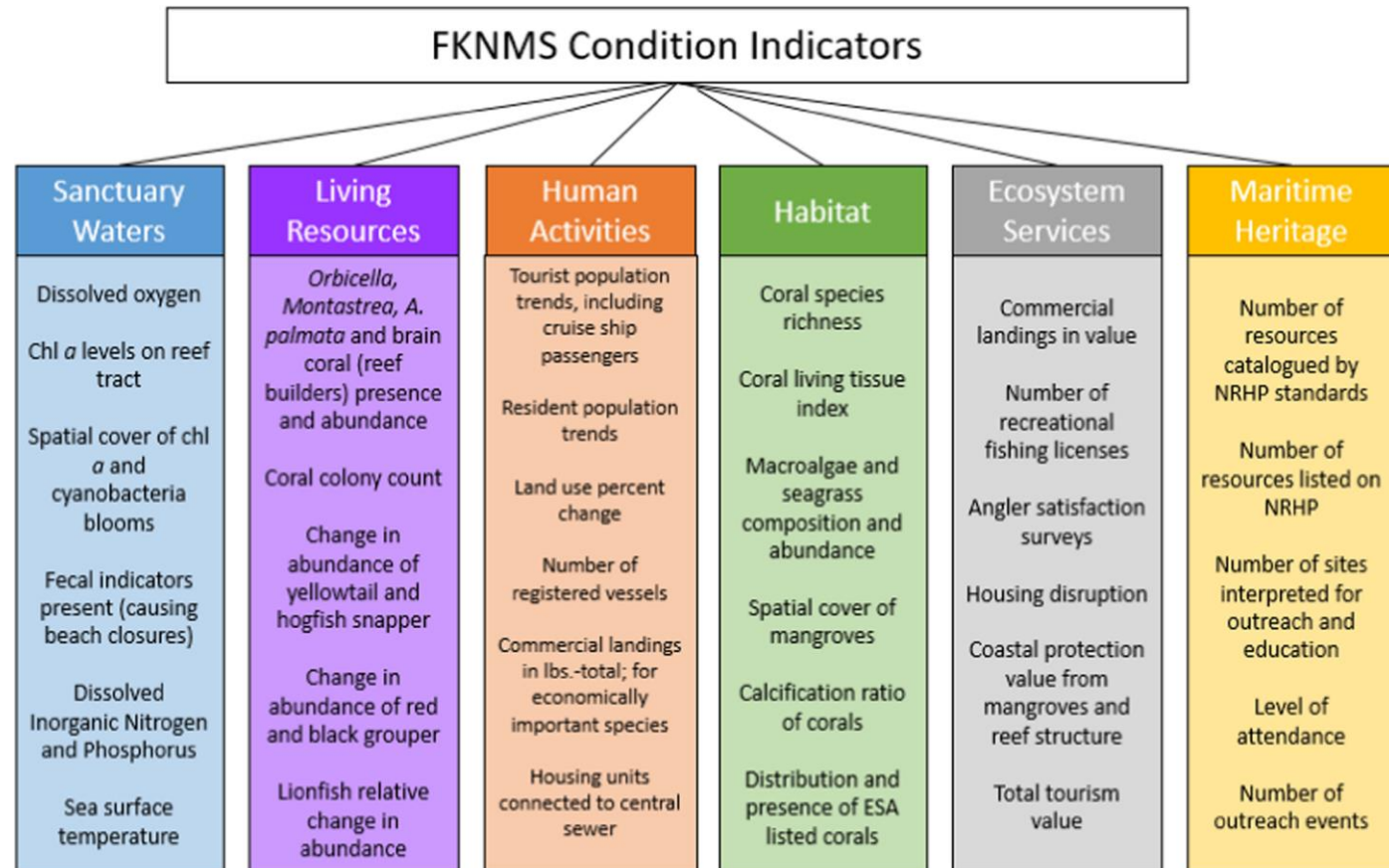


Qualitative approach

Marine Policy 129 (2021) 104489

A quantitative and qualitative decision-making process for selecting indicators to track ecosystem condition

Kelly Montenero [a,b,*](#), Chris Kelble [b](#), Kathy Broughton [c](#)



1.b) Select and calculate indicators

Quantitative approach

[Ecological Indicators 124 \(2021\) 107403](#)

A hypothesis-driven statistical approach for identifying ecosystem indicators of coho and Chinook salmon marine survival

Kathryn L. Sobocinski [et al., 2021](#).

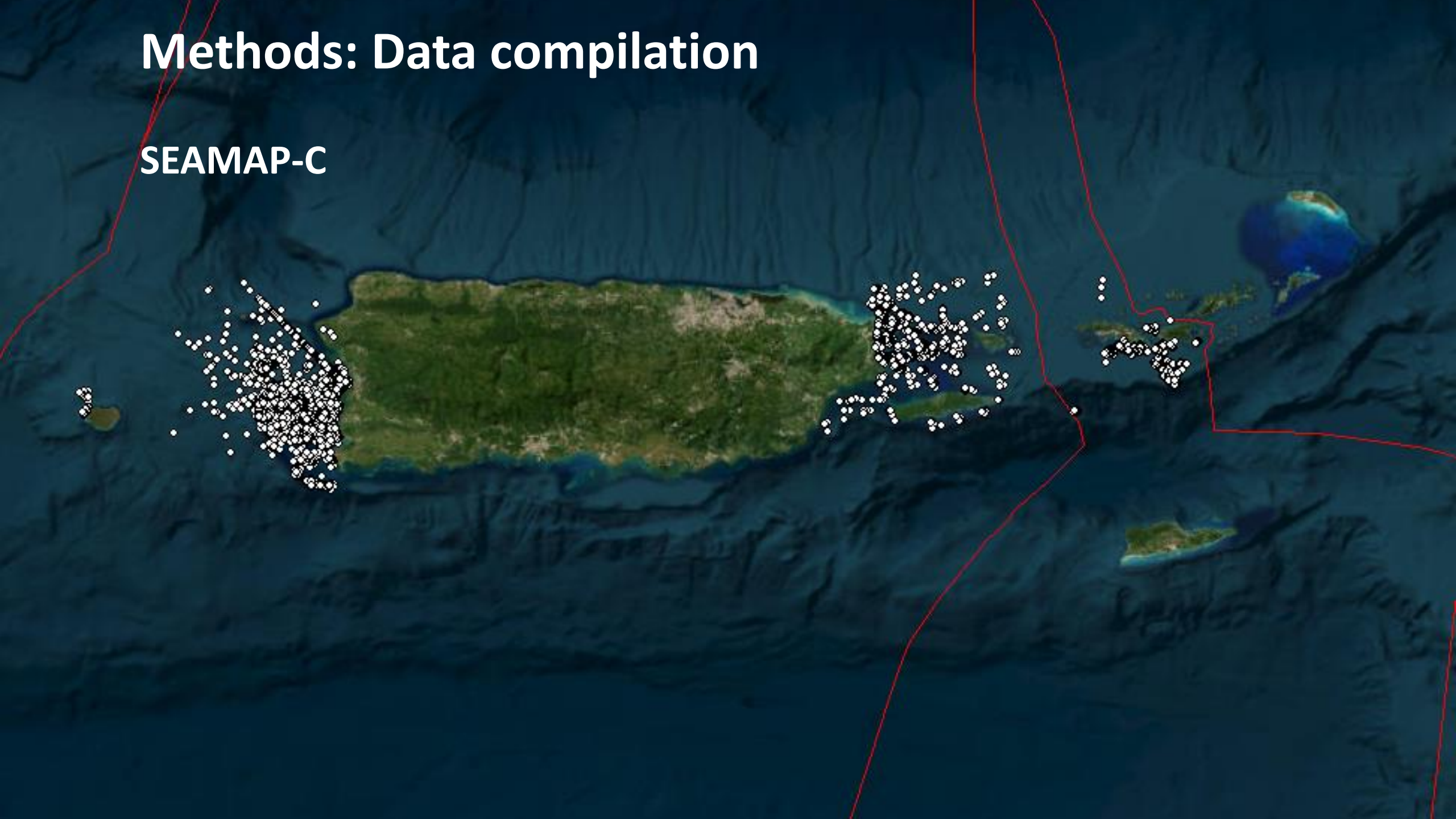
H1: Predator Buffering (Abundance)

Indicators	VIW	Direction of Rel.	Best Models	ΔAIC_c	$\omega_i AIC_c$	r^2
 Seal Abundance	0.82		  	0	0.142	0.353
 SOG Herring Abundance	0.57		 	0.500	0.111	0.340
 PS Pink Abundance (outmigrating)	0.49		    	1.212	0.077	0.342
 Y Chinook Hatch Release Abundance	0.32			1.436	0.069	0.339
 Fraser Pink Abundance (outmigrating)	0.25		   	1.726	0.060	0.355
 PS Herring Abundance (total)	0.23		   	1.784	0.058	0.359
 PS Herring Abundance (by subbasin)	0.09		 	1.989	0.052	0.349
 Orcas Abundance	0.09		 	2.349	0.044	0.345
 SY Chinook Hatch Release Abundance	0.08		  	2.388	0.043	0.345
 Y Coho Hatch Release Abundance	0.00		  	2.513	0.040	0.357
 Ocean Salmon Abundance	0.00		  	2.591	0.039	0.341
			 	2.804	0.035	0.342

MULTISPECIES/MULTIDRIVER Option

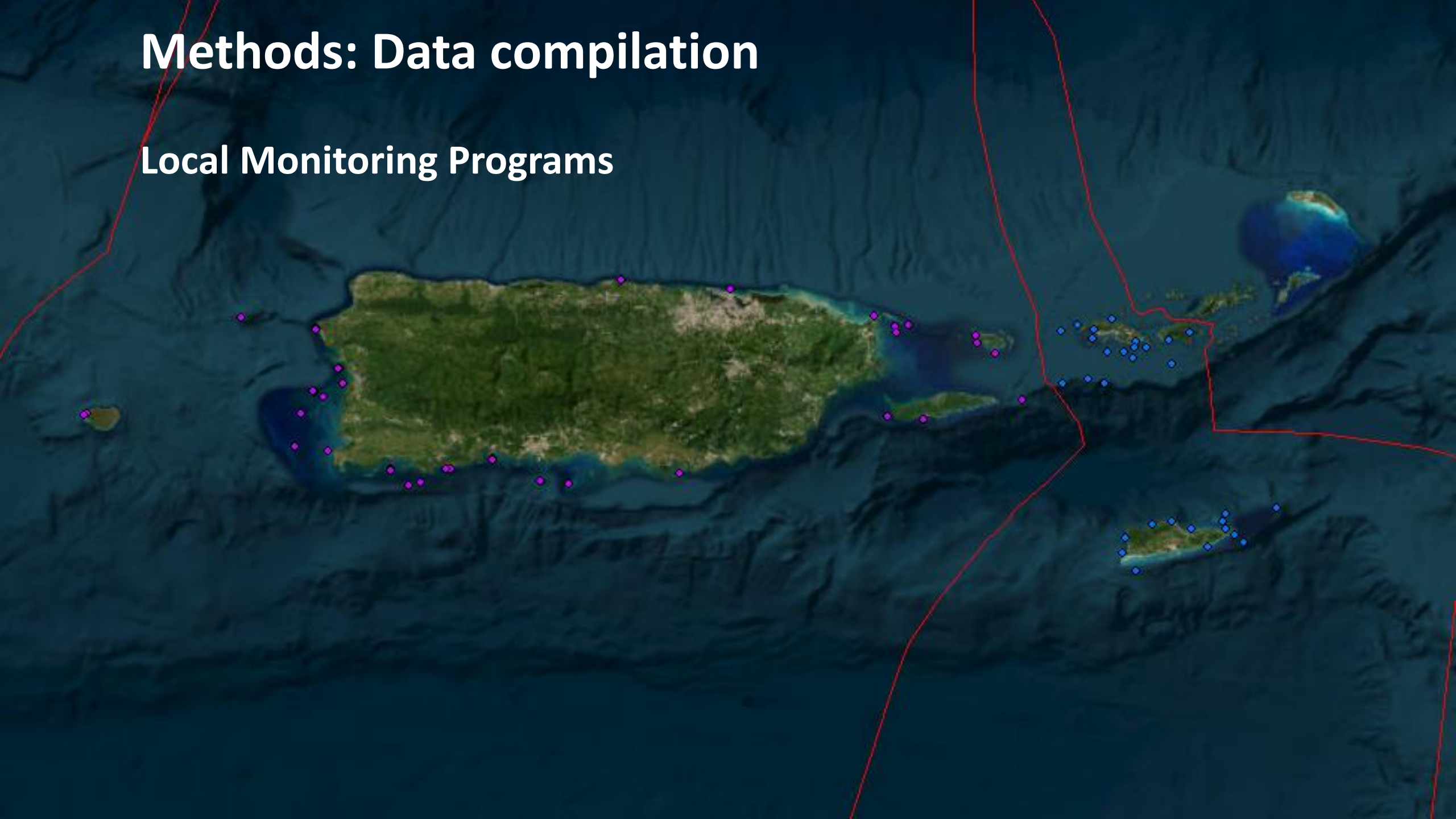
Methods: Data compilation

SEAMAP-C



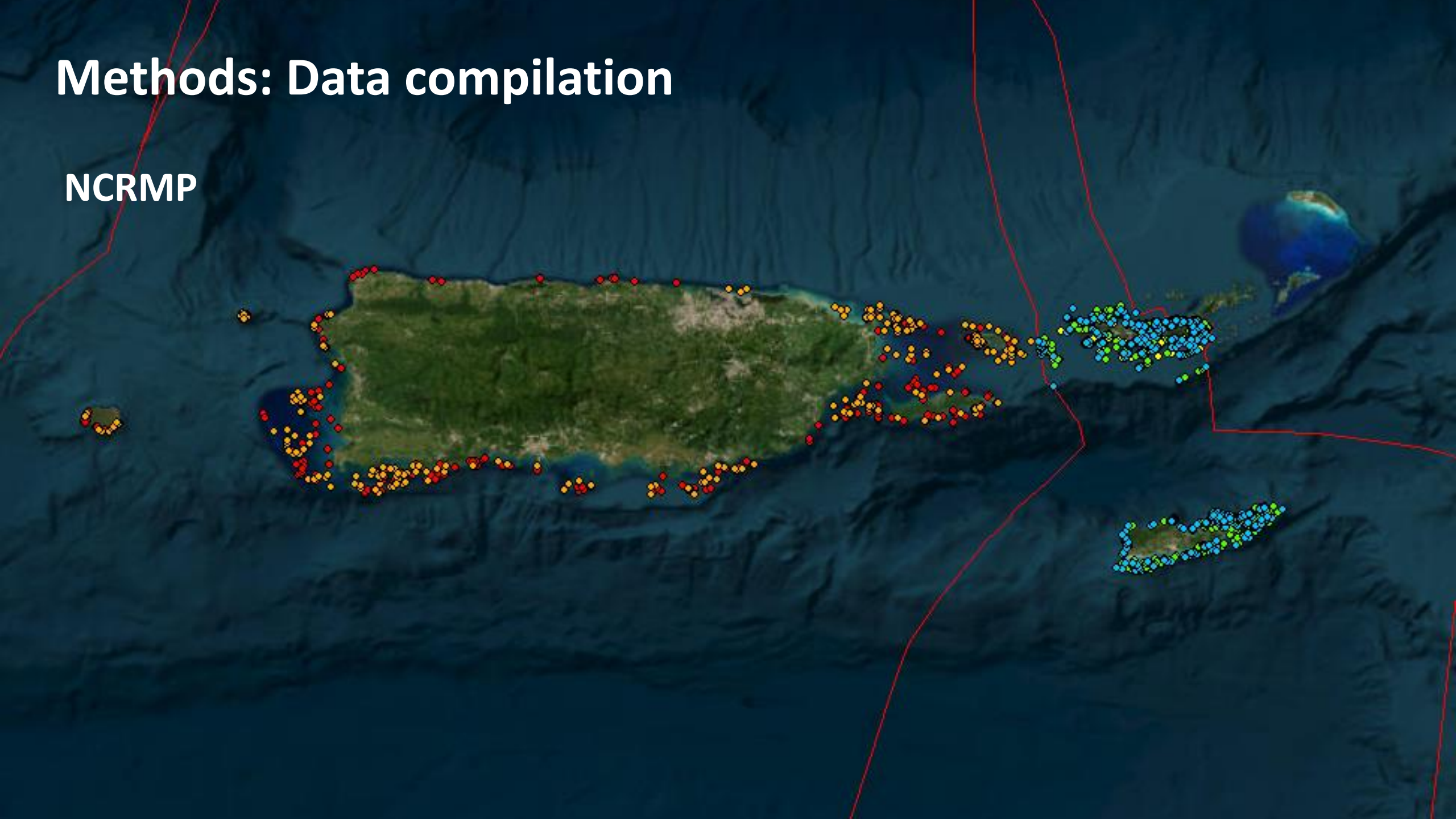
Methods: Data compilation

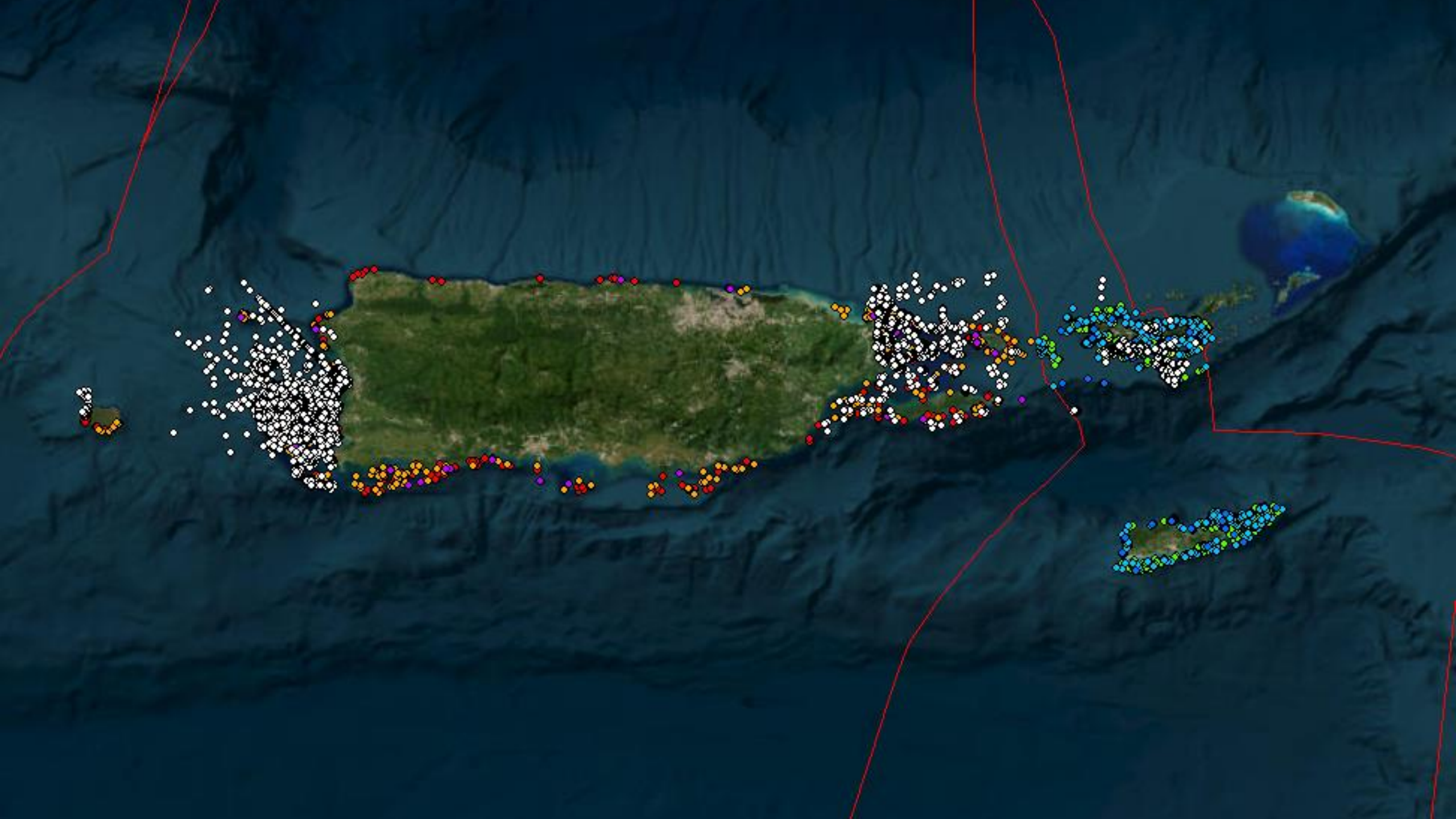
Local Monitoring Programs



Methods: Data compilation

NCRMP





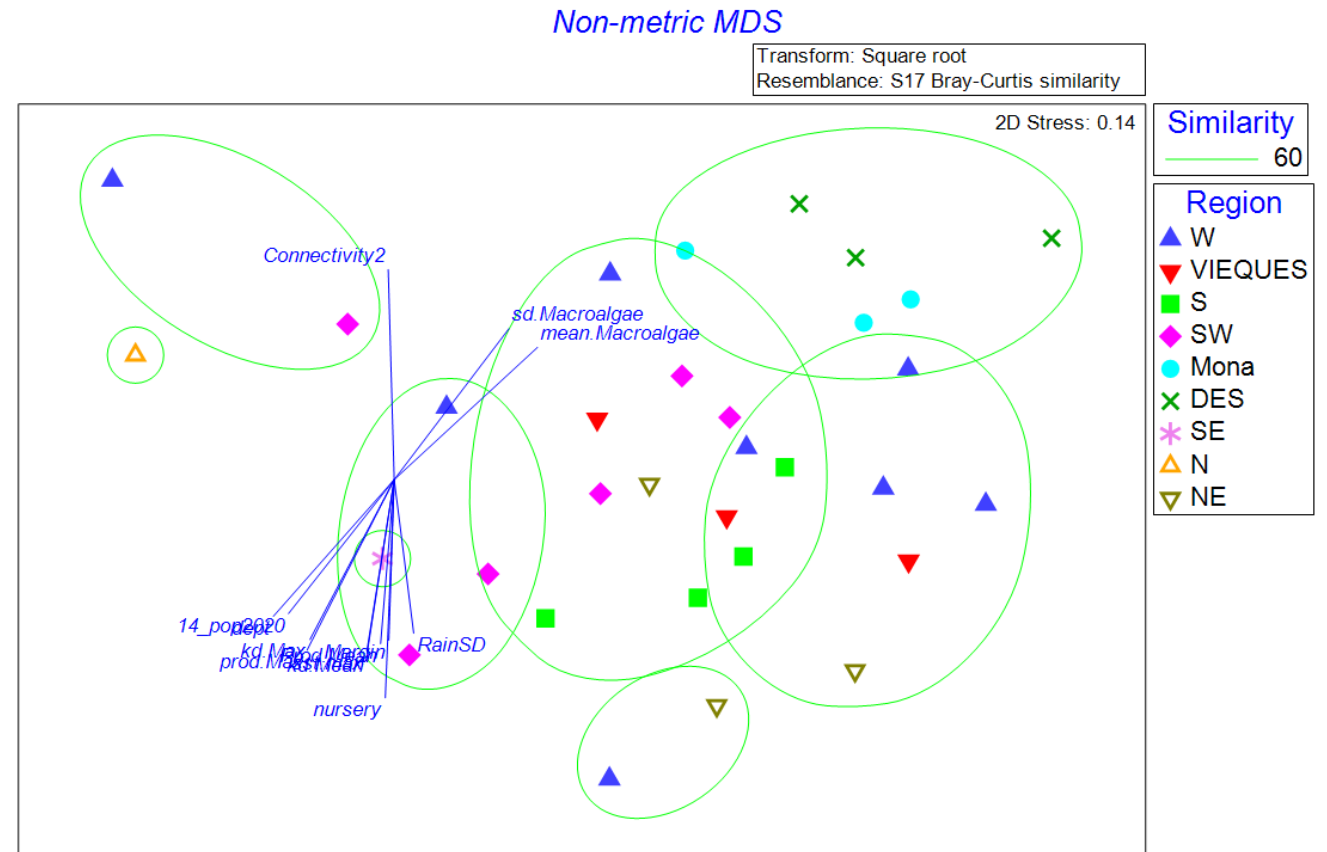
Socio-Economic
Census
CSVl
NCRMP
TIP
Landings

Landings
Fishers
Observs

Variable	Data source
Wave exposure*	Significant Wave Height
Currents	Current speed
Rainfall*	Rainfall
Hurricanes*	Hurricane tracks
Sea surface temperature*	Sea Surface Temperature
Sea surface temperature anomalies (DHW)*	Sea Surface Temperature
Turbidity*	Diffuse attenuation K490
Productivity*	Net primary production
Watershed Pollution	Reef at Risk
Inorganic Pollution	Halpern Model
Depth	Bathymetry
Slope	Bathymetry
Orbital velocity	Sig. wave height & period + depth
Distance from a major river discharge	Hydrography
Distance from port	Port location
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	Gravity of human impacts
Distance from shelf break	Continental margin

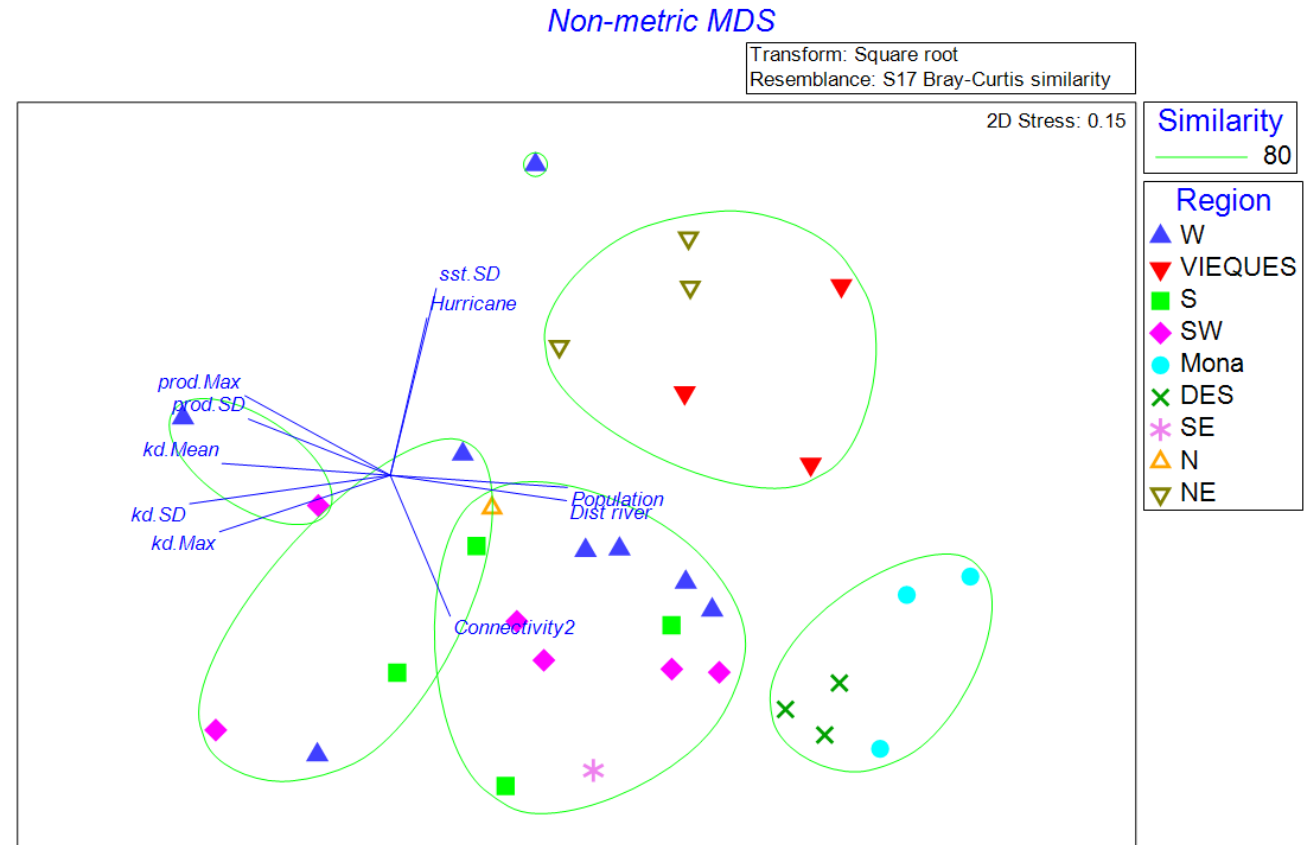
PRCRMP Mean Fish Abundance

Mean macroalgae
Connectivity
Change in macroalgae
Distance from nursery
Depth
Max Kd
Max productivity
Max SST
Population density
Watershed pollution



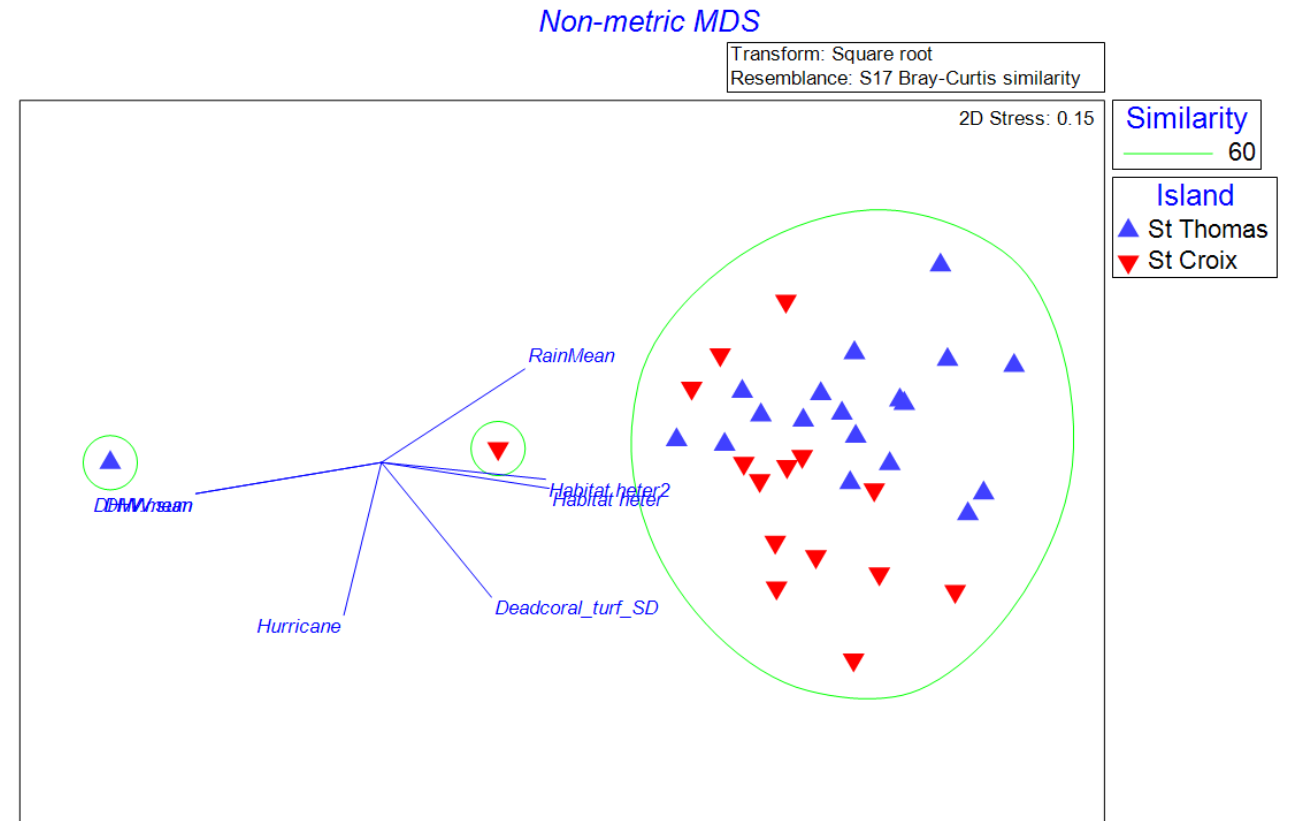
PRCRMP Benthic change

Variation Kd
Max Kd
Mean Kd
Variation SST
Change in population
Max productivity
Connectivity
Distance from river
Distance from nursery habitat
Mean productivity



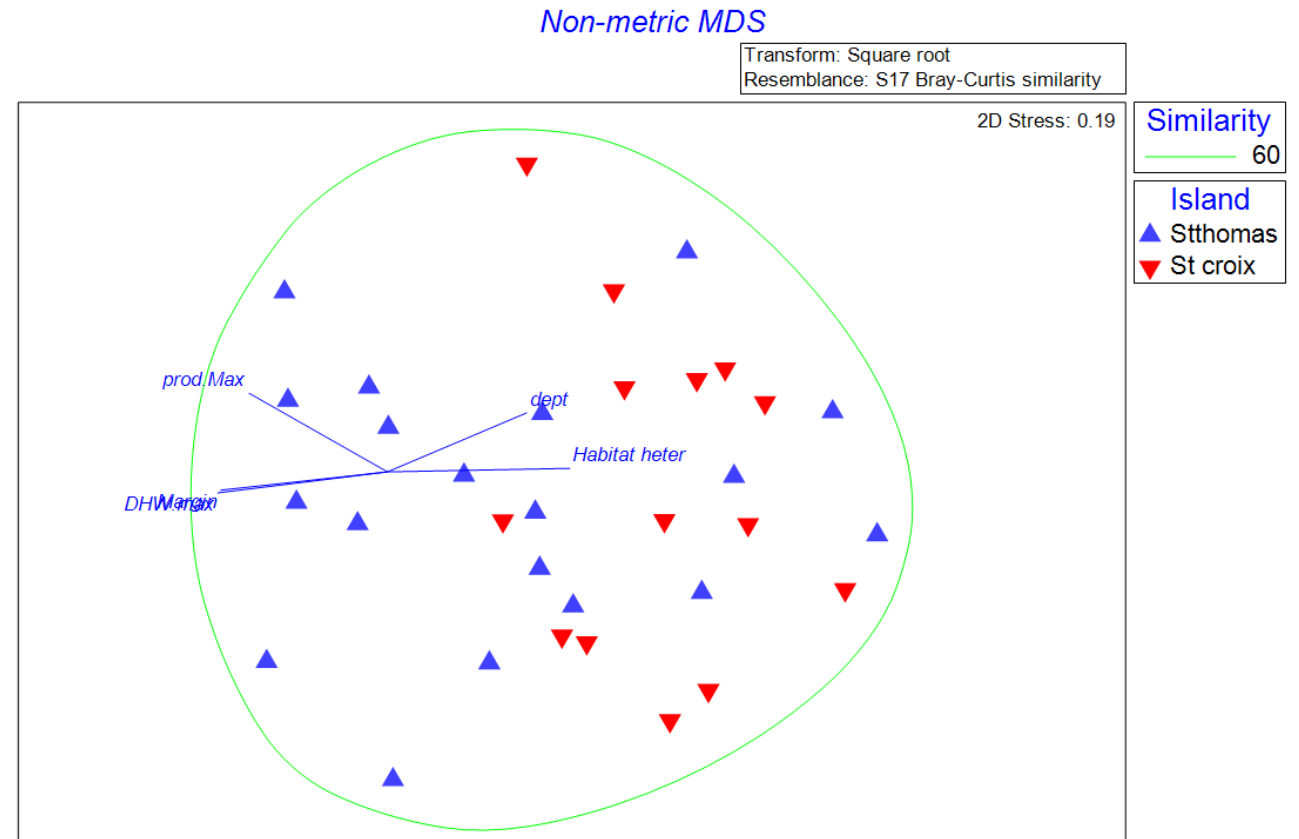
USVI-CRMP Mean Fish abundance

Sum DHW
Mean DHW
Habitat heterogeneity
Mean Rainfall
Mean SST
Variation of dead coral with turf
Distance from Spawning
Connectivity
Max Kd
Hurricane



USVI-CRMP Change in benthic cover

Habitat heterogeniety
Max DHW
Margin
Depth
Max productivity
Variation productivity
Variation in rain
Sum DHW
Mean DHW
Max SST



Fish abundance

PR

Mean macroalgae *	*
Connectivity *	
Change in macroalgae	
Distance from nursery	
Depth	
Max Kd	
Max productivity	
Max SST	
Population density	
Watershed pollution	

USVI

Sum DHW	*
Mean DHW	
Habitat heterogeneity	
Mean Rainfall	
Mean SST	
Variation of dead coral with turf	
Distance from Spawning	
Connectivity *	
Max Kd	
Hurricane	

Quantitative vs Qualitative

Mean macroalgae

Connectivity

Change in macroalgae

Distance from nursery

Depth

Max Kd

Max productivity

Max SST

Population density

Watershed pollution

Drivers	Receivers
Recreational Fishing	Recreational Fishing
Coral Reefs	Coral Reefs
Run-off	Run-off
Tourism	Tourism
Education/Outreach	Education/Outreach
Marine Diseases	Marine Diseases
Disturbances	Water Quality
Coastal Development	Mangroves
Local Cultural and Religious Traditions	Seagrass

1c, Inventory threats: factors or activities that may adversely affect a fishery system.

Also extracted from Conceptual Models

Table 1 Top indicators for anthropogenic pressures in the California Current ecosystem (CCE) (Appendices 1 and 2 provide evaluation and selection, source of data and calculations of indicators for each pressure, see supplementary materials at [Journals.cambridge.org/ENC](https://journals.cambridge.org/ENC)). *Pressures used in cumulative pressures index and principal components analysis, CA = California, OR = Oregon and WA = Washington.

Pressure	Indicator	Definition	Time series	Sampling frequency
*Aquaculture: finfish	Finfish production	Estimates of Atlantic salmon production in CCE waters	1986–2011	yearly
*Aquaculture: shellfish	Shellfish production	USA shellfish (clams, mussels and oysters) production	1985–2010	yearly
*Atmospheric pollution	Deposition of sulphate	Annual precipitation-weighted mean concentrations of sulphate measured at sites in CA, OR and WA	1994–2010	yearly
*Benthic structures	No. offshore oil and gas wells	Total number of offshore oil and gas wells in production	1981–2009	yearly
*Coastal engineering	Human coastal population	Population size of coastline counties in CA, OR, WA	1970–2012	yearly
Commercial shipping activity	Volume of water disturbed	Calculated using draft, breadth and distance travelled within CCE of domestic and foreign vessels	2001–2010	yearly
Dredging	Dredge volumes	Dredge volumes for individual private contracts and Army Corps operated dredge projects in WA, CA and OR	1997–2011	yearly
*Fishery removals	Total landings	Tonnes of all species landed by commercial and recreational fisheries in CA, OR and WA	1981–2011	yearly
*Freshwater retention	Impoundment storage volume	Total reservoir storage volume in CA and Pacific Northwest water resource regions	1900–2011	yearly
Habitat modification	Distance trawled	Kilometres trawled by the limited-trawl groundfish fishery in CA, OR and WA	1999–2004	yearly
*Inorganic pollution	ISA-toxicity-weighted chemical releases	Total pounds of inorganic pollutants disposed of or released on site to the ground or water for '1988 core chemicals' weighted by toxicity scores and impervious surface area (ISA) in the drainage watersheds of the CCE	1988–2010	yearly
*Invasive species	Tonnes of cargo	Tonnes of cargo moved through ports in CA, OR and WA	1993–2010	yearly
*Light pollution	Average night-time visible light	Data are cloud-free composites of average visible night-time lights made using all the available archived DMSP-OLS smooth resolution data for each calendar year	1994–2010	yearly
Marine debris	Predicted counts of debris	Estimates from the National Marine Debris Monitoring Program separated into north and south CCE estimates	1999–2007	yearly
*Nutrient input	Nitrogen and phosphorus input	Total farm and non-farm nitrogen and phosphorus input from fertilizer used in counties within CCE watersheds	1945–2010	yearly
Ocean-based pollution	Commercial shipping activity combined with tons of cargo	Combines 'Commercial shipping activity' and 'Invasive species' datasets	2001–2010	yearly
*Offshore oil activities	Offshore oil and gas production	Normalized sum of the number of barrels of oil and cubic feet of gas produced from offshore wells in CA	1970–2010	yearly
*Organic pollution	Toxicity-weighted concentrations	Toxicity-weighted concentrations of 16 pesticides measured in water samples from stream-water sites in WA, OR and CA	1993–2008	yearly
Power plants	Saline water withdrawal volumes	Average daily withdrawal volumes of saline water from thermoelectric power plants in the Pacific Northwest and California regions	1955–2005	Every 5 years
Recreational beach use	Beach attendance	Summed beach attendance from CA, OR and WA	2002–2011	yearly
*Seafood demand	Total consumption	Total consumption of edible and non-edible fisheries products in the USA	1962–2011	yearly
*Sediment retention	Impoundment storage volume	Same as 'Freshwater retention'	1900–2011	yearly

Another example = the Aleutian Islands Fishery Ecosystem Plan (NPFMC, 2007)

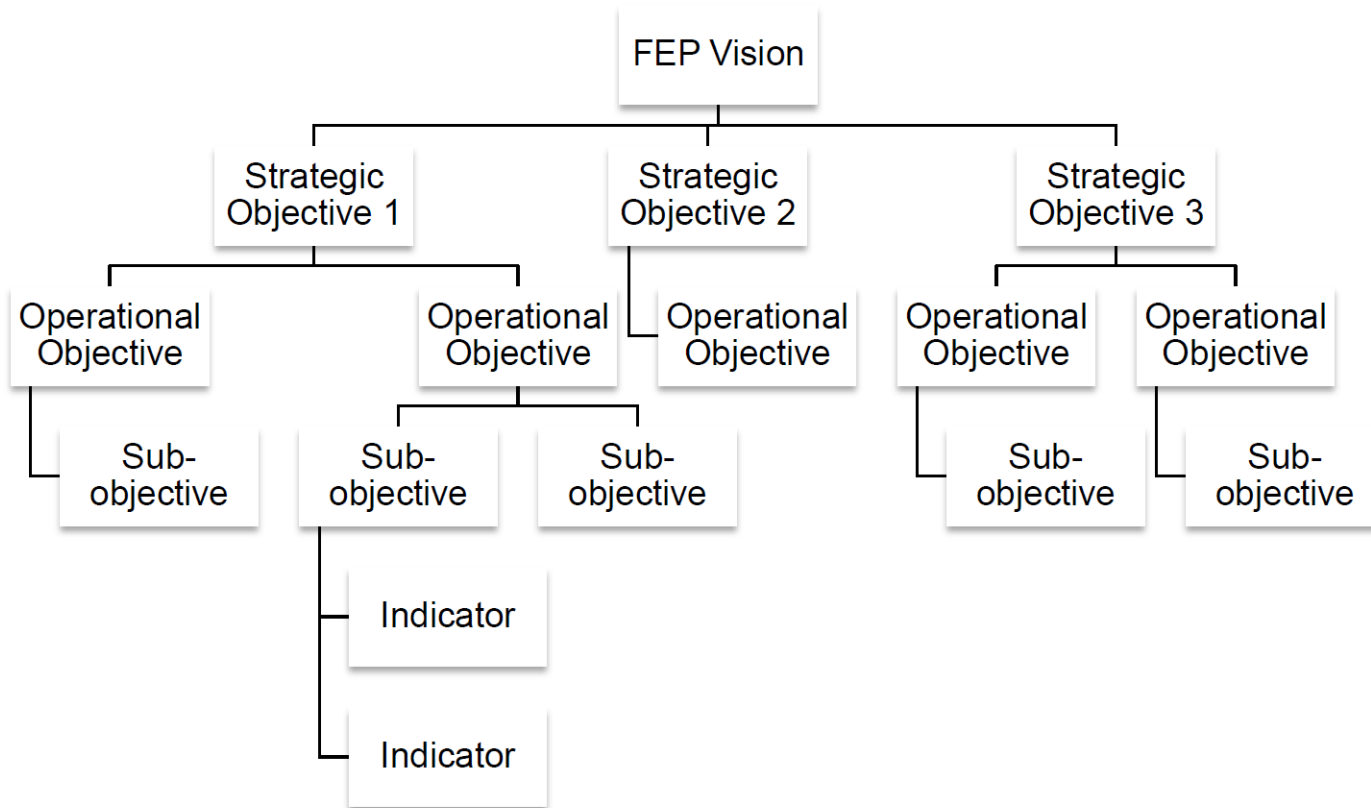
- 1) 21 potential threats
- 2) 2) Classified into five types of interactions:
climate/physical interactions, predator-prey interactions, endangered species interactions, fishery interactions, and socioeconomic activities.
- 3) Conducted a qualitative risk assessment of these threats (see step 2d)

Interactions	
Climate and Physical	A Changes in water temperature may impact ecosystem processes
	B Increased acidification of the ocean may impact ecosystem processes
	C Changes in nutrient transport through the passes and changes in the predominant current patterns that drive primary production impact ecosystem processes
	D Changing weather patterns impact ecosystem processes
Predator-prey	E Fishing mortality and predation mortality both impact managed species
	F Bottom up change in ecosystem productivity impacts predators and fisheries
	G Top down changes in predation and fishing impact ecosystem structure and function
Fishing Effects	H Total removals from the ecosystem due to fishing impact ecosystem productivity
	I Differences between spatial stock structure and the spatial scale of fishery management may impact managed species
	J Impact of one fishery on another through fishing impacts on habitat
	K Impact of a fishery on other biota through fishing impacts on habitat
	L Impact of bycatch on fisheries
	M Commercial fishery may impact subsistence uses
Regulatory	N Changes in the population status of ESA-listed species impact fisheries through specific regulatory constraints
	O Sector allocations can impact the ecosystem and communities
	P Fishery participation permit systems (such as limited entry and harvest quotas) impact the flexibility of fishers to react to changing ecosystem conditions
Other Socio-economic Activity	Q Changes in fishery activities impact the sustainability of AI communities
	R Coastal infrastructure and development impact the ecosystem and communities
	S Vessel traffic, and risk of vessel grounding and spillage, may impact ecosystem productivity
	T Changes in the level of military activity in the area may impact communities
	U Oil and gas development may impact ecosystem productivity
	V Research activity may impact fisheries

Step 2: “Where are we going?”

2.A **Strategic Vision**: fundamental, ambitious sense of purpose (long term)

1. **CFCM strategic plan**: *Thriving and resilient island ecosystems, fisheries, and fishing communities that provide cultural, social, and economic benefits for all.*
2. **EBFM TAP**: *....resilient and productive marine ecosystems and the fisheries resources dependent upon those ecosystems, within the context of the unique biological, ecological, economic, social and cultural characteristics of those fishery resources and the communities dependent on them.*



2.B Strategic Objectives:

- 1) Statements of what we want
- 2) Still general....not used in management
- 3) Several strategic objectives per vision...helps to unfold vision.
- 4) Focused on particular on domains or groups of components (e.g. social, economic, ecological, institutional)

CRITICAL PARTICIPATION OF STAKEHOLDERS

2.B Strategic Objectives:

- 1) Build upon the Conceptual Models
- 2) Based on key attributes of the system: CFCM/NMFS control vs NOT.
- 3) Highest level of concerns incorporated into vision and strategic objectives

No data...no enforcement....we rely on stakeholder information and support to implement FEP

Example:

- To maintain integrity of coral reef habitats
- To understand the effect of recreational fisheries on the fisheries system

2.C Prioritize strategic objectives...Based on:

- 1) ESR, Conceptual models
- 2) Risks (Below)
- 3) Feasibility, Logistic, Governance
- 4) Costs AND...
- 5) Stakeholder support

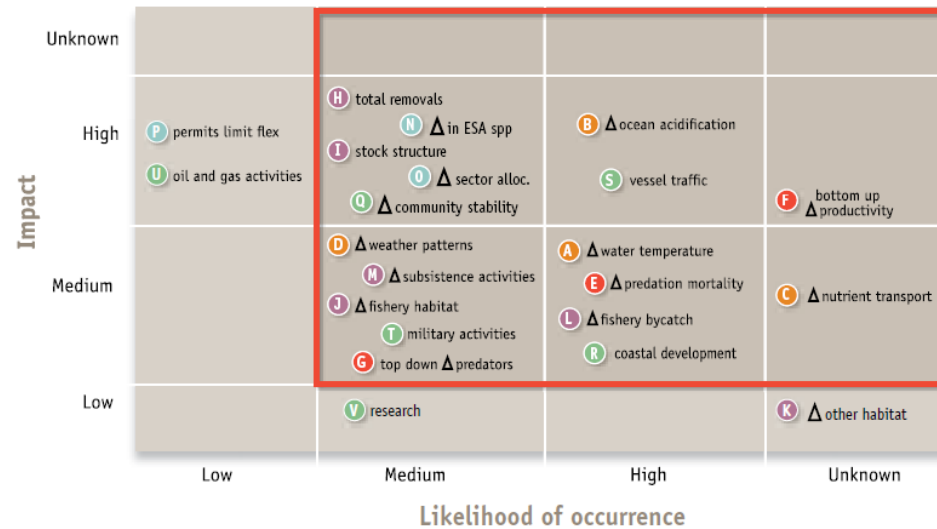
2.d Risk assessment to meeting strategic objectives

- 1) Risk of a stressor (social, land base, coastal, atmospheric, etc) affecting a component (conceptual model) deemed important.
- 2) Risk to meet chosen strategic objective
- 3) Likelihood of one or more component will reach or remain at an undesirable state.
- 4) Example: Australian framework (ERAEF)

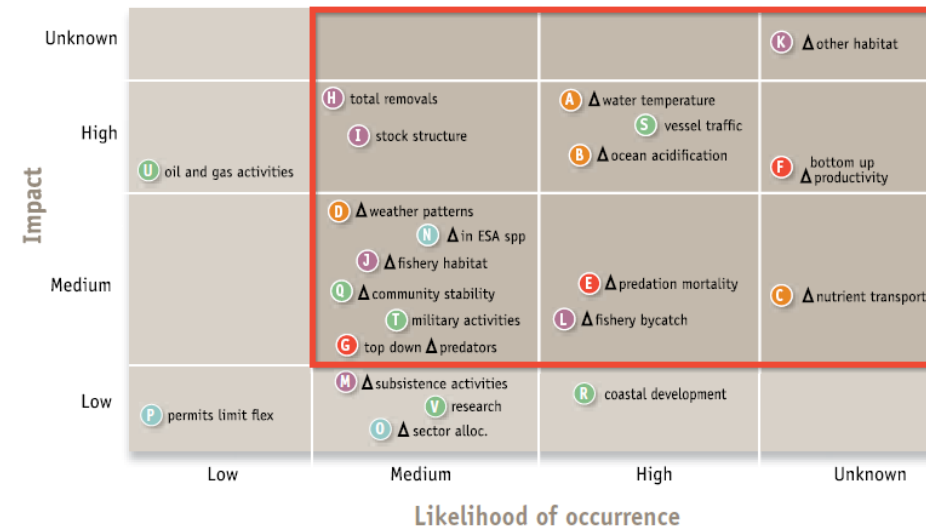
Likelihood of occurrence and impact assessment of the interactions

(based on the professional judgment of the Aleutian Islands Ecosystem Team)

Economic



Ecological



Red boxes in upper right hand quadrant highlights those interactions with a medium to high or unknown likelihood of occurrence or impact.

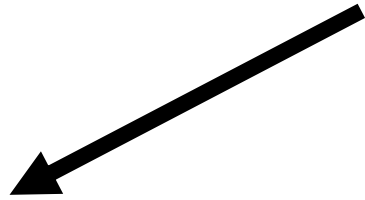
2.e Develop operational objectives

High priority
Strategic Objectives



Concrete Measurable Objectives or
Statement of Specific goal of management action

NOTE: This is already known for IBFMP



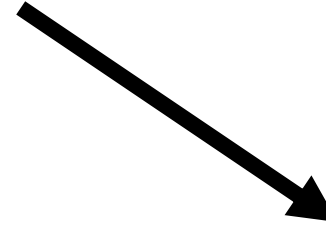
CHARACTERISTICS

- Specific
- Measurable
- Achievable
- Realistic
- Time-bound



EXAMPLES of changes in fishery system

- Increase, Minimize, reduce, change:
 - Revenues
 - Equity
 - Fish Biomass (total)
 - Ecosystem productivity
 - Structure and composition natural assemblages



That will generate benefits such as:

- Greater well being
- Profits
- Biodiversity
- Greater Area nursery habitat
- Resilience and Resistance
- Extinction Risk of vulnerable species

Example Objective 2 PRFMP: Reduce bycatch and waste in the fishery.

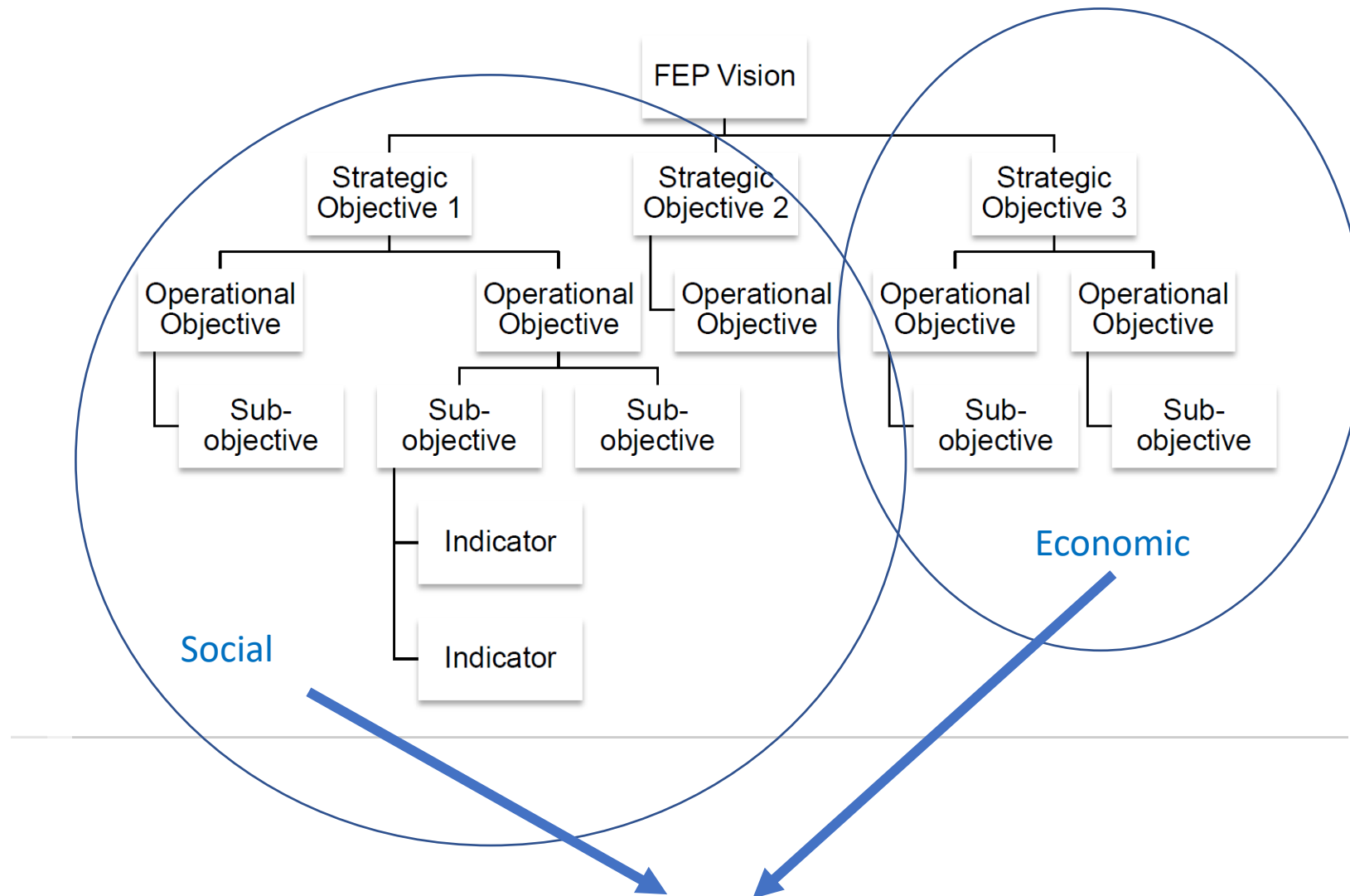
2.e Develop operational objectives

Example Objective 2 PRFMP: *Reduce bycatch and waste in the fishery.*

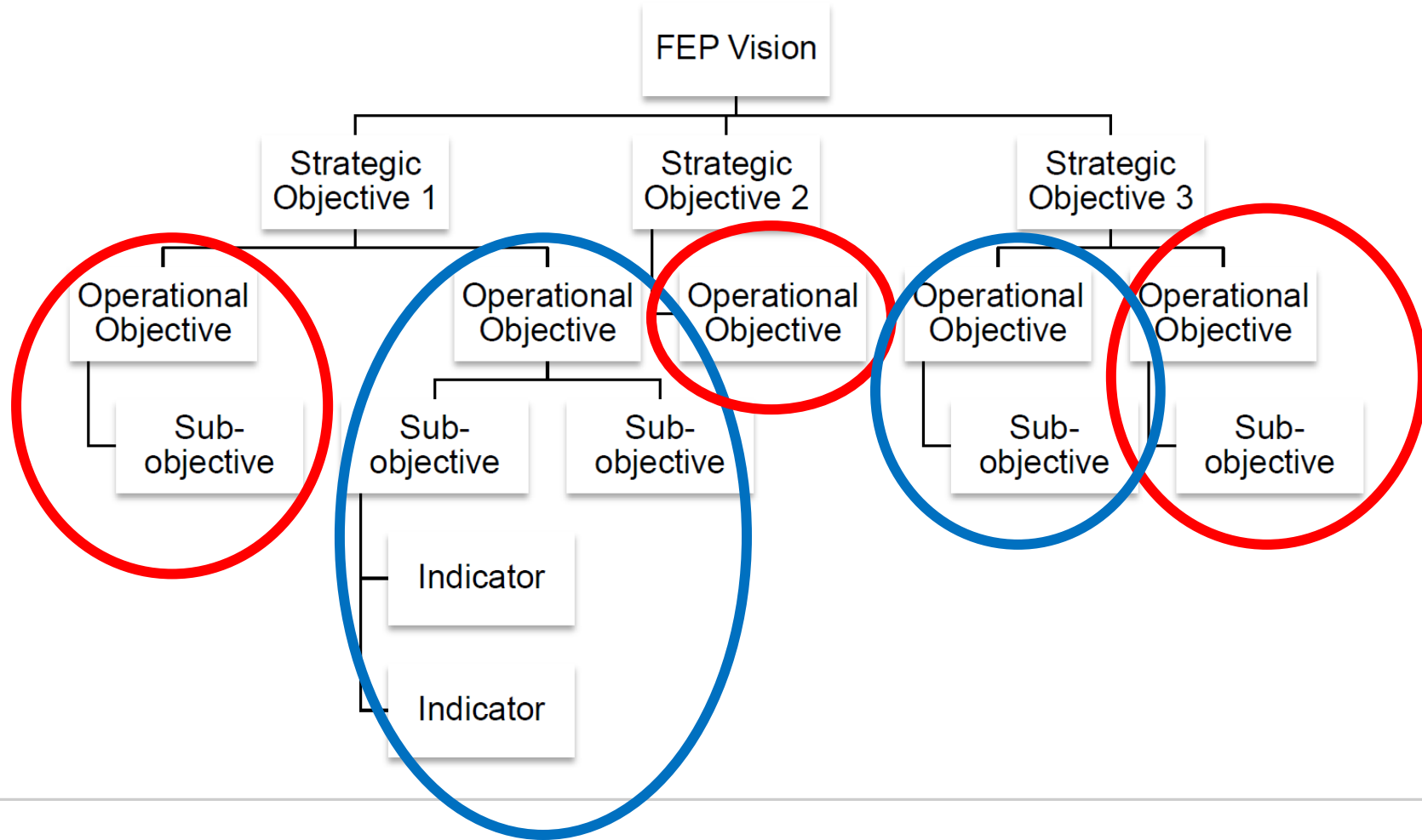
we would add (for example): to increase/maintain diversity of commercially important fish assemblages

Example:

- To maintain integrity of coral reef habitats
 - Increase total coral cover to improve fish habitat
 - Increase herbivore biomass to improve coral recruitment
 - Minimize anchoring to maintain/increase coral cover
- To understand the effect of recreational fisheries on the fisheries system
 - Create Fisheries Information Data to increase data availability
 - Create recreational fishing licensing to initiate fleet censing



7 categories proposed based on SSC work



CFCM

OTHERS

The overarching goal of the FEP is to promote ecosystem-based approaches to ensure healthy, resilient, and productive marine ecosystems and the fisheries resources dependent upon those ecosystems, within the context of the unique biological, ecological, economic, social, and cultural characteristics of those fishery resources and the communities dependent on them.

I. Increase human community resilience within the context of changing ecosystems.

II. Promote ecosystem resilience within the context of changing ecosystems.

III. Define present ecosystem status/functionality....Baseline (description of trend)

IV. Understand dynamics of fisheries and ecosystem services.

V. Describe key ecosystem linkages.

VI. Identify research priorities.

VII. Identify additional ecosystem-essential species in need of conservation and management.

VIII. Understand the risks to the fishery ecosystem and tradeoffs from different management strategies.

IX. Improve the data and information needed to support marine ecosystem management;

X. Prevent overfishing and/or ecosystem overfishing.

XI. Achieve optimum yield.

XII. Incorporate ecosystem considerations into stock assessments.

XIII. Bring ecosystem considerations into the decision-making process.

XIV. Promote adaptive management policies (Revising MSA, National SSC, CCC).

- Strategic Objectives

- Operational objectives

- Sub objectives or tasks

- Perhaps eliminate...impos

- Strategy

Step 3: How do we get there?

- 1) Developing performance measures: Describing the optimal state of the Fishery system in relation to the specific operational objective.
 - A. Identify attributes that matter to stakeholders. Example: Total Cover, Number of recreational licenses = **performance metrics (PM)**.
 - B. Identify desired levels or direction of changes or the above = **reference points of reference changes (RP)**
 - C. $PM + RP = \text{performance measures}$
 - D. RP could be + or -

Trends indicators  Performance metrics

Example in SSA context: % fished overstock

CHALLENGE:

We have not the equivalent to MSA or ESA to set to reference points.

How do we know that we have the “best available science”?

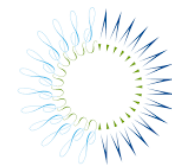
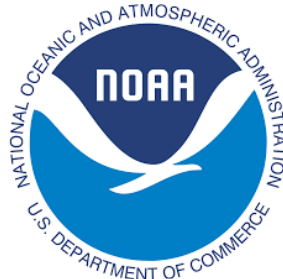
EAFM....how indicators can be used in stock assessment....as uncertainty, as assumptions, as choices, as covariate

BUT WE have an idea using multivariate approaches.

The idea is to look at trends of indicators to define a baseline and define reference points based on that baseline....Adaptative management.

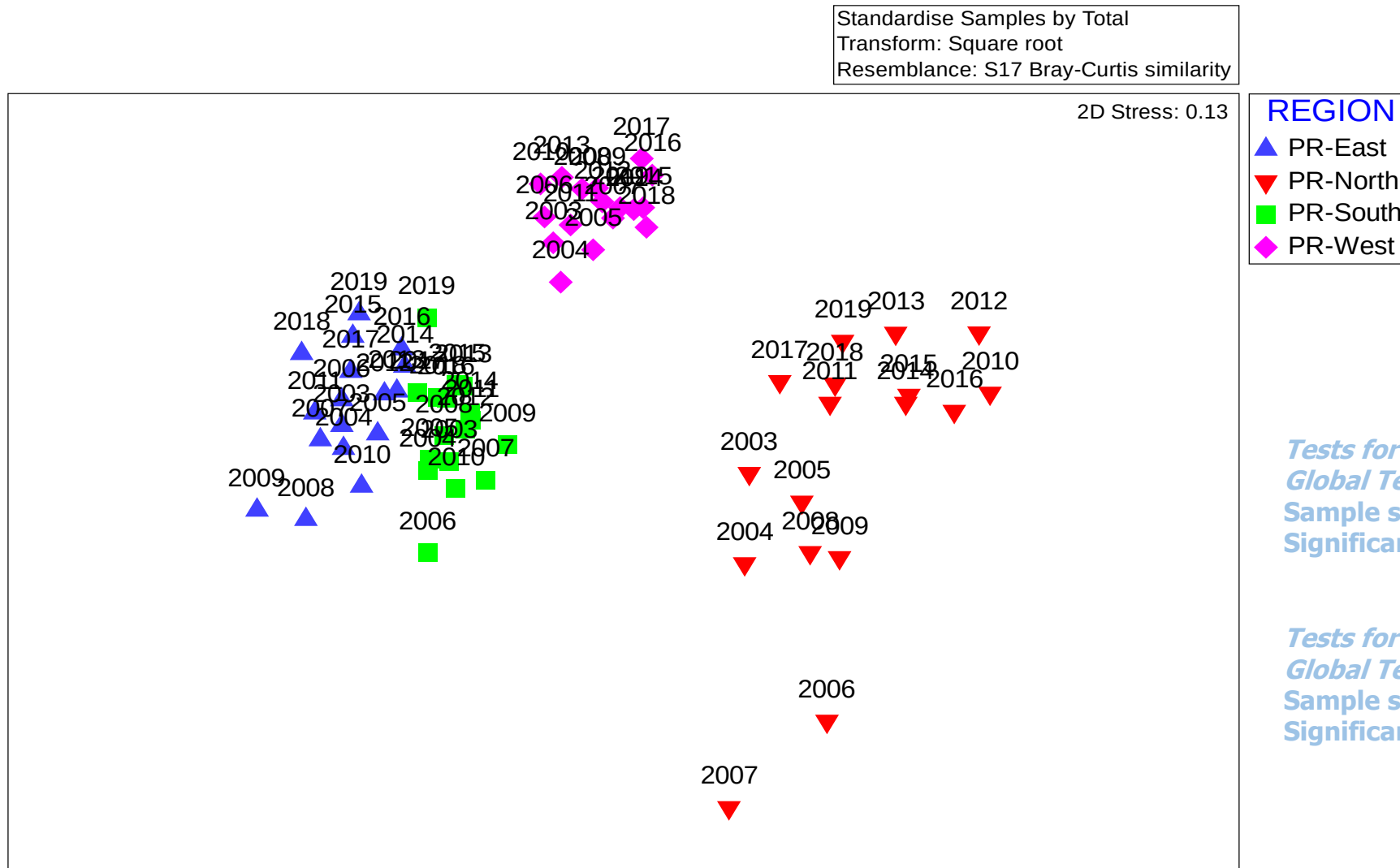
Multivariate approaches for EBFM implementation in the U.S. Caribbean

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.



Description of Temporal Trends and Spatial patterns Landings 2003-2019

Non-metric MDS



Analysis of similarities

*Tests for differences between unordered **REGION***

Global Test

Sample statistic (Average R): 0.742

Significance level of sample statistic: 0.1%

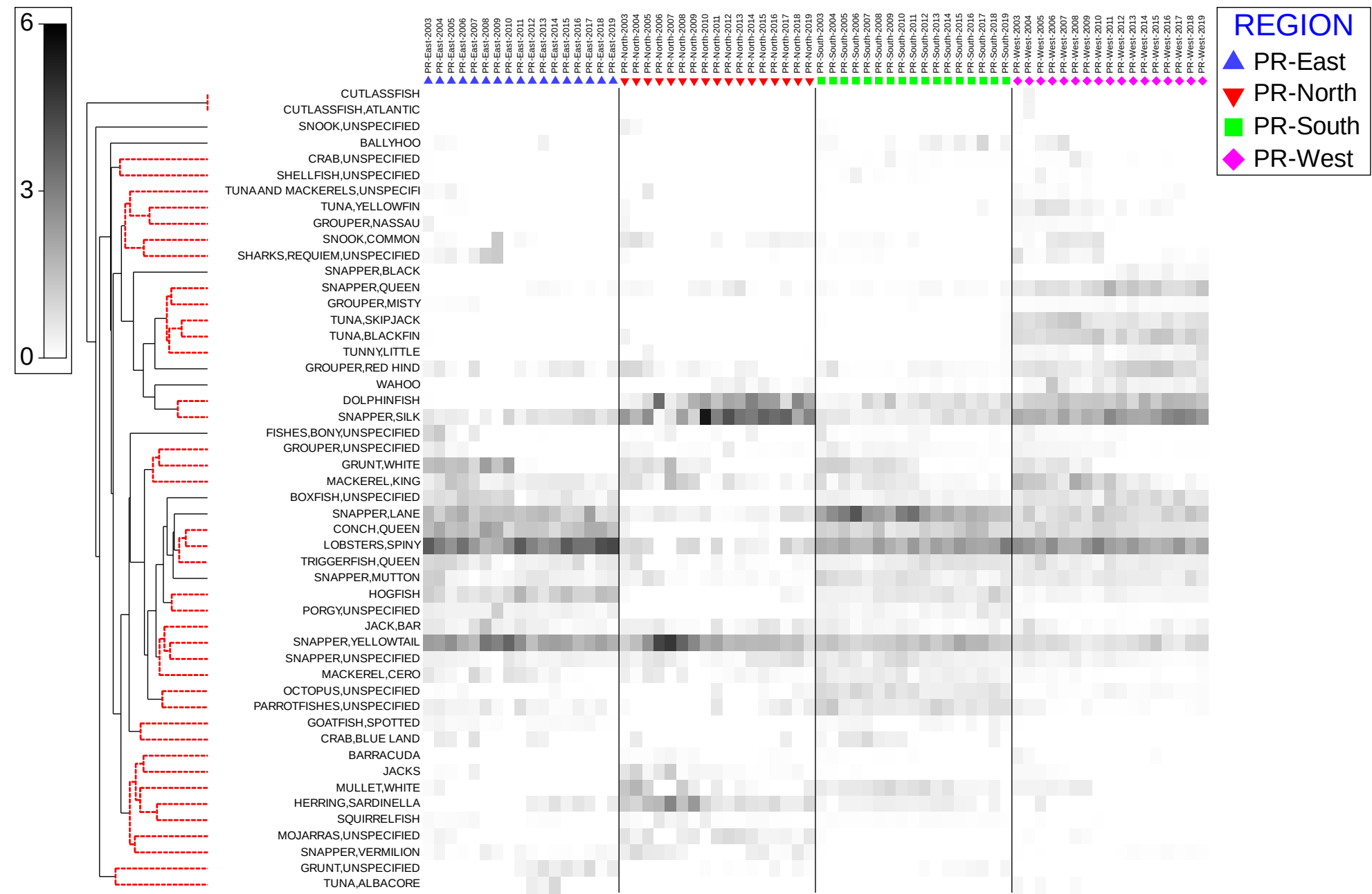
*Tests for differences between ordered **YEAR***

Global Test

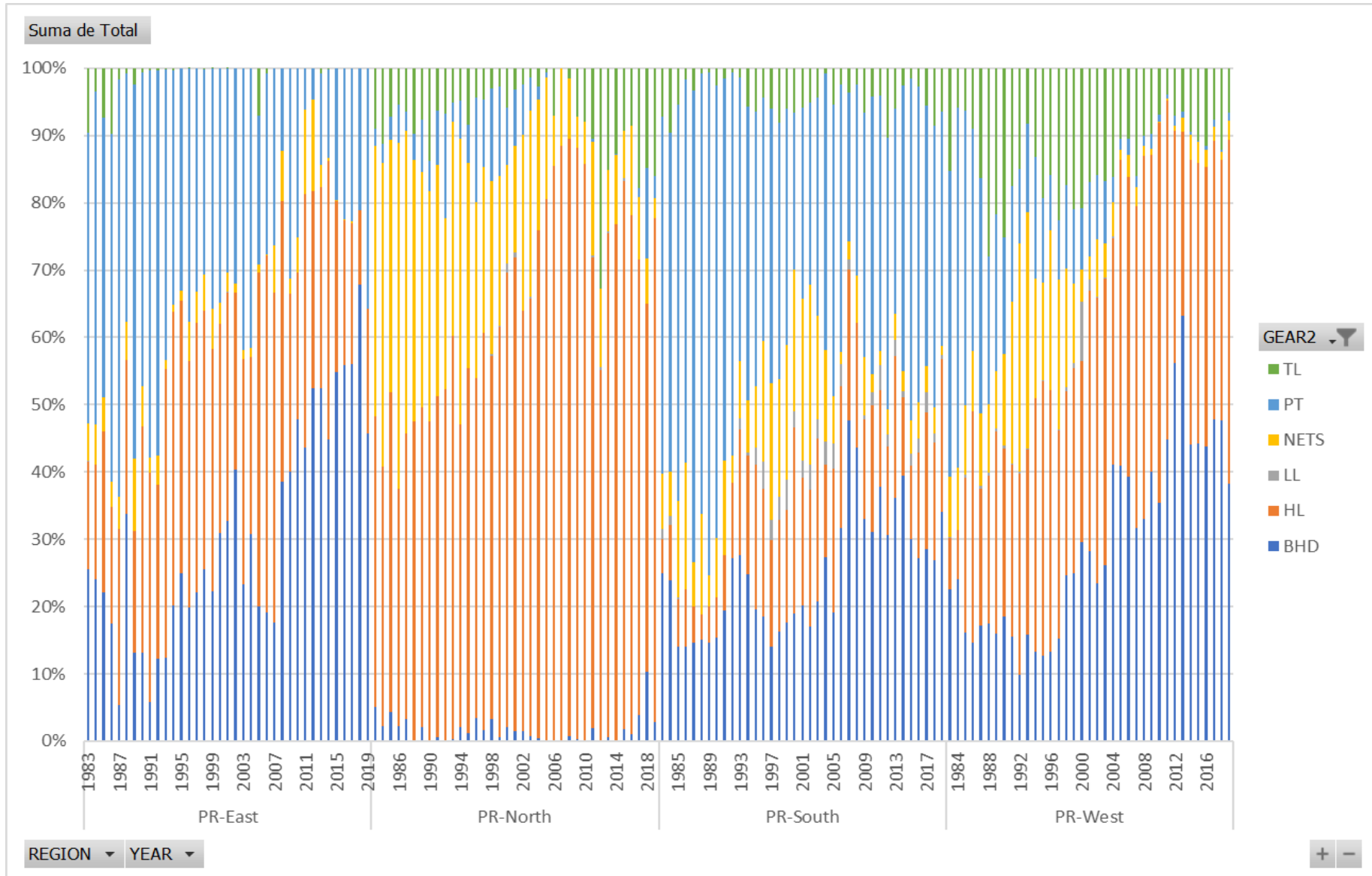
Sample statistic (Average R): 0.646

Significance level of sample statistic: 0.1%

Relative contribution of groups to spatial/temporal patterns



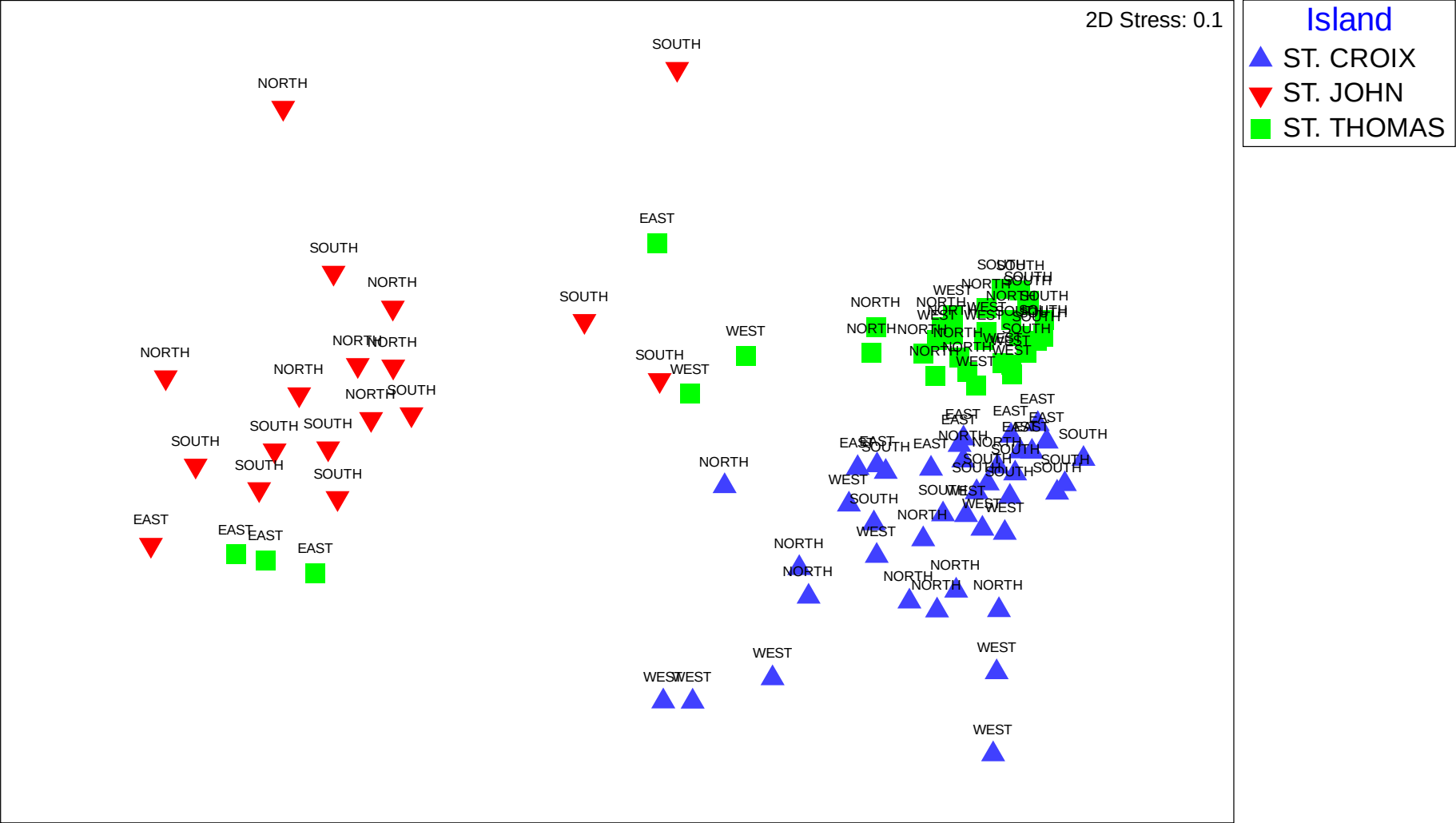
Relative Landings per gear/region/year



Clear differences between Islands.

Non-metric MDS

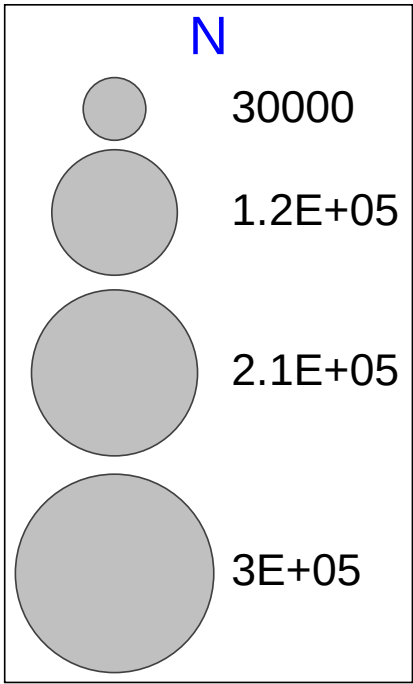
Standardise Variables by Maximum
Resemblance: S17 Bray-Curtis similarity



Non-metric MDS

Differences driven by low landings in STJ

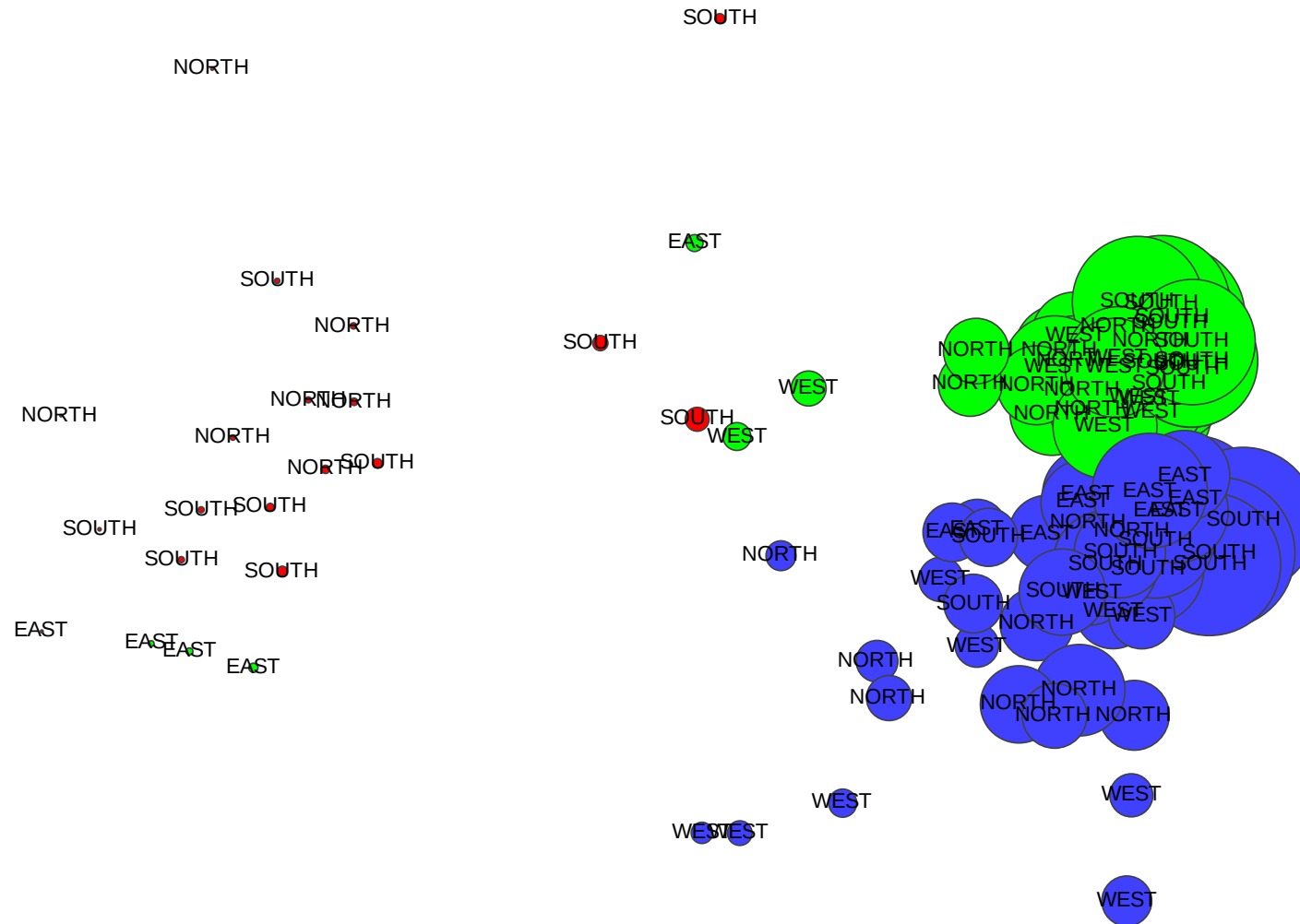
Standardise Variables by Maximum
Resemblance: S17 Bray-Curtis similarity



2D Stress: 0.1

Island

- ST. CROIX
- ST. JOHN
- ST. THOMAS



Only STT and STX...STT east also low landings
Support for Analysis per island (IBMP)

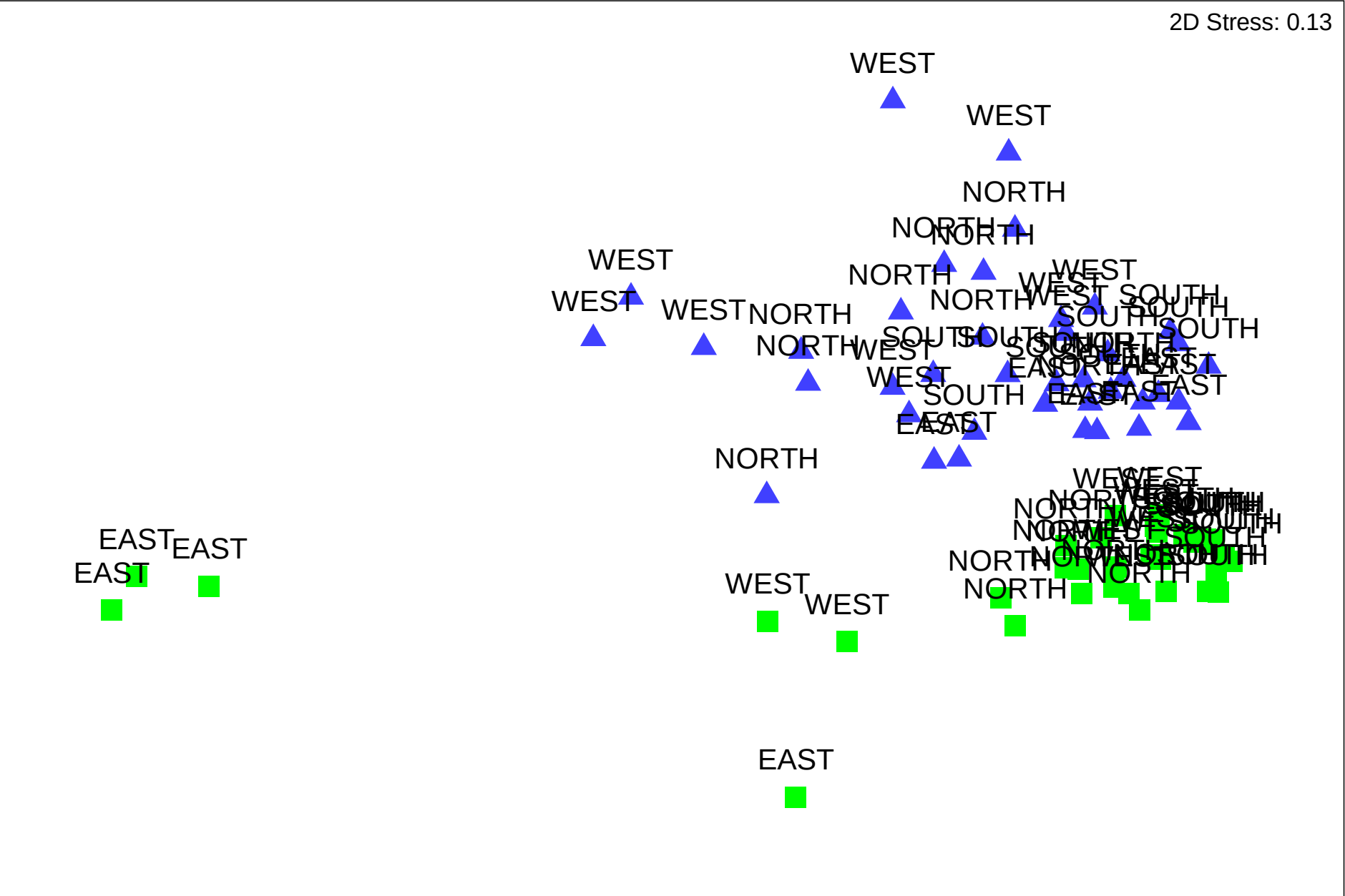
Non-metric MDS

Standardise Variables by Maximum
Resemblance: S17 Bray-Curtis similarity

2D Stress: 0.13

Island

- ST. CROIX
- ST. THOMAS



Non-metric MDS

Standardise Variables by Maximum
Resemblance: S17 Bray-Curtis similarity

2D Stress: 0.07

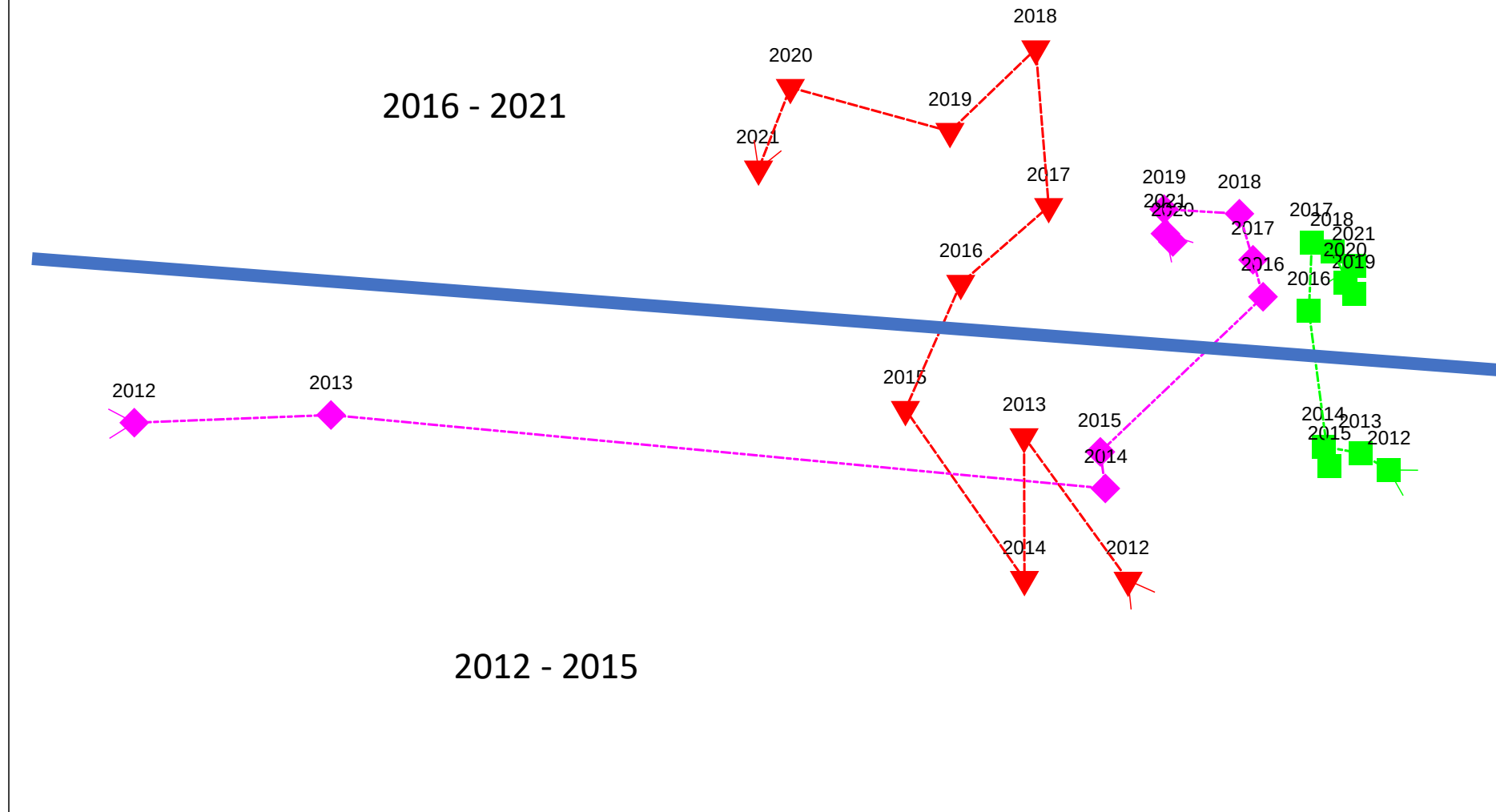
Only STT (no east), temporal trends.

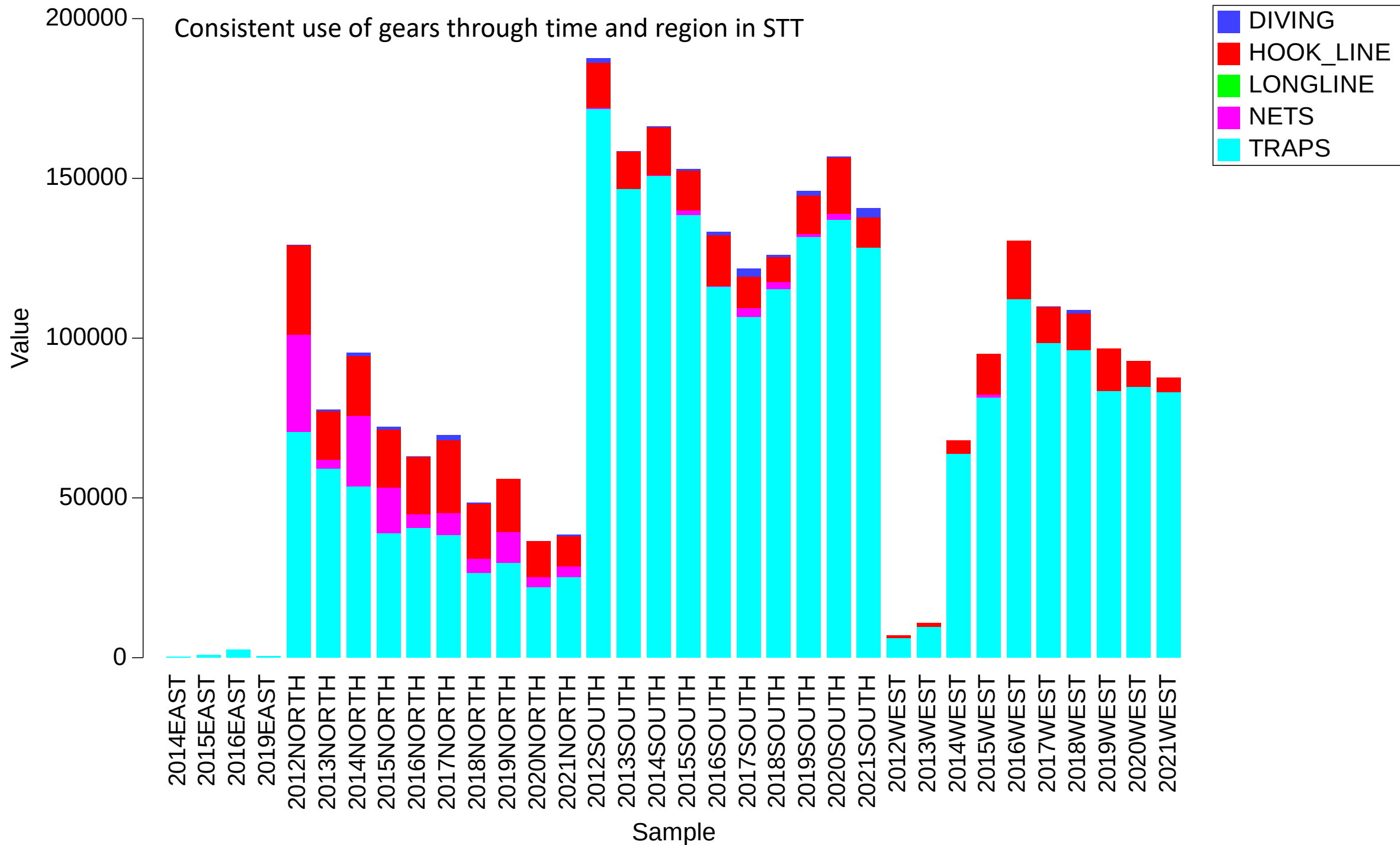
Clear shift in 2015

Differences between regions related to total landings...check next slide.

Zone
▼ NORTH
■ SOUTH
◆ WEST

Zone
--- NORTH
--- SOUTH
--- WEST





Metric MDS

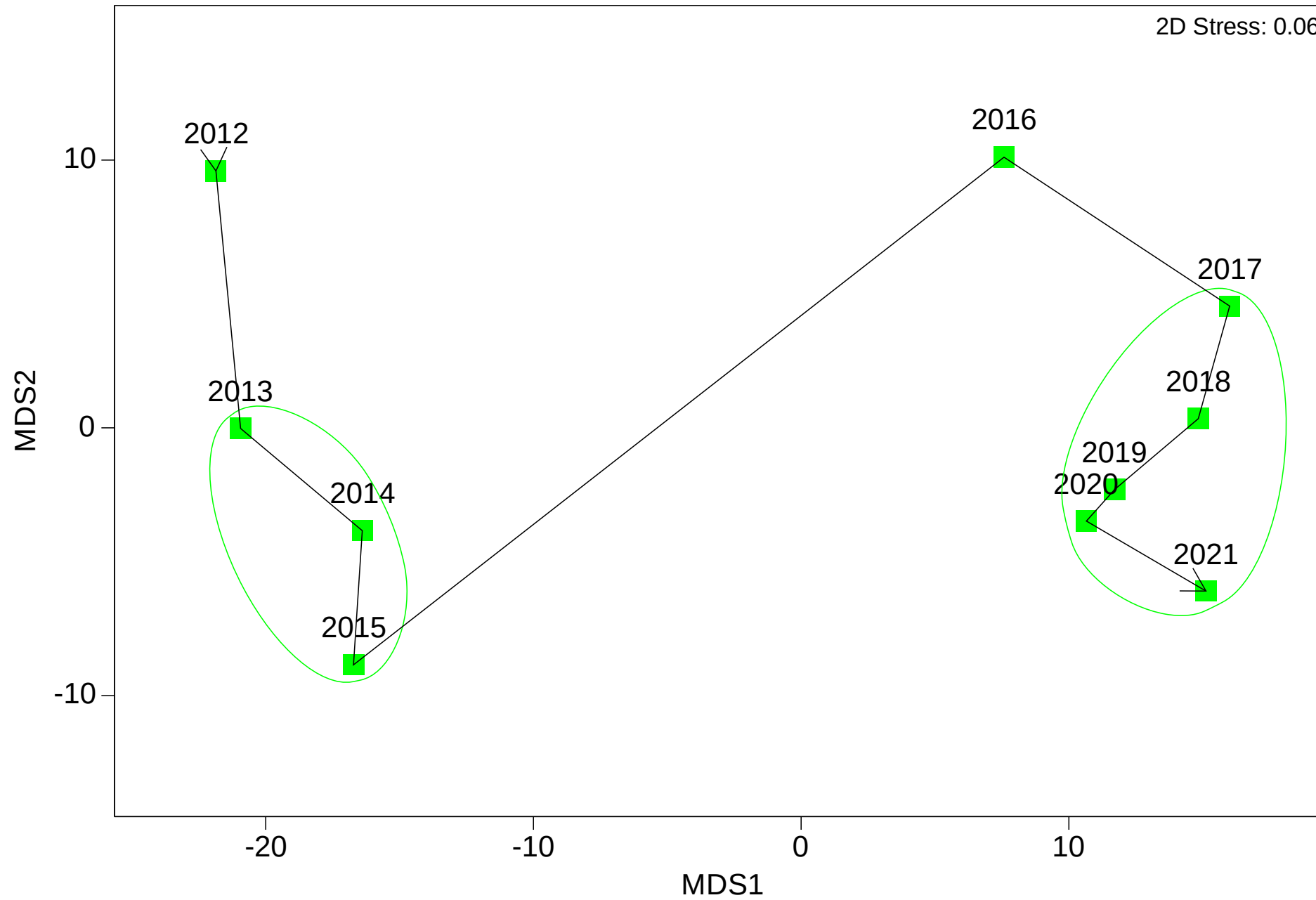
Only South...circles....significant groups (SIMPROF)

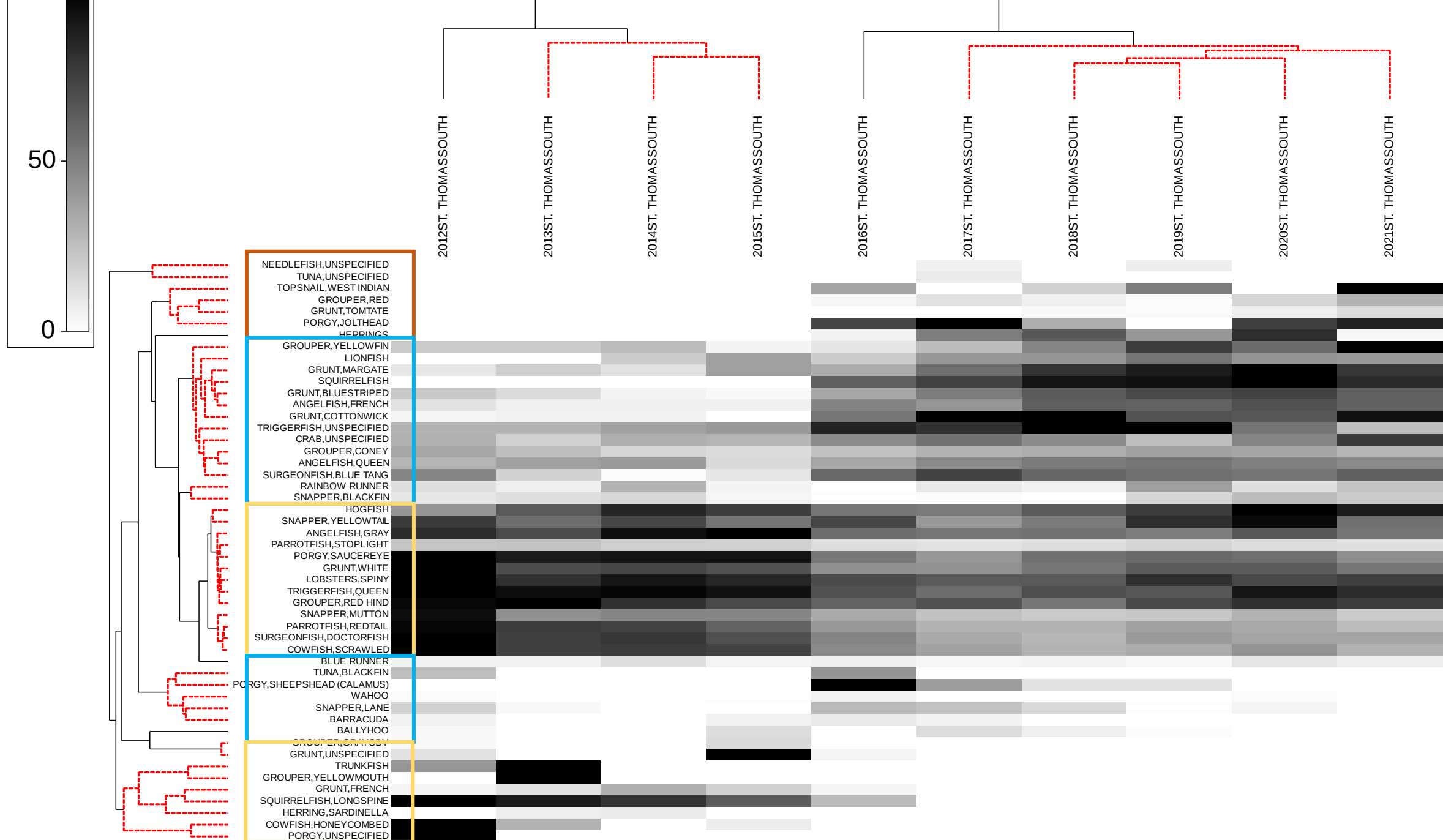
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Resemblance: S17 Bray-Curtis similarity

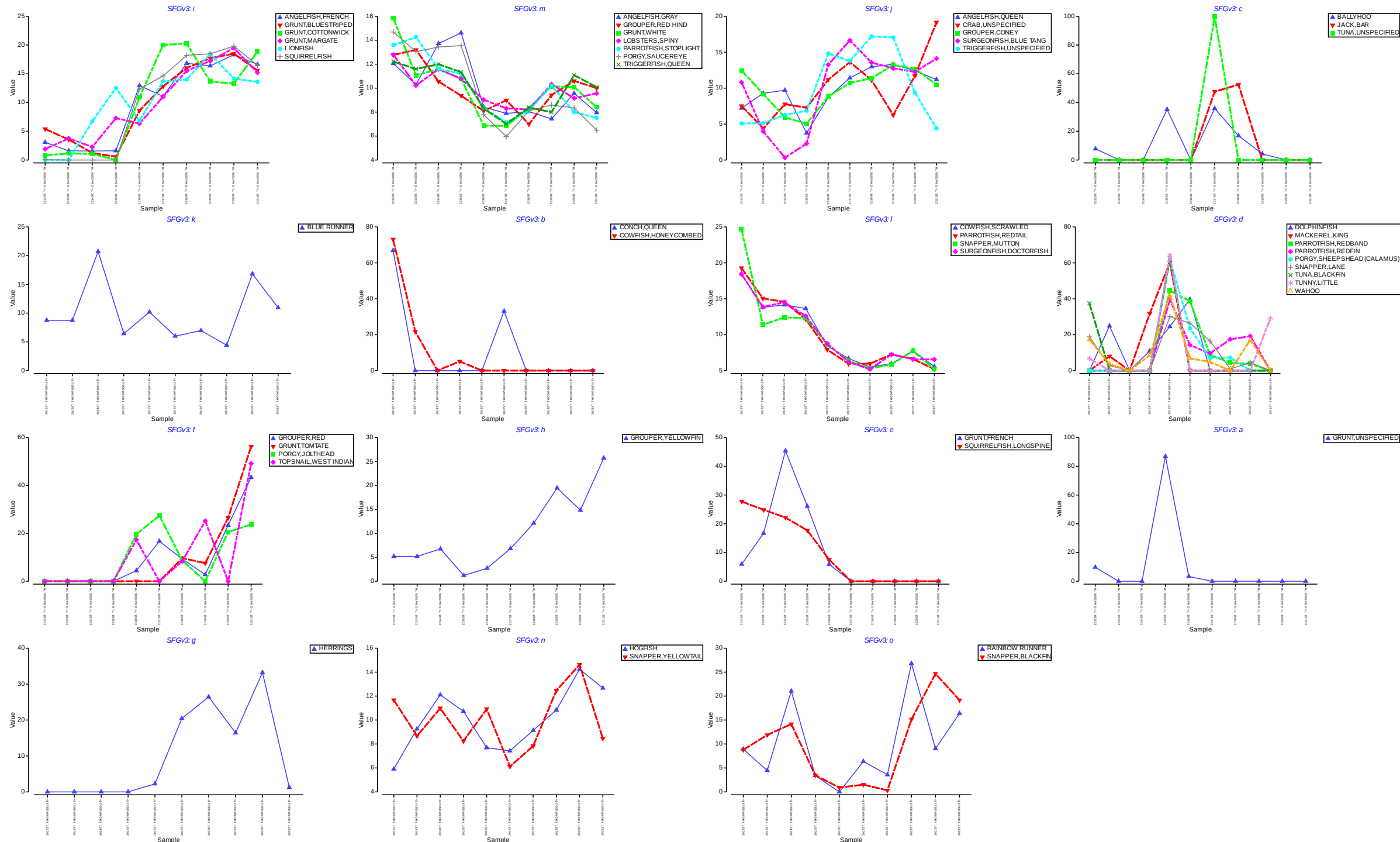
2D Stress: 0.06

SIMPROF

Zone
■ SOUTH







Type of objective	Specified objective
Overall	• the integration of both long-term and short-term economic, environmental, social and equity considerations
	• adherence to the precautionary principle
	• the implementation of harvesting strategies consistent with the principles of biological sustainability and rational long-term economic use
	• facilitation of ecological monitoring, catch and economic reporting
Ecological	• accountable management executed under a cost recovery structure
	• the conservation of biological diversity and ecological integrity
	• prevention of activities that could cause significant impact to a listed threatened, endangered or protected species or habitat (including all marine environments)
	• minimisation of waste and discards
Economic	• improved valuation, pricing and incentive mechanisms to be promoted
	• efficient and cost-effective fisheries management; maximisation of net economic returns
Social	• inter-generational equity
	• promotion of a co-operative approach to the protection and management of the environment involving governments, the community, land-holders (or rights-holders) and indigenous peoples

doi:10.1371/journal.pone.0084242.t001

Fulton EA, Smith ADM, Smith DC, Johnson P (2014) An Integrated Approach Is Needed for Ecosystem Based Fisheries Management: Insights from Ecosystem-Level Management Strategy Evaluation. PLoS ONE 9(1): e84242.
<https://doi.org/10.1371/journal.pone.0084242>

Class of performance measure	Index	Notes
Non-economic industry measures	Overall discards*	Summed over all species
	Habitat-impact*	Area impacted
	TEP interactions*	
	Total effort*	
	Total landings	
	Catch-per-unit-effort	Target species
	Average size (cm) of the catch	
	Catch composition*	Maximum proportion of catch due to one species
Operator perception measures	Access to fishery	Reflects spatial or other regulatory constraints
	Stability of management	Year-to-year
	Volume of quota trading	
Measure of management costs	Overall management costs*	General administration
	Research costs*	Ecological data for assessments
	Enforcement costs*	Patrolling; VMS costs
	Costs of monitoring*	Surveys & observers
	Assessment costs*	
Social measures	Public image	Based on the relative state of the ecological system, port population size and profitability of the system
	Frequency of gear conflict*	Count of adverse gear interactions
	Level of port activity	Function of landings
Economic measures	Gross value of landed catch	
	Total operating costs*	Summed over fuel, gear, refrigeration & transport, unloading, capital & fixed costs.
	Total profits	With a penalty function for losses
	Profit per tonne landed	Across all species
	Profit per effort	
Ecological measures	Biomass of target species	
	Biomass of bycatch species	
	Microfaunal biomass*	
	Biomass of threatened, endangered & protected species	
	Biomass of higher trophic level species	Sea birds, marine mammals, large sharks
	Proportional habitat cover	Per habitat type
	Demersal:pelagic biomass ratio	Of finfish
	Piscivore:planktivore biomass ratio	Of finfish
	Change in slope of biomass size spectra*	

When combined into composite “overall performance indices” those measures marked with a * were inverted, so that a high value always indicated a better performance with regard to management objectives.

doi:10.1371/journal.pone.0084242.t003

Identify Potential Management Strategies

Selected from various alternatives.

Stakeholder involvement.

One of the strategies is “Status quo”.

Ideally...adaptive strategies.

Step 3c, Evaluate consequences of alternative management actions (MSE) and select management action....but this last step is policy related

Management Control	Strategy 1	Strategy 2	Strategy 3	Strategy 4 ¹
<i>Logic</i>	2003 Status quo	Enhanced quota management	Integrated management	Conservation dominated management
<i>Total Allowable Catch (TAC)</i>				
Method for setting TAC	Catch trends-based	Based on dynamic assessments	Based on dynamic assessments	Based on dynamic assessments
Frequency of assessment	Annual	1–3 years	1–3 years	1–3 years
Number of species (groups) under TAC	17 target species	30 target, bycatch & conservation species	17 target species + gulper sharks	17 target species
Tiered harvest control rules used	No	Yes	Yes	Yes
Non-quota species under TAC	No	Yes (Baskets ²)	Yes (Baskets ²)	No
Companion TACs	No	Weak stock limiting	Weak stock limiting	No
Accounting for discards (against quota)	No	No	Yes	Yes
Regional TACs	No	Yes	Yes	Yes
Quota reconciliation	Annual	Before landing	Before landing	Before landing
<i>Spatial management (also see Figure S1)</i>				
Fisheries zoning	Yes (largely ineffective)	Yes	Extensive (differential access by gear type)	Very extensive (up to 80+% closure of some habitat types)
Fishery closures (no take)	No	No	Yes and voluntary spawning closures	Yes and compulsory spawning closures
Sectoral closures (by method)	Those existing in 2003	Additional (based on depth and gear)	Extensive closures outside well established existing grounds.	Extensive across the board.
Industry closures	No	No	No	No
Compliance with zoning	Variable ³	Variable ³	Variable ³	High
<i>Gear controls</i>				
Trawl – mesh size	90 mm	90 mm	100 mm	110 mm
Prawn trawl – mesh size	40–60 mm	40–60 mm	40–60 mm	40–60 mm
Danish seine – mesh size	38 mm	38 mm	38 mm	45 mm
Gillnet – length, height, mesh size	150–165 mm, 5000 m set	150–165 mm, 5000 m set	150–165 mm, 5000 m set	150–165 mm, 6000 m set
Auto longline – no. hooks/licence	15,000 hooks per set	15,000 hooks per set	15,000 hooks per set	Unlimited
Drop line, trap, shark long line	As of 2003	As of 2003	As of 2003	As of 2003
Restrictions on new fishing methods	No	Yes	Yes	Yes
Bycatch Reduction Devices	Poor uptake of voluntary reduction of bycatch	1–80% reduction in bycatch rates	Compulsory bycatch reduction (by 1–80%)	Compulsory bycatch reduction (by 1–80%)
Targeting	Unchanged	50–80% reduction in discarding rates		
<i>Input controls</i>				
Limited entry	Yes	Yes	Yes	Yes
Increase in number of licences ⁴	No	No	No	No
Buy back of licences	No	No	No	Yes (after 5 years)
Choice of gear	No	No	Yes (can switch gear or vessel size)	Yes
Vessel length (GABTF)	Yes	No	No	Yes (for auto longliners)
<i>Other</i>				
Logbooks and landing records	Yes	Yes	Yes	Yes
Observer coverage	25% ⁵	25% ⁵	25% ⁵	25% ⁵
Fishery independent survey	No	Yes (largely acoustic)	No	Yes (largely acoustic)
Discard monitoring and enforcement	No	No	Yes	No

Evolving indicates the gear control is changing through time in the course of the simulation (through variable uptake or staged implementation), while increasing indicates a relaxation (an increase) in the number of hooks allowed for use by auto longline.

¹. Drawn up by the Australian Marine Conservation Society to emphasise conservation and recovery of overfished and threatened marine species by mitigating fishing impacts on species, food webs and habitats and enhancing productivity in fished areas.

². Basket quotas: where a species group (e.g. all Oreos, or all sharks taken from the upper slope) are under a single cumulative quota.

³. Without increases in enforcement, compliance remains a dynamic decisions made by simulated fishers and so remains variable across personality types, vessel classes and sectors based on the changing conditions through time.

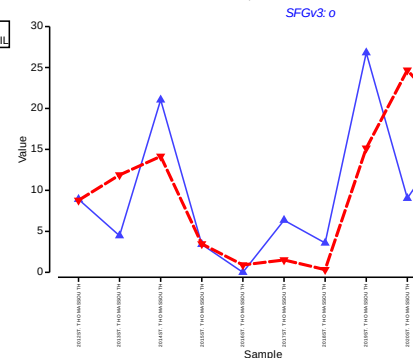
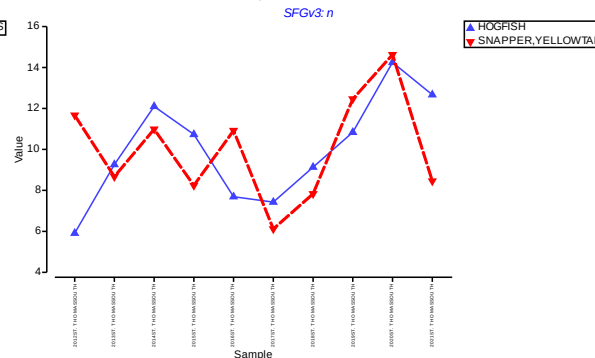
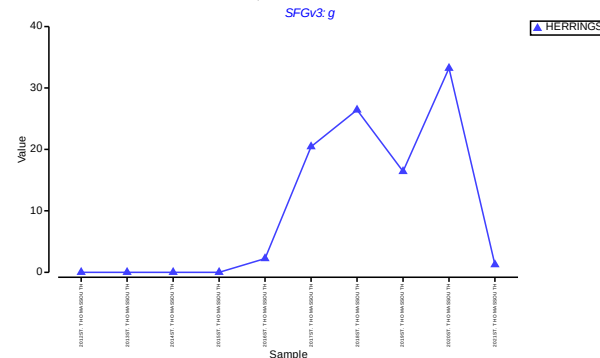
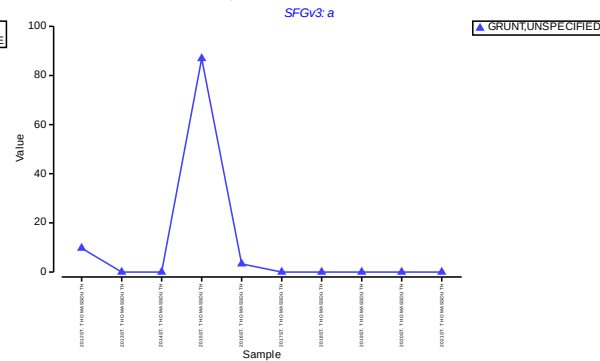
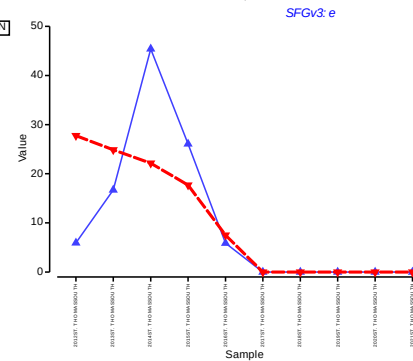
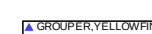
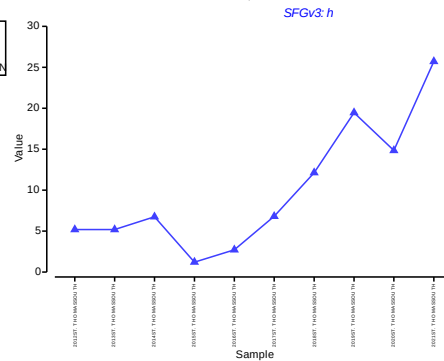
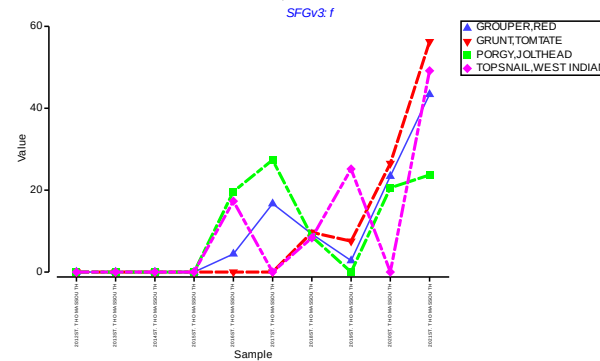
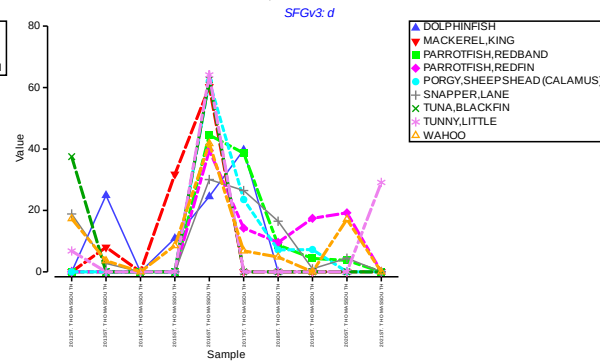
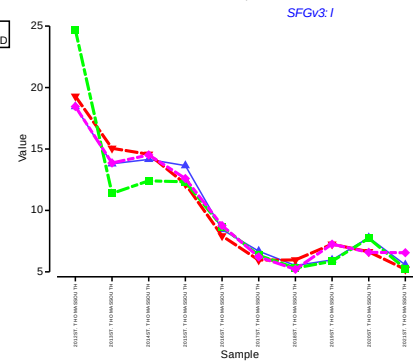
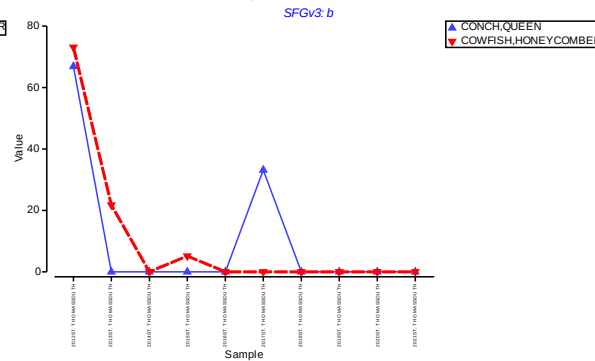
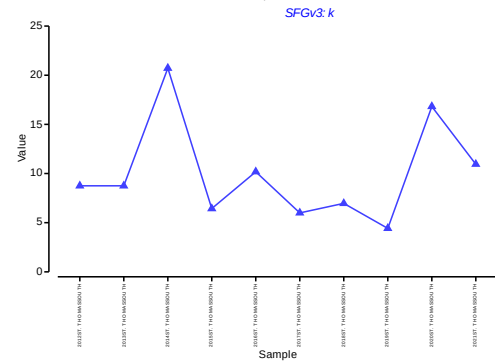
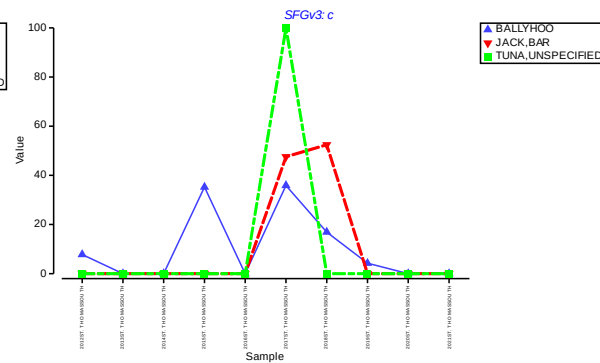
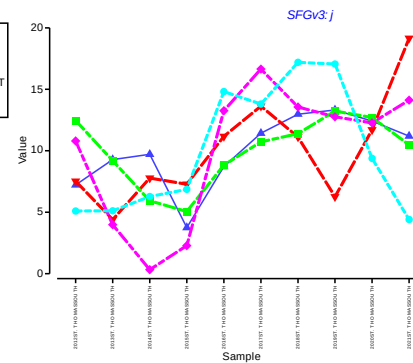
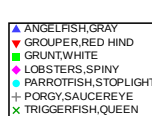
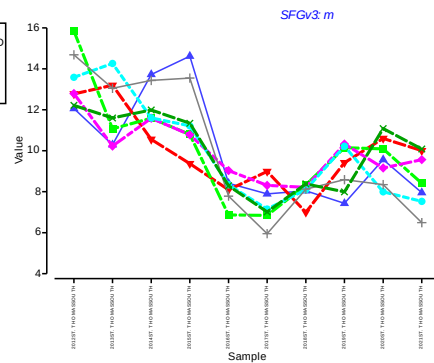
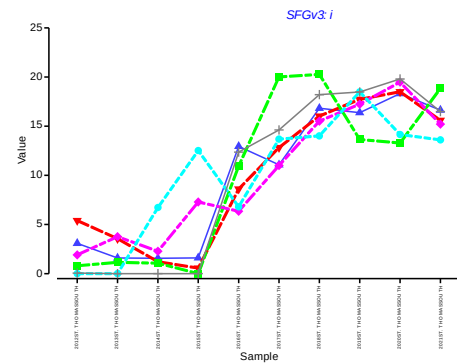
⁴. Licensees may retire licences (or let them sit latent) if they can't profitably execute them, though they will attempt to sell the licence if their criteria for sale are met.

⁵. Not fisheries independent, it is only recording information on catch and discards, but it can influence the error rates assumed by the assessment method and rates of compliance.

doi:10.1371/journal.pone.0084242.t002

Step 4: “Implement the Plan” and

Step 5: “Did we make it?” Evaluate the plan.



A framework for selecting a suite of indicators for fisheries management

Jake C. Rice and Marie-Joëlle Rochet Rice, J.C., and Rochet, M.-J. 2005.

ICES Journal of Marine Science, 62:516-527.

Include complete list of alternatives

Criterion	Technical experts and advisors	Decision-makers and managers	General audience
Concreteness	<i>Minor</i>	<i>Moderate/High</i> : Decisions would be easy to explain to the public, and to relate to other management activities (5/6)	<i>High</i> : Low score means that it would be difficult to relate personal experience to indicator (2)
Theoretical basis	<i>High</i> : Inconsistency with established theory means low confidence, but a solid empirical basis (3/4)	<i>Minor</i> : Management generally based on values and performance, not ecological theory	<i>Minor</i>
Public awareness	<i>Minor</i>	<i>Moderate</i> : Valuable for getting compliance with management plans (5/6)	<i>High</i> : If general knowledge is lacking, a major education programme would be required (1)
Cost	<i>Minor</i> : In general, not their concern	<i>High</i> : Governance systems are budget-conscious (3)	<i>Minor to High</i> : Value for money (4)
Measurement	<i>High</i> : Low or unknown accuracy and precision; often sufficient grounds for rejection (1/2)	<i>Minor</i> : As long as technical advisors and public have confidence	<i>Minor</i> : Unless sampling design is not considered representative of personal experience (scientific survey debate) (5)
Historical data	<i>High</i> : For estimating reference points, and to have confidence in interpretation (2/3)	<i>Minor</i> : As long as technical advisors and public have confidence. May become <i>Moderate to High</i> when management has to function without technical support	<i>Minor to High</i> : Depends on how much context is needed to interpret changes in value
Sensitivity	<i>High</i> : Poor sensitivity may be sufficient reason for rejection (1)	<i>Moderate</i> : To interpret biological and economic importance of changes in value (4)	<i>Moderate</i> : To attach meaning to changes in value (3)
Responsiveness	<i>Moderate</i> (5/6)	<i>High</i> : For those wanting feedback on effectiveness of management plans (1)	<i>Minor</i>
Specificity	<i>Moderate</i> : To disentangle fishing effects from other impacts (5/6)	<i>High</i> : For those wanting to take proper actions to remedy problems in fishery (or other managed activities) (2)	<i>Minor to Moderate</i> : To understand how fishery relates to the “big picture”

Selecting Indicator Portfolios for Marine Species and Food Webs: A Puget Sound Case Study

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Example of goals for the bearing sea

- Maintain, rebuild, and restore fish stocks at levels sufficient to protect, maintain, and restore food web structure and function;
- 2. Protect, restore, and maintain the ecological processes, trophic levels, diversity, and overall productive capacity of the system;
- 3. Conserve habitats for fish and other wildlife;
- 4. Provide for subsistence, commercial, recreational, and non-consumptive uses of the marine environment;
- 5. Avoid irreversible or long-term adverse effects on fishery resources and the marine environment;
- 6. Provide a legacy of healthy ecosystems for future generations.

Tier	Definition	Puget Sound example
1. Goal	The broadest category of division that combines societal values and scientific understanding to define a desired ecosystem condition [13,14].	Healthy and sustaining populations of native species, including a robust food web [11].
2. Focal Components	The major ecological characteristics of an ecosystem that can be used to organize relevant information in a limited number of discrete, but not necessarily independent categories [15].	(1) Marine Species and (2) Marine Food Webs
3. Key Attributes	The characteristics that define the structure, composition, and function of a focal component [13,14,15]	(1) Marine Species: <i>Population Size</i> and <i>Population Condition</i> and (2) Marine Food Webs: <i>Energy and Material Flows</i> and <i>Community Composition</i>
4. Indicators	Quantitative biological, chemical, or physical measurements that reflect the structure, composition, or functioning of an ecological system [14,45]	(1) Marine Species: <i>Population Size</i> (e.g., harbor seal population status and trends, marine bird population estimates) and <i>Population Condition</i> (e.g., toxics in Chinook salmon, salmonid population spatial structure) and (2) Marine Food Webs: <i>Energy and Material Flows</i> (e.g., chlorophyll a) and <i>Community Composition</i> (e.g., harbor seal – food web interaction, forage fish)

Indicators listed are for example only.
doi:10.1371/journal.pone.0025248.t001