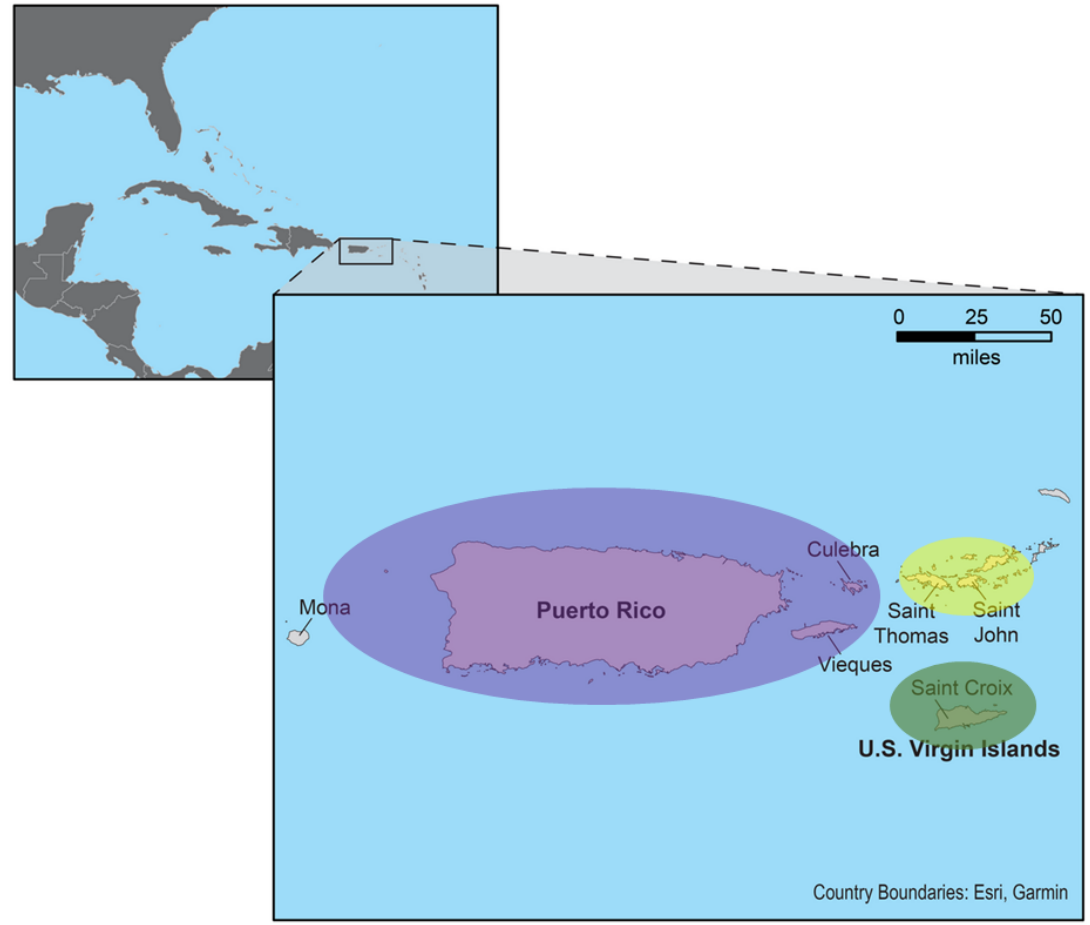
A Decision-Support Tool for Ecosystem-Based Fisheries Management in the U.S. Caribbean

Juan J. Cruz-Motta

U.S. Caribbean

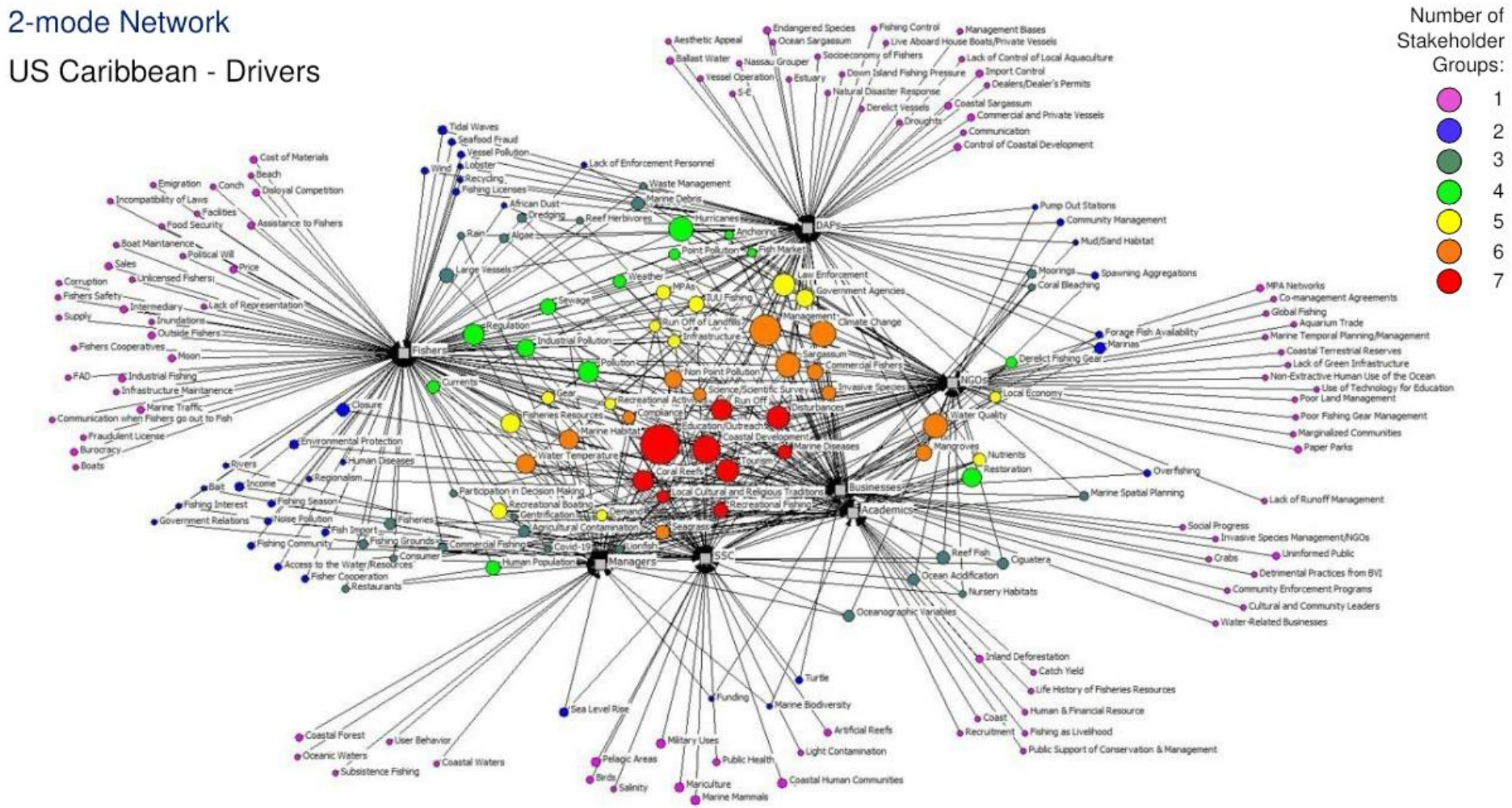


U.S. Caribbean

- Lowest landings
- Lowest total revenue
- Limited shelf area
- Lowest Absolute Population
- Data poor
- Fully artisanal fishery

- Highest Diversity
- Highest number of Managed Species
- Coral reef Dependent
- Highest Population Density
- High Stakeholder Involvement
- Coastal = Other sources of Mortality

USCFE CONCEPTUAL MODEL: Complex Socio Ecological System
Seara et al, 2024



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

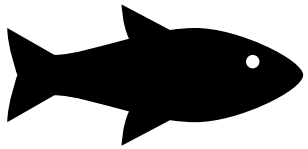
Ideal system to implement EBFM

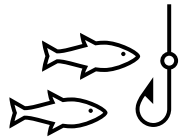
Perhaps EBFM the only option?

AIM

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

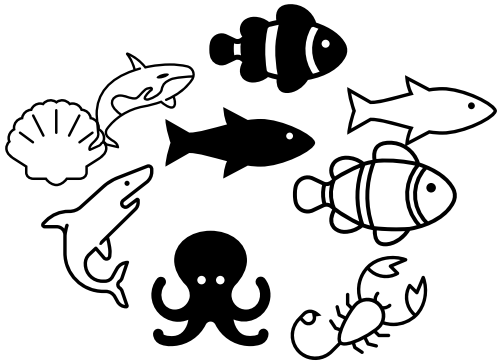
SSFM





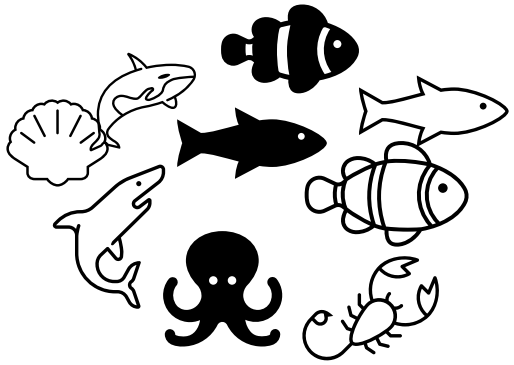
FMP

EBFM



FEP

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

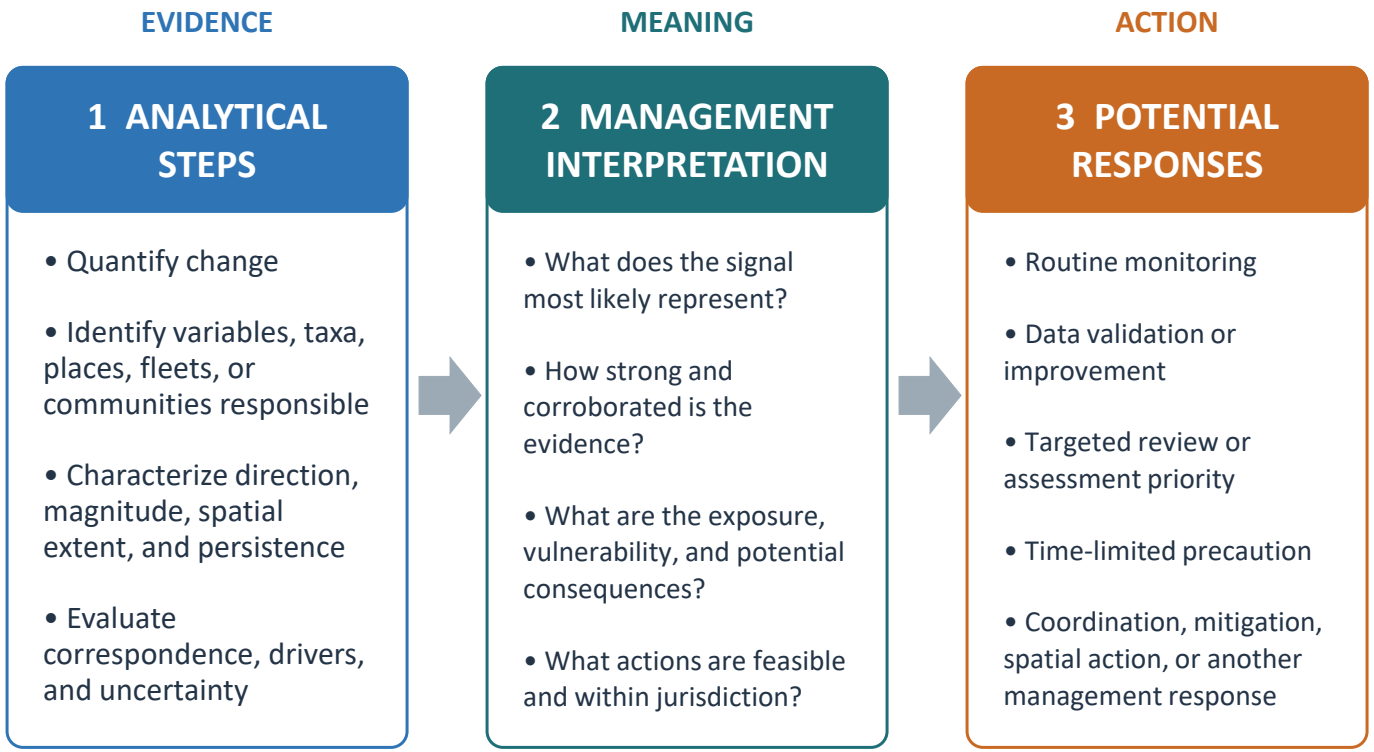
OBJECTIVE:

To conduct a comprehensive diagnosis of the USCFE using a three-stage sequence for each management unit (PR, STT/STJ and STX)

Analysis establishes the pattern and its drivers.

Management interpretation evaluates what the signal means.

A **potential response** is then selected

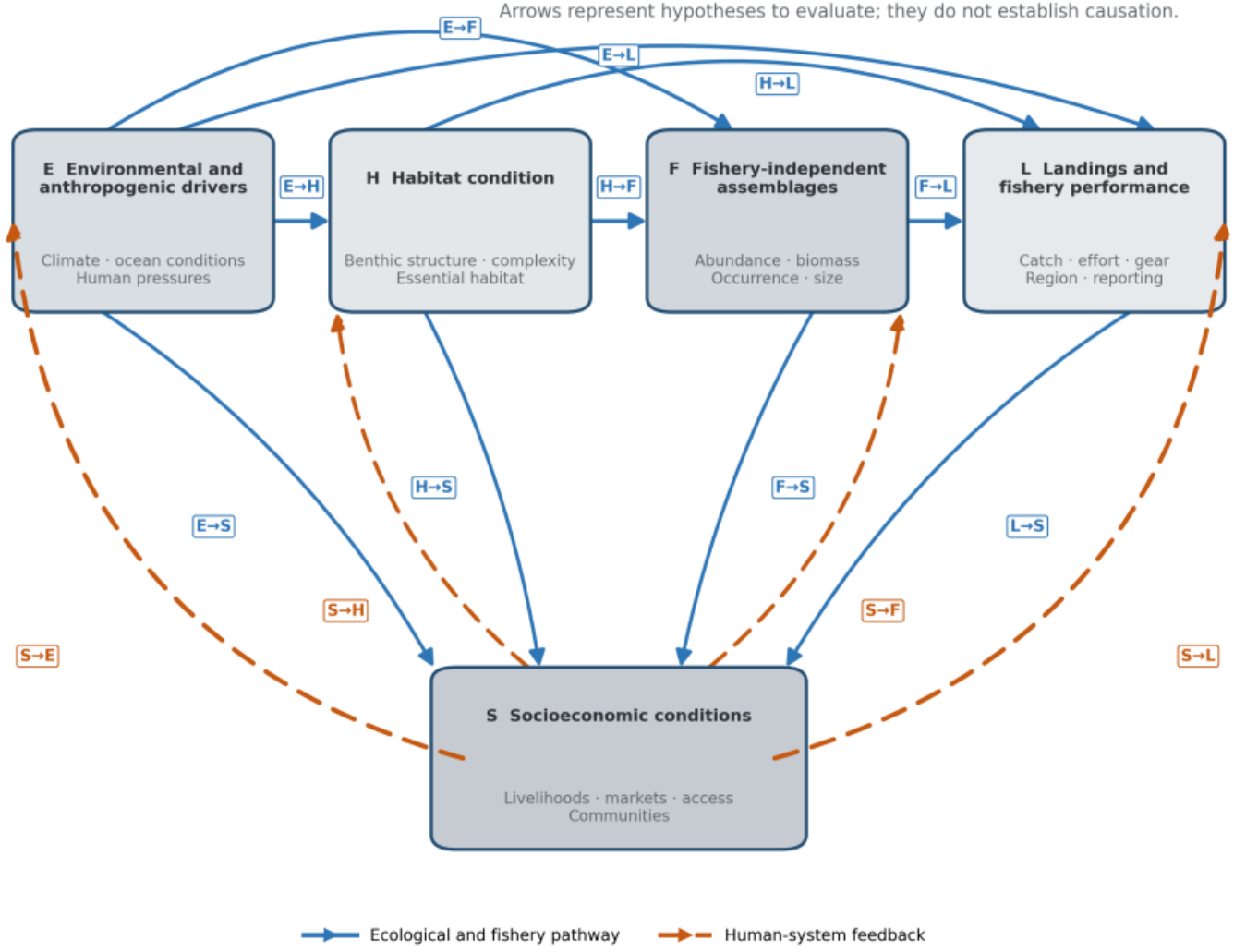


Designed to answer these QUESTIONS:

1. Has any USCFE component changed beyond the selected screening threshold?
2. Which component or combination of components changed?
3. Which species, species complexes, functional groups, fishing regions, gears, environmental variables, habitat attributes, or socioeconomic indicators contributed to the change?
4. What are the direction, magnitude, spatial extent, and persistence of the signal?
5. Do independent datasets, Local Ecological Knowledge (LEK), or stakeholder observations support the interpretation?
6. Does the evidence indicate a stock-related signal, an ecological shift, a fishery-performance change, or an ecosystem or socioeconomic early-warning signal?
7. What analytical, management, monitoring, assessment, or coordination response is proportional to the evidence and risk?

Potential connections among the five USCFE components

Arrows represent hypotheses to evaluate; they do not establish causation.



Ecological and fishery pathways

E→H	Physical and environmental forcing
E→F	Distribution, survival, and productivity
E→L	Operating conditions, accessibility, and catchability
H→F	Recruitment, refuge, and habitat capacity
H→L	Fishing-ground distribution and catchability
F→L	Resource availability and catchability
E→S	Exposure and operating conditions
H→S	Ecosystem services and access
F→S	Resource condition and availability
L→S	Income, employment, and food provision

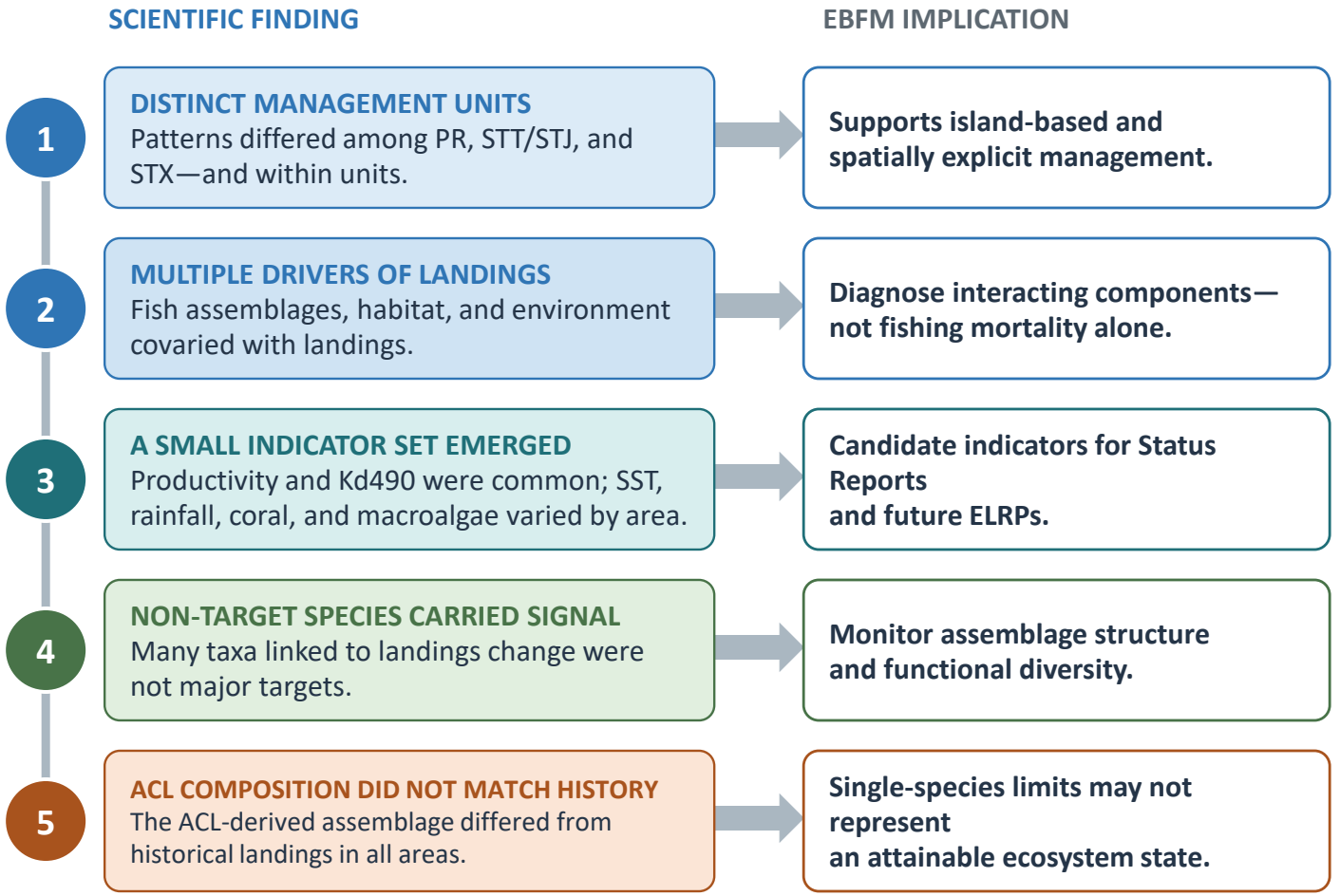
Human-system feedbacks

S→E	Pollution and other anthropogenic pressures
S→H	Fishing, coastal-use, and gear effects
S→F	Fishing pressure
S→L	Effort, markets, access, and reporting

The tool narrows competing explanations without assuming causation.

FIVE FINDINGS EBFM

The USCFE does not behave as a single fishery system. Its dynamics are spatially heterogeneous, multispecies, and shaped by interacting ecological and human drivers.

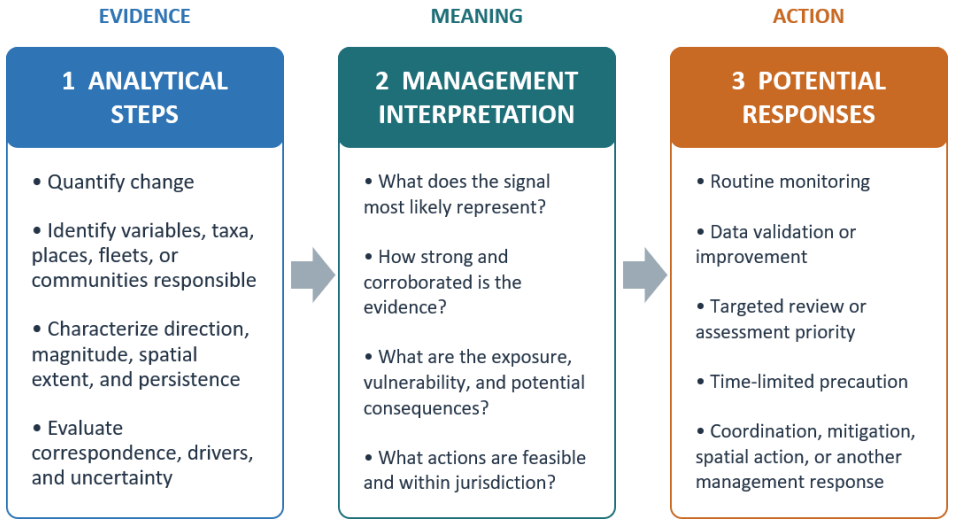


. Cruz Motta et al (under review). Description of the U.S. Caribbean Fisheries Ecosystem using a multivariate approach to inform Ecosystem Based Fisheries Management in the region.

WHAT DOES THE USCFE DECISION-SUPPORT TOOL DO?

Within an adaptative Management framework

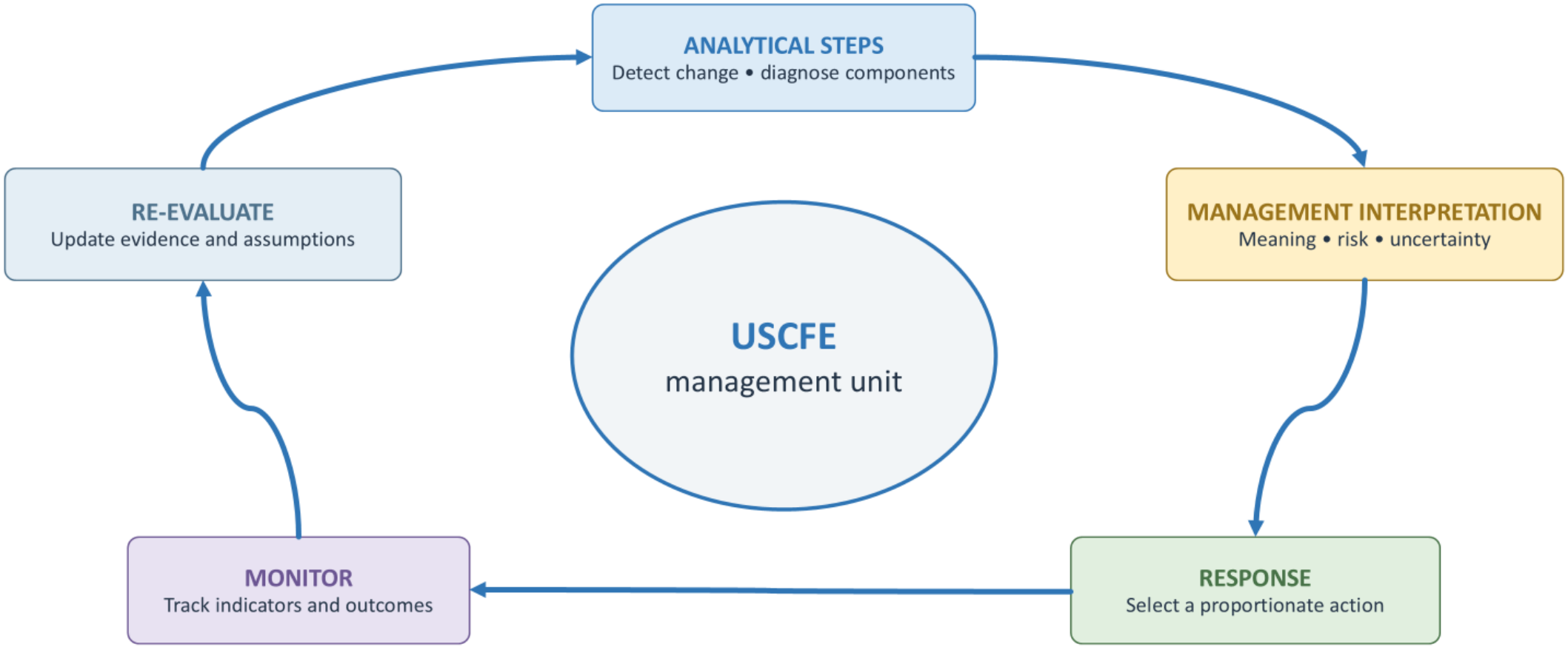
It identifies what changed, which evidence is responsible, which diagnostic pathway follows, and how the response will be documented and revisited.



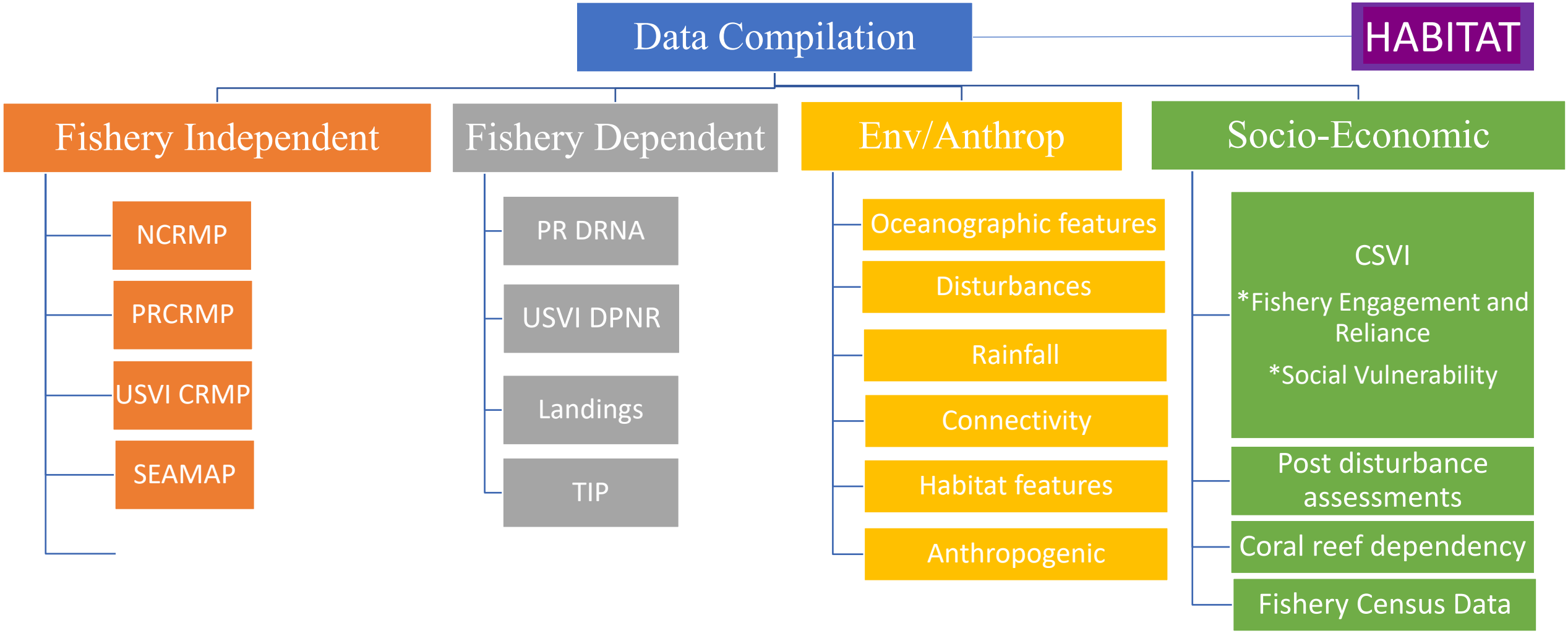
WHAT IT DOES NOT DO?

- Estimate stock status,
- Set ABCs or ACLs;
- Prove causation from correspondence;
- Forecast ecosystem states;
- Automatically prescribe a management measure.

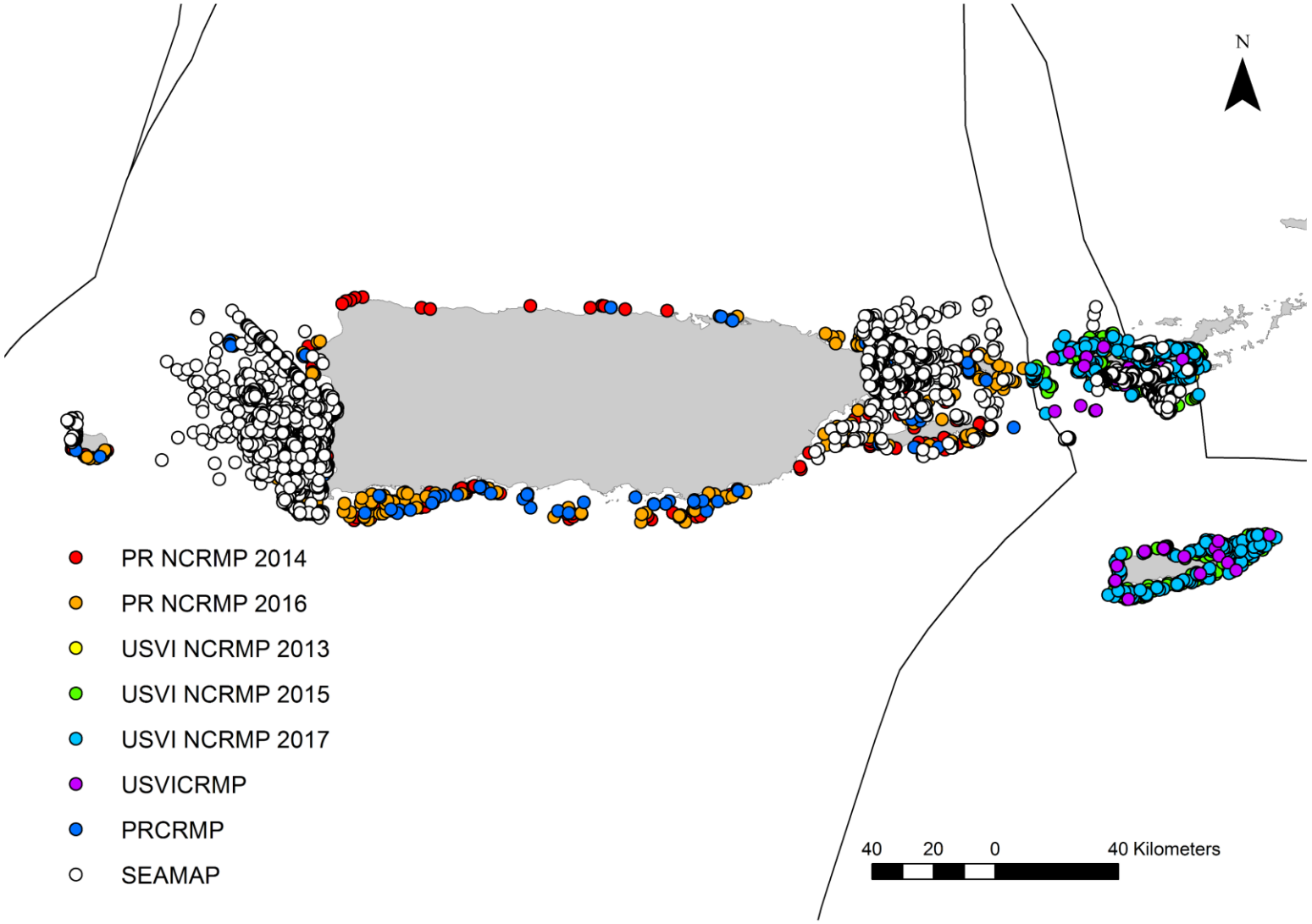
ADAPTIVE MANAGEMENT



DATA INPUT:


Data Compilation
HABITAT
Fishery Independent
NCRMP
PRCRMP
USVI CRMP
SEAMAP
Fishery Dependent
PR DRNA
USVI DPNR
Landings
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



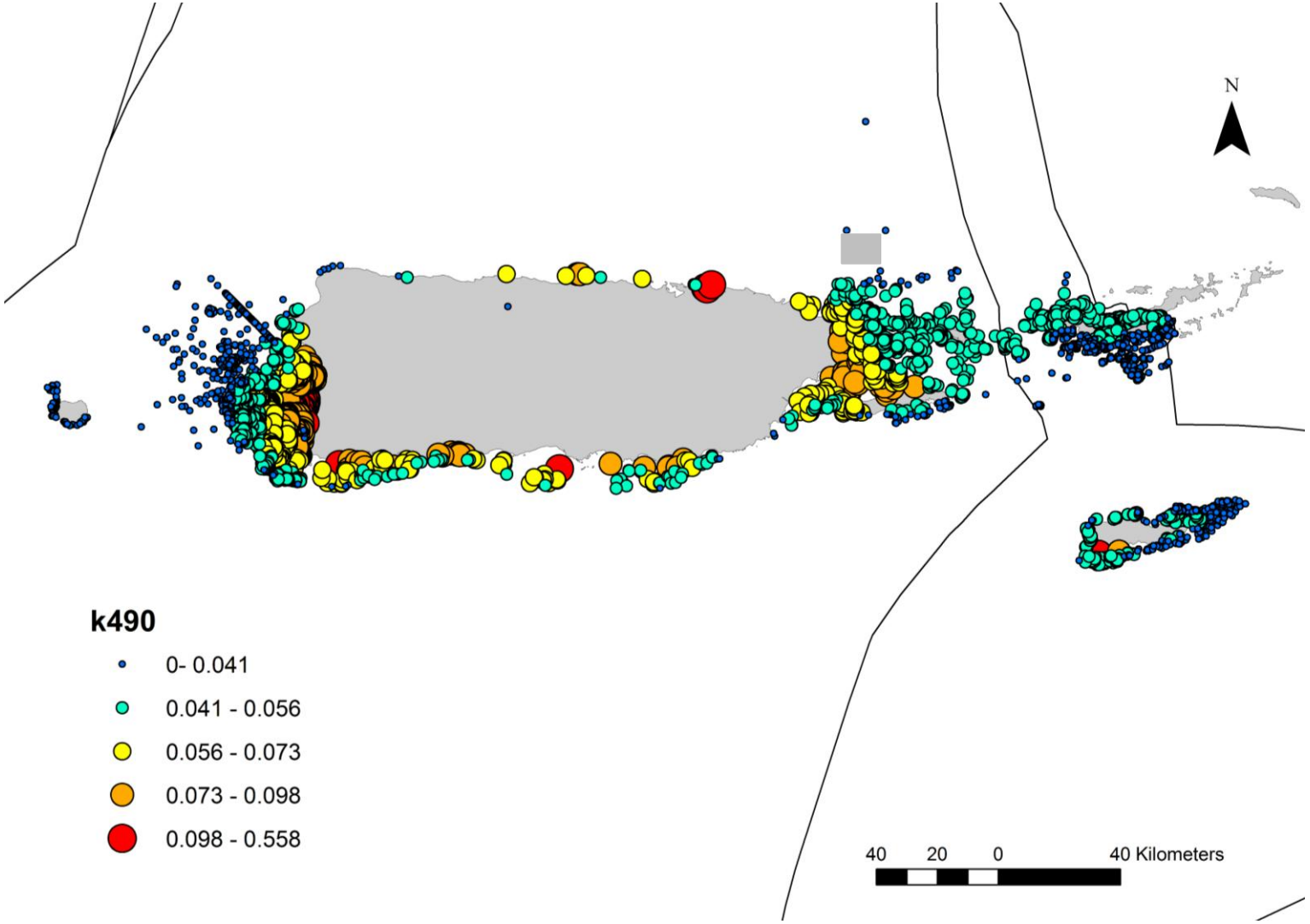
Habitat:

-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



https://oceancolor.gsfc.nasa.gov/l3/order/

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	Same as 21
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

Analytical steps: Spatial and Temporal Patterns are described using mutlivariate analyses

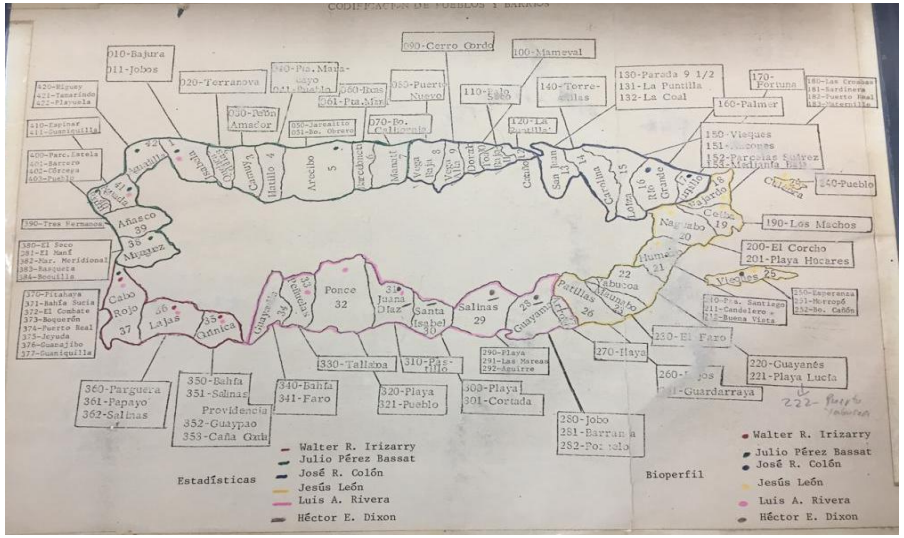
- Instead of evaluating each indicator independently, multivariate analysis examines many variables simultaneously.

- It retains relative composition, covariance among variables, and differences among whole observations.

- Questions:

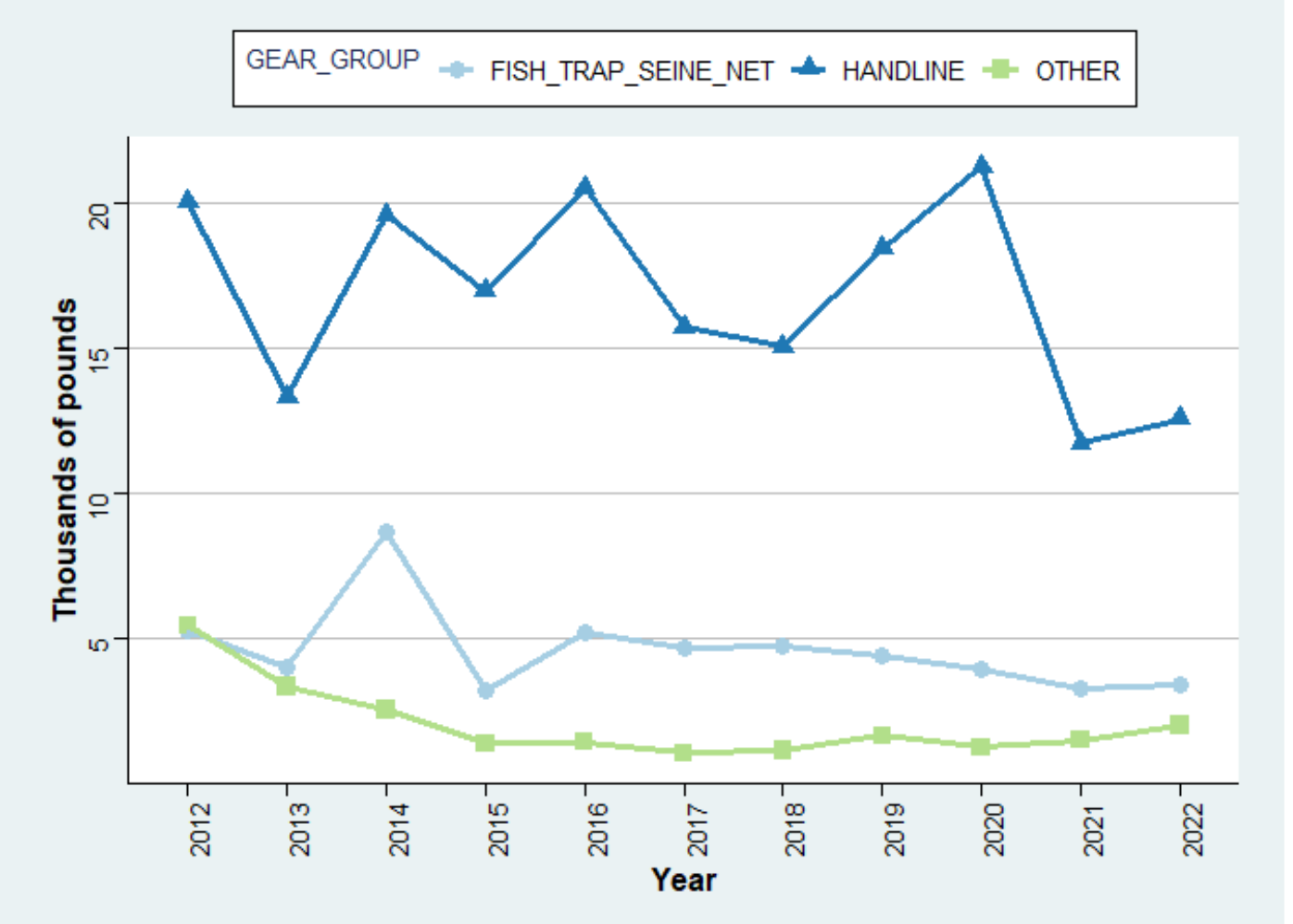
    - How different is the system from its reference?
    - In what direction is it moving?
    - Which variables are responsible?
    - Do changes correspond across components?

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



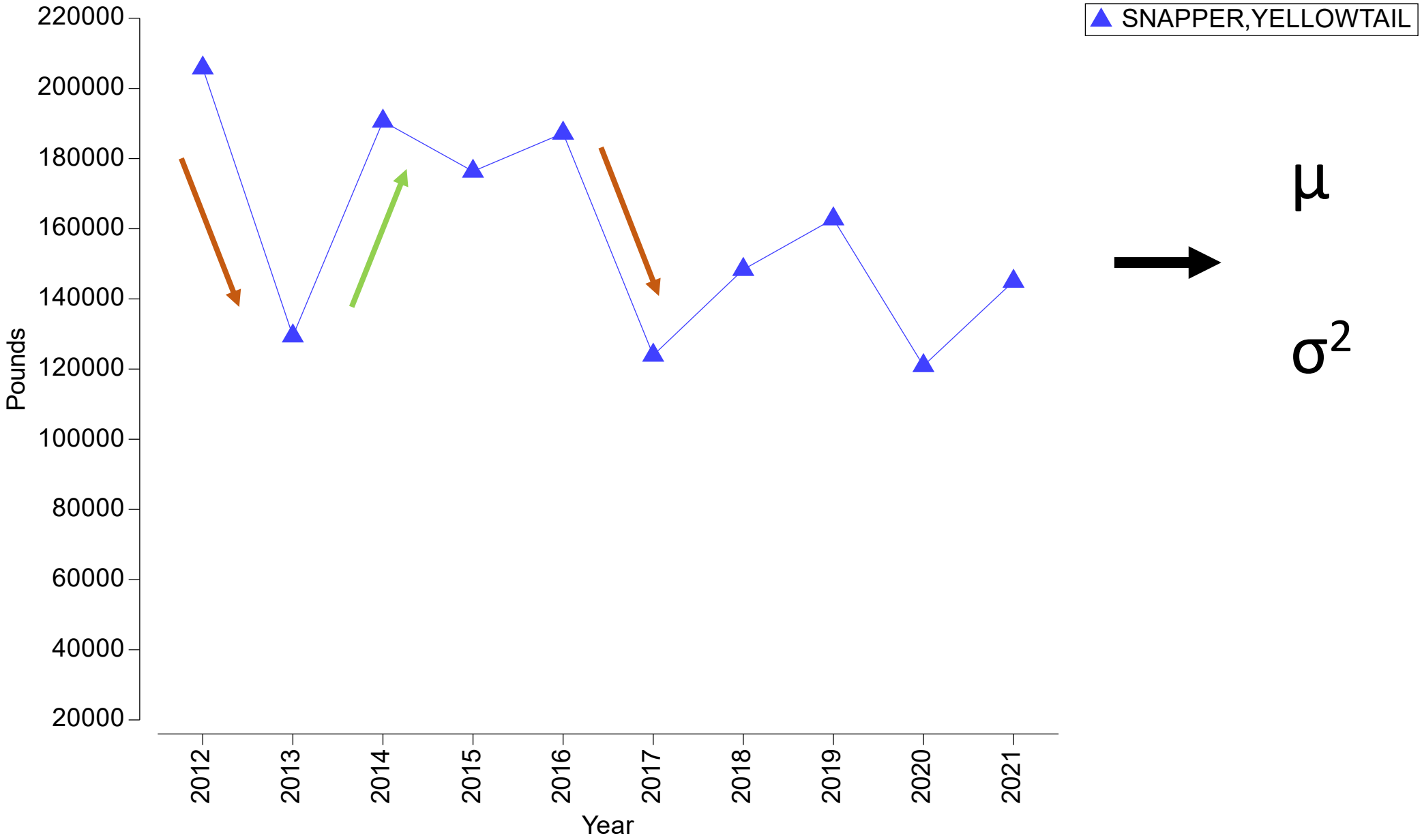
	BARRACUDA	JACKS	MACKEREL, KING	PORGY, UNSPECIFIED	TUNA AND MACKERELS, UNSPECIFI	GROUPER, UNSPECIFIED	SNAPPER, LANE	SNAPPER, MUTTON	SNAPPER, SILK	SNAPPER, YELLOWTAIL	LOBSTERS, SPINY	SNAPPER, UNSPECIFIED		YEAR	REGION	LOCATION	GEAR
S1	0	0	0	0	0	0	0	0	0	0	2359.01639	0		1983	PR-East	CEIBA	BY HAND, DIVING GEAR
S2	0	0	0	0	0	0	0	0	0	0	0	0		1983	PR-East	CEIBA	HAUL SEINES
S3	0	0	0	906.557377	0	1732.786885	627.868852	88.5245902	0	1345.90164	0	0		1983	PR-East	CEIBA	HOOK AND LINE, BOTTOM
S4	0	0	0	1909.836066	0	3455.737705	9993.44262	724.590164	0	1422.95082	301.639344	0		1983	PR-East	CEIBA	POTS AND TRAPS, FISH
S5	0	0	108.196721	0	0	0	0	0	0	0	0	0		1983	PR-East	CEIBA	TROLL LINES
S6	0	0	0	0	0	0	0	0	0	0	2498.36066	0		1983	PR-East	CULEBRA	BY HAND, DIVING GEAR
S7	0	0	195.081967	0	0	3906.557377	0	0	0	2419.67213	0	0		1983	PR-East	CULEBRA	HOOK AND LINE, BOTTOM
S8	0	0	0	0	0	1632.786885	122.95082	106.557377	0	1062.29508	0	0		1983	PR-East	CULEBRA	POTS AND TRAPS, FISH
S9	0	0	0	0	0	0	0	0	0	0	1677.04918	0		1983	PR-East	CULEBRA	POTS AND TRAPS, SPINY LOBSTER
S10	0	0	1139.34426	0	0	60.65573771	0	0	0	0	0	0		1983	PR-East	CULEBRA	TROLL LINES
S11	0	0	0	0	0	0	0	0	0	0	7829.5082	0		1983	PR-East	FAJARDO	BY HAND, DIVING GEAR
S12	0	0	0	0	0	73.7704918	118.032787	0	0	36.0655738	0	0		1983	PR-East	FAJARDO	GILL NETS, OTHER
S13	1290.163934	0	278.688525	0	0	0	0	19.6721311	0	647.540984	0	0		1983	PR-East	FAJARDO	HAUL SEINES
S14	0	0	2800	19.67213115	0	2318.032787	1308.19672	929.508197	788.52459	28239.3443	0	0		1983	PR-East	FAJARDO	HOOK AND LINE, BOTTOM
S15	0	0	0	0	0	62.29508197	103.278689	65.5737705	0	50.8196721	0	0		1983	PR-East	FAJARDO	LONG LINES, BOTTOM
S16	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
S17	0	0	25301.6393	0	0	204.9180328	0	0	0	0	0	0		1983	PR-East	FAJARDO	TROLL LINES
S18	0	0	0	0	0	18.03278689	0	0	0	0	2467.21311	0		1983	PR-East	HUMACAO	BY HAND, DIVING GEAR
S19	0	0	0	0	0	0	0	0	0	0	0	0		1983	PR-East	HUMACAO	CAST NETS
S20	0	0	0	0	0	0	386.885246	0	0	0	0	0		1983	PR-East	HUMACAO	GILL NETS, OTHER
S21	0	0	0	0	0	0	0	0	0	0	0	0		1983	PR-East	HUMACAO	HAUL SEINES
Indicators	Barracuda	Jacks	Scomb	Porgy	Scomb	Grouper	Snapper	Snapper	Snapper	Snapper	obster	Snapper					

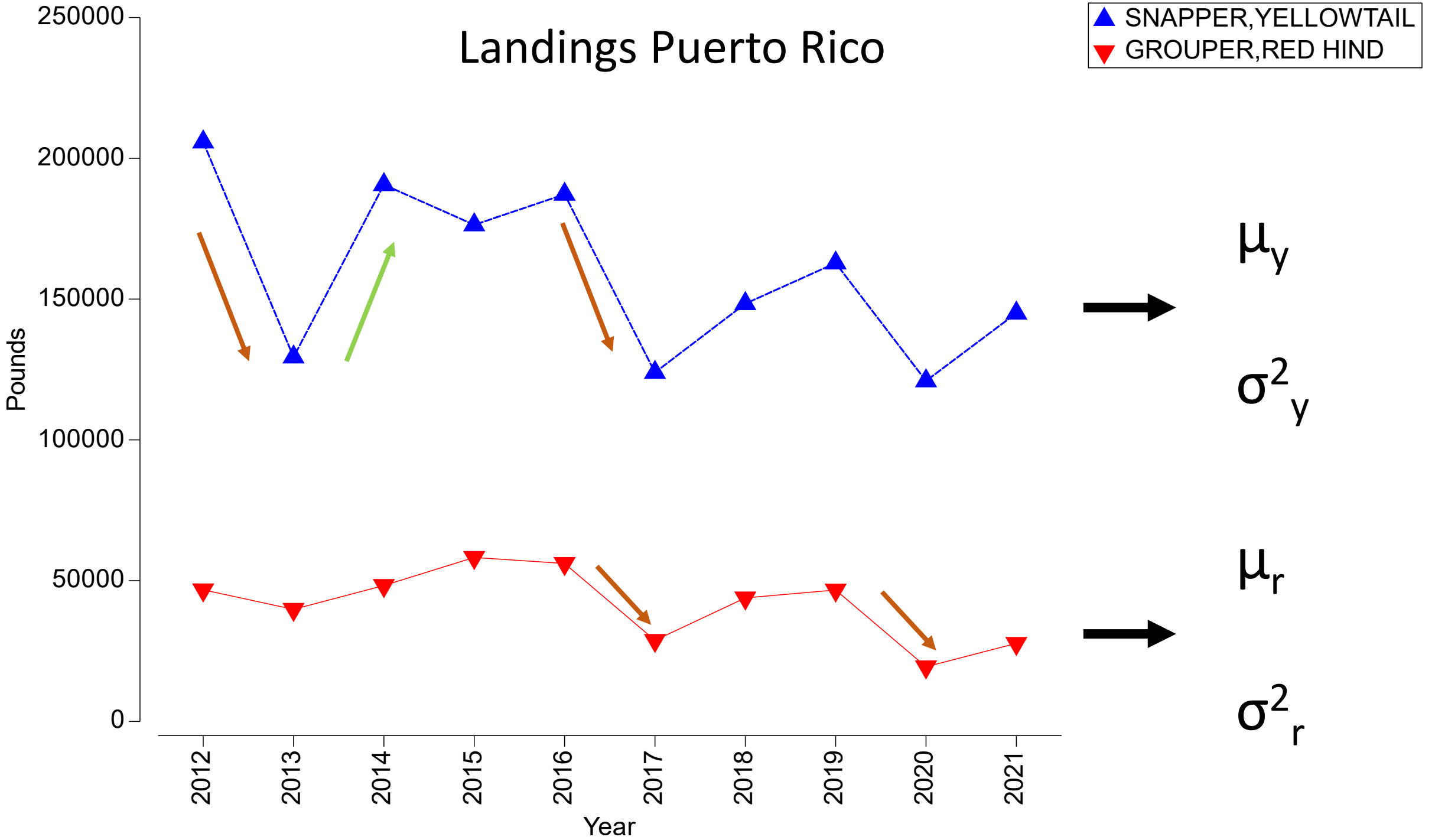
Working paper SEDAR 84



Martínez Rivera, Stephanie, Kimberley Johnson, and M. Refik Orhun. 2024. SEDAR 84 Commercial fishery landings of Yellowtail Snapper (*Ocyurus chrysurus*) in St. Thomas and St. John, US Caribbean, 2012-2022. SEDAR84-WP-02. SEDAR, North Charleston, SC. 15 pp.

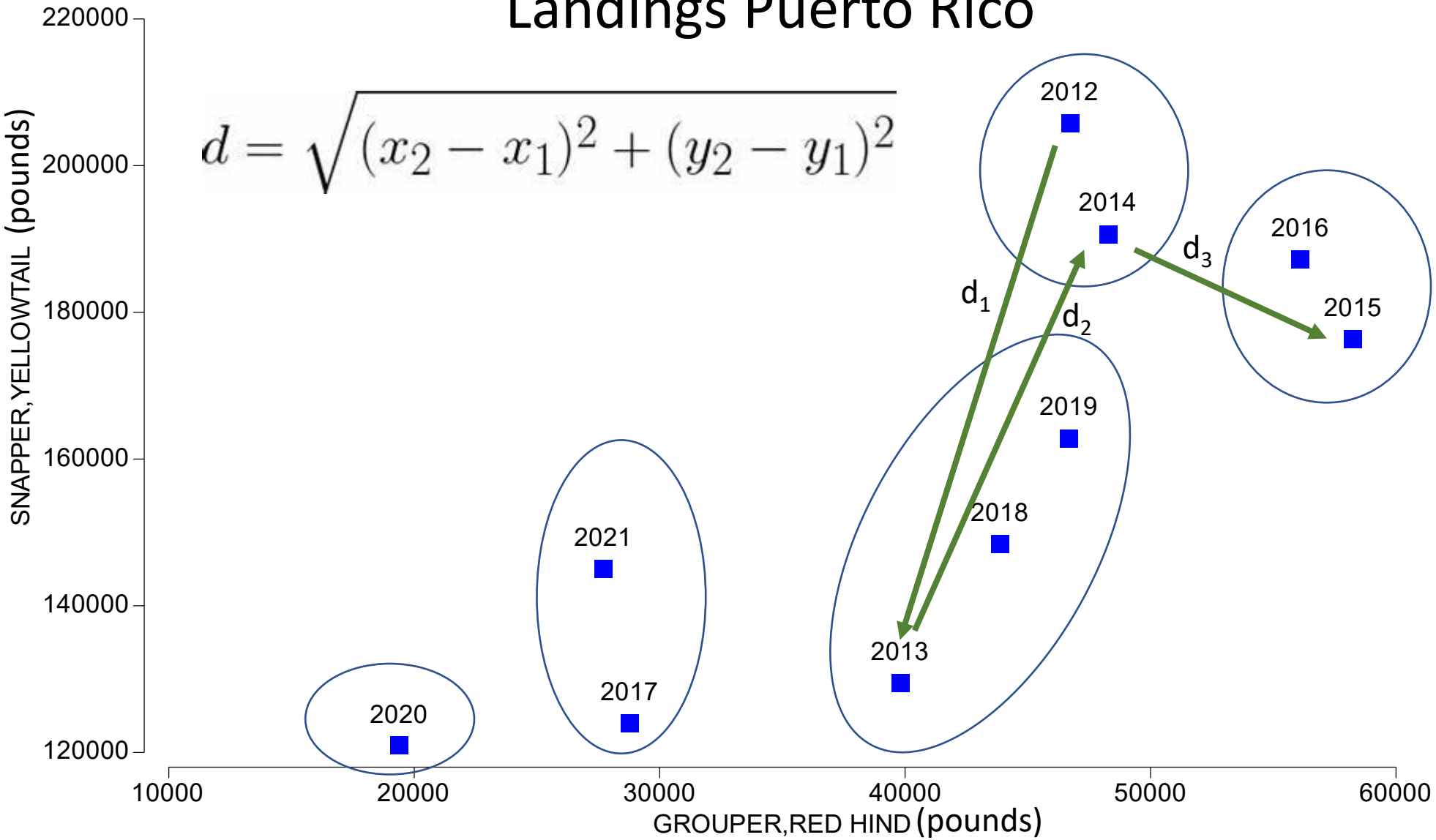
Landings Puerto Rico

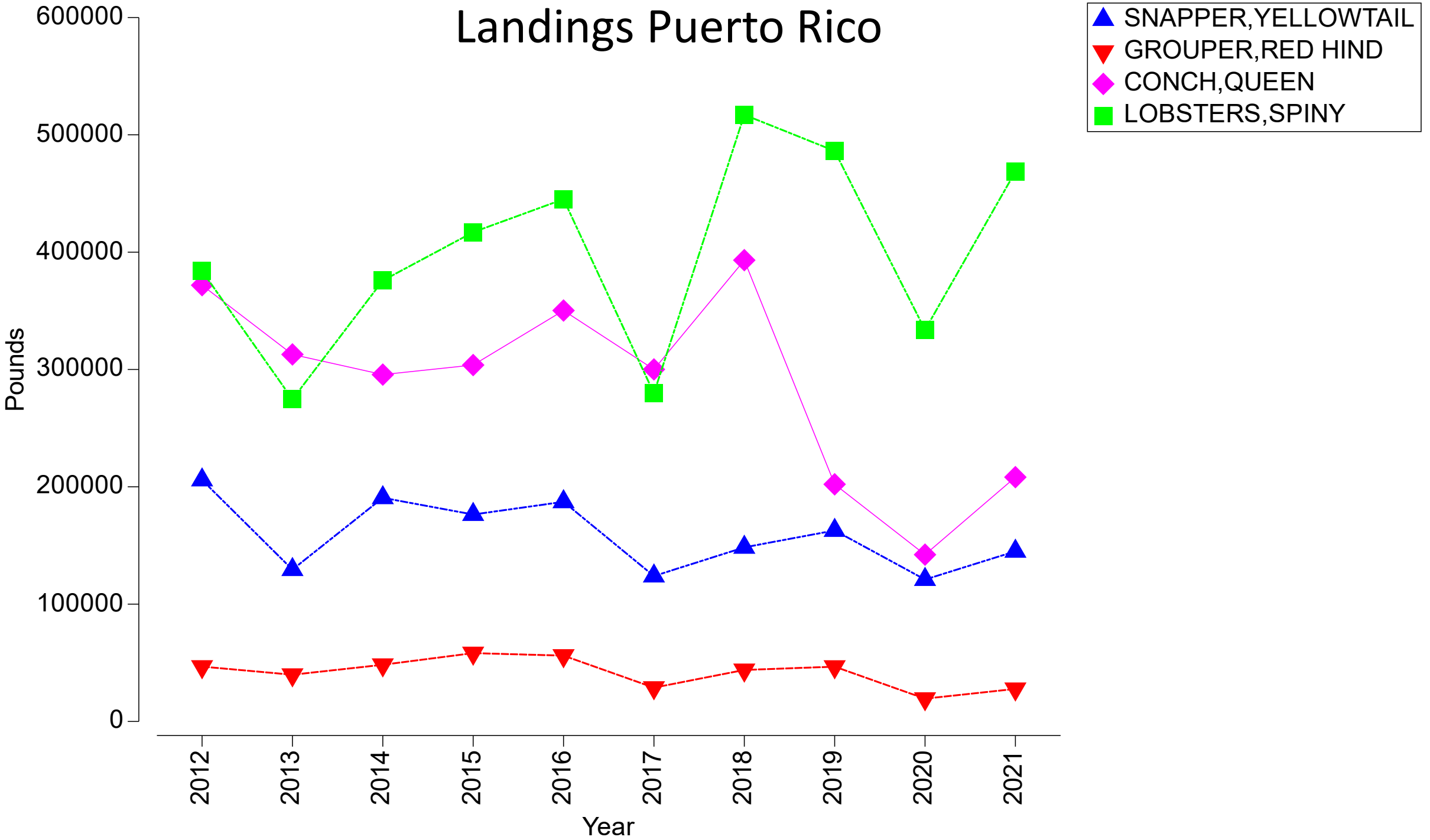


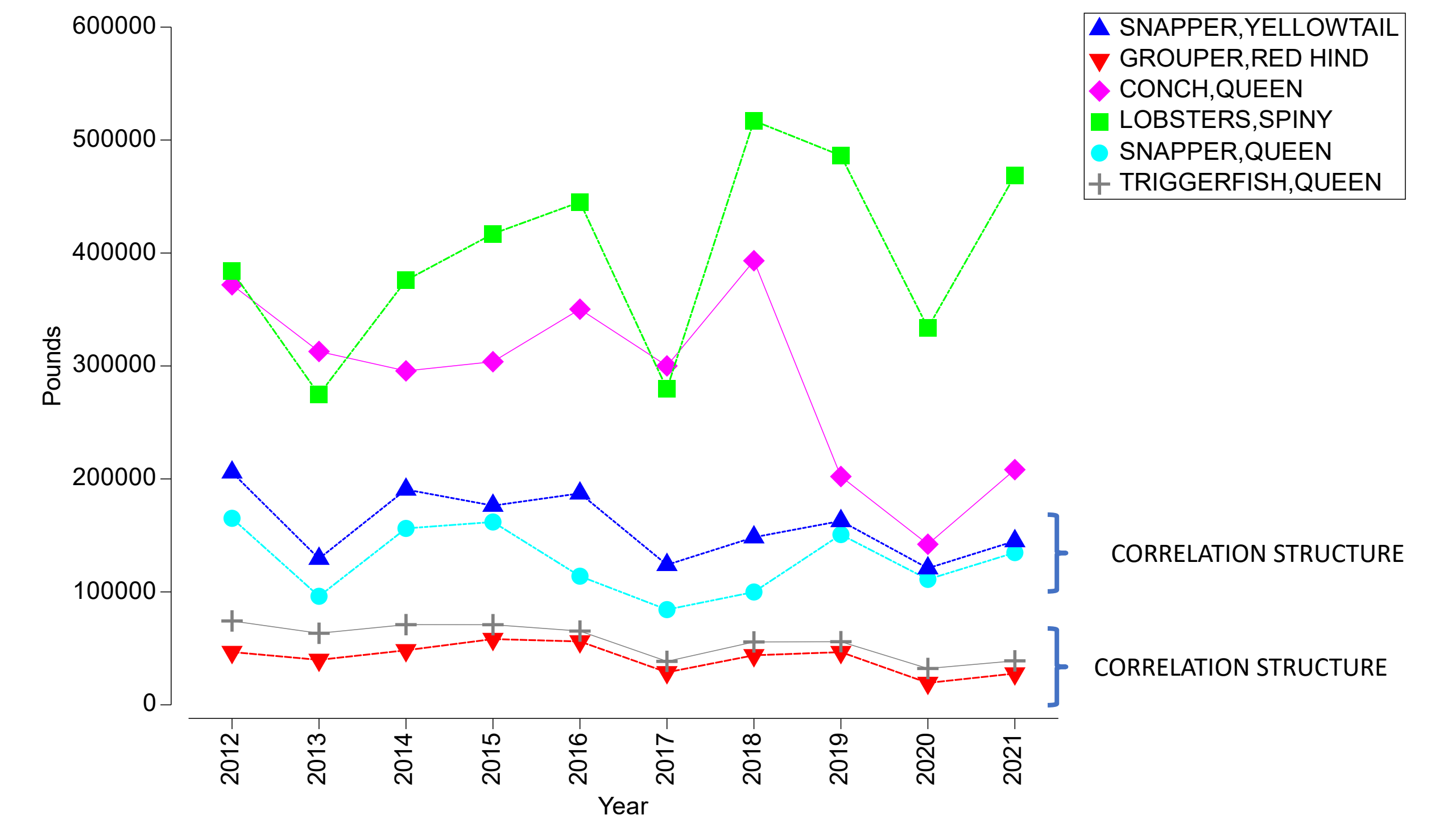

Landings Puerto Rico
SNAPPER,YELLOWTAIL
GROUPER,RED HIND
250000
200000
150000
100000
50000
0
Pounds
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Year
μ_y
σ^2_y
μ_r
σ^2_r

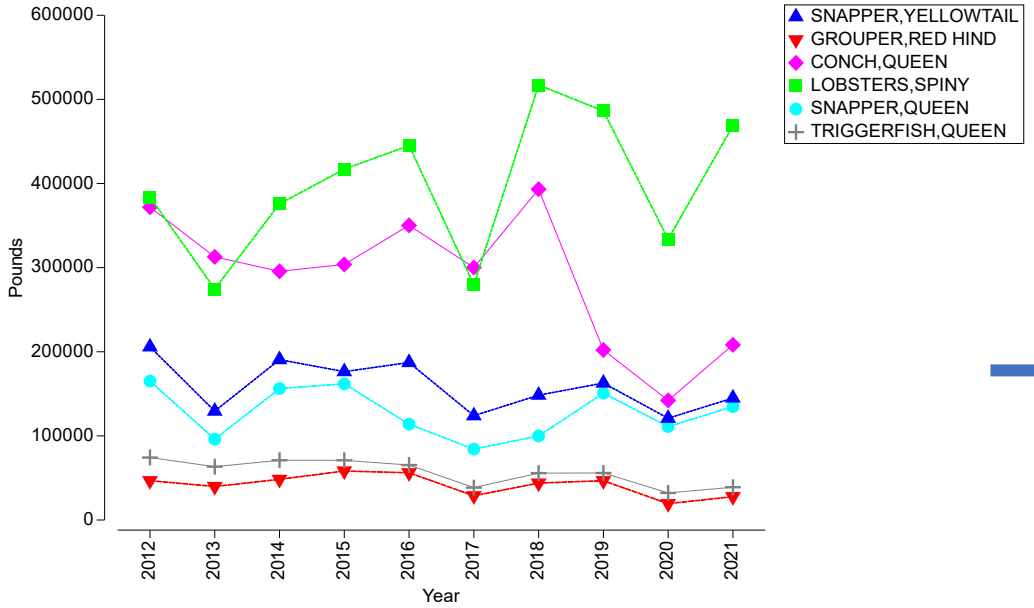
Landings Puerto Rico

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$




Landings Puerto Rico
SNAPPER,YELLOWTAIL
GROUPER,RED HIND
CONCH,QUEEN
LOBSTERS,SPINY
Pounds
600000
500000
400000
300000
200000
100000
0
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Year


600000
500000
400000
300000
200000
100000
0
Pounds
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Year
SNAPPER,YELLOWTAIL
GROUPER,RED HIND
CONCH,QUEEN
LOBSTERS,SPINY
SNAPPER,QUEEN
TRIGGERFISH,QUEEN
CORRELATION STRUCTURE
CORRELATION STRUCTURE



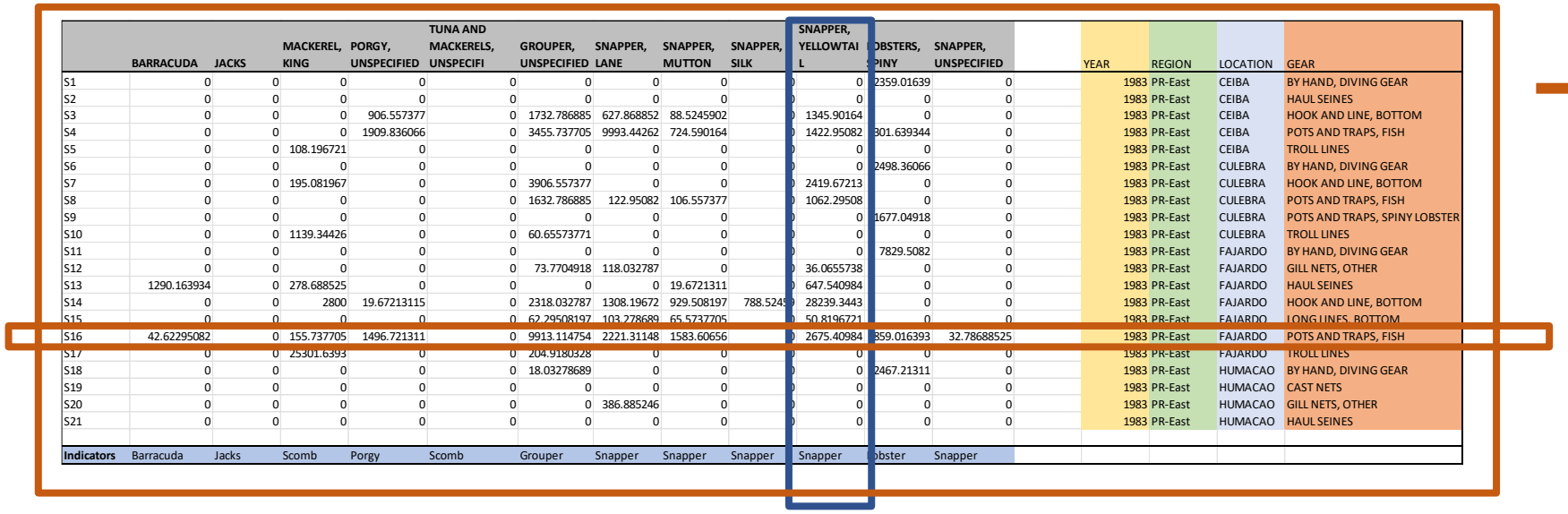
WARNING →

Only as an example
Not for Actual interpretation

↓

NOT STANDARDIZED by gear, effort and or effort

Corrrelation Structure



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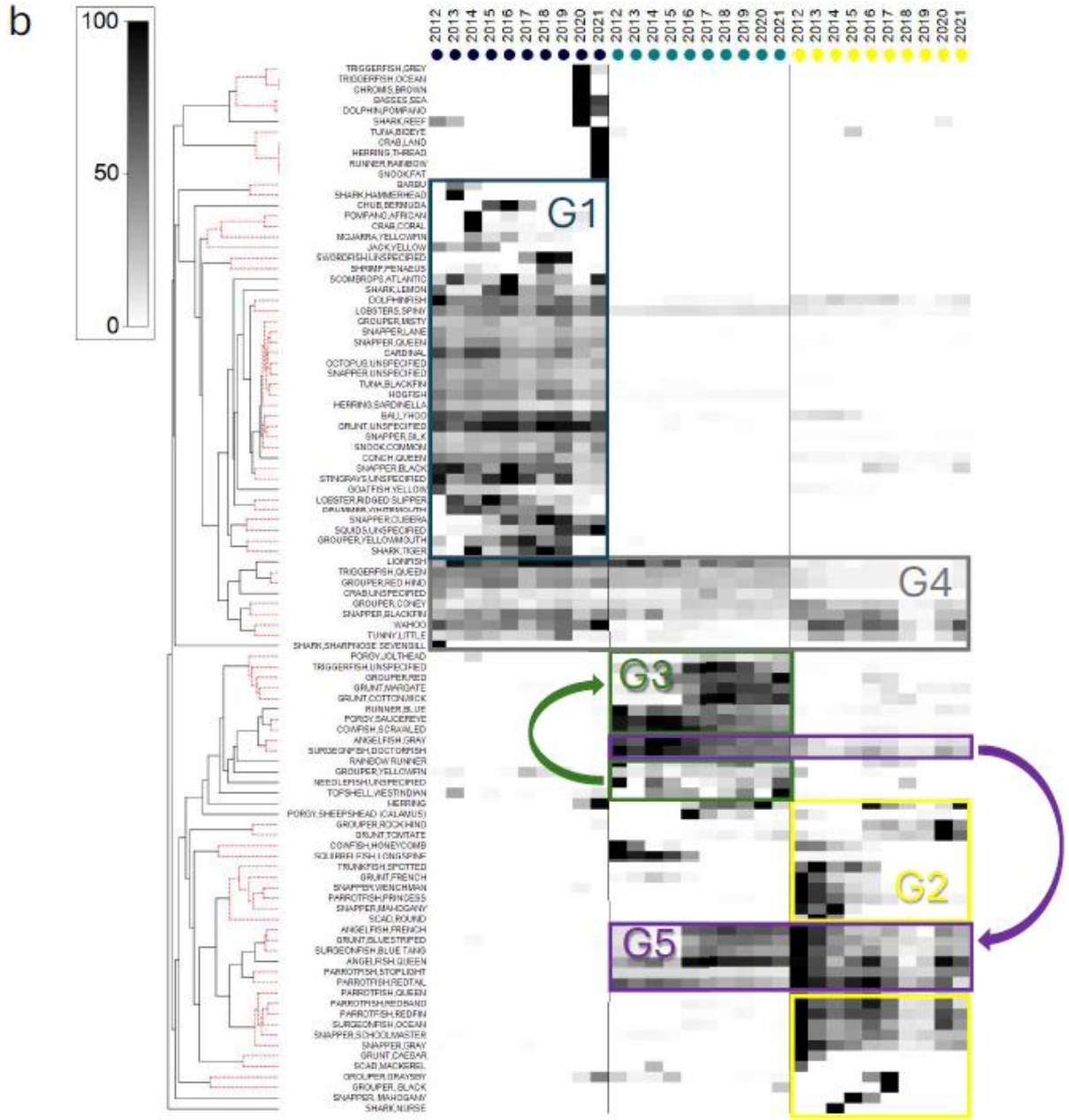
Indicators	Barracuda	Jacks	Scomb	Porgy	Scomb	Grouper	Snapper	Snapper	Snapper	Snapper	obster	Snapper					

Multivariate:
- Centroids
- Dispersion

Evenness
Diversity

μ, σ^2

Univariate



Cruz Motta et al., under review

	Yellowtale Snappe	Red Hind	CONCH,QUEEN	Spinny lobster	Queen Snapper	Queen Troggerfish		..... AND 212 MORE	
1983	30772.13115	37965.57378	64118.03284	655067.2131	661278.6886	31409.83617	115142.623	447081.9674	359124.5901
1984	14105.08475	14776.27119	62733.89832	499615.2542	557916.9492	30250.84751	116371.1865	419013.5595	264294.9153
1985	27250	11926.78571	59773.21429	464351.7857	489291.0714	32950.00003	71689.28571	374457.1429	228614.2857
1986	4839.999999	16622.66666	45320.00002	250469.3333	240452	15237.33326	46809.33333	279056	149984
1987	6146.666666	21566.66667	46786.66668	187712	208849.3334	15059.99989	41760.00001	203481.3333	109874.6667
1988	0	13630.35714	78.571428	407889.2857	154675	11442.85718	44141.07143	250205.3572	135992.8572
1989	1521.568626	25919.60785	4915.686277	311017.6471	150286.2746	19321.56863	46845.09805	360305.8825	181462.7451
1990	24337.2549	7341.176477	45270.58828	211196.0784	229098.0393	12298.03922	39721.56867	328080.3924	158147.0589
1991	50947.05883	24064.70589	62964.70594	211001.9608	274013.7255	34260.78432	55892.15691	413200.0002	173105.8824
1992	27695	11693.33334	63610.00001	150948.3333	193848.3334	26251.66667	33441.66667	266683.3334	99096.66667
1993	37361.66667	10949.99999	88893.33333	274023.3333	267325	21430.00001	30543.33333	280486.6667	173771.6666
1994	41579.6875	16457.8125	81334.375	266390.625	218040.625	34401.5625	45301.5625	299634.375	146873.4375
1995	73667.60563	22683.09858	92504.22537	299750.7042	198029.5775	34881.69015	65407.04224	392446.4789	213245.0704
1996	76545.07041	26281.69014	89657.74653	337004.2254	235633.8029	33260.56338	82611.26763	392897.1832	140318.3098
1997	67957.6923	31655.1282	102502.5641	305108.9744	208311.5384	38735.89742	85755.12823	362697.4361	133603.8461
1998	57088.46152	40800.00001	114870.5128	333957.6923	142552.5641	27117.94872	61256.4103	380914.1027	135619.2308
1999	59985.89742	28676.92306	105248.718	272878.2051	149194.8718	32323.07691	57266.66671	417232.0513	160714.1025
2000	80431.57894	40968.42111	144066.667	490482.4562	199408.7722	40936.84211	98859.64947	448261.4041	212363.158
2001	86561.76473	24402.94118	109419.1176	356526.4706	222052.9412	33541.17647	97808.82349	410583.8236	139991.1765
2002	78933.72094	25391.86046	91093.02312	273016.279	170548.837	32361.62787	77912.79055	348845.3486	135287.2092
2003	62081.74358	17629.62665	101669.1905	344602.6305	183845.8104	32506.47723	66107.34992	395763.3344	141426.3759
2004	70661.74095	14875.61845	113466.1379	377290.2506	211070.3036	32374.42464	86200.00348	475716.8882	95496.82264
2005	48616.35819	14603.93598	192772.67	726291.148	294332.7272	18838.65476	127302.5546	772042.9109	259189.9256
2006	17576.14071	8234.421129	59246.56893	240873.3539	88442.54746	20975.45615	51712.67721	275025.8896	79593.14356
2007	25738.41728	2989.992057	48392.93138	251269.5756	59917.3574	15375.48883	54154.98984	263699.6016	59467.63431
2008	33101.32499	1953.107591	49757.46482	234501.3709	69209.35803	107356.8687	52284.29101	325832.4819	124282.3364
2009	45872.48167	2981.439648	57374.58386	271491.988	80044.30896	46550.14256	65100.70569	322016.5783	90587.64376
2010	30255.46703	1908.380255	55648.59918	269952.0684	51952.21384	49393.3923	54565.28943	288534.1282	76196.47805
2011	48214.37942	1789.410931	39450.71637	234701.8032	25437.54949	20957.35738	52560.41235	272944.9259	39593.64808
2012	62522.18369	1698.769051	47373.23792	371843.0665	12573.64451	46441.30262	66949.80495	383896.2165	45674.56745
2013	54039.30112	383.800034	34967.78198	312828.2278	7000.303038	26414.24072	48386.25835	274598.4282	29853.726
2014	48275.83209	2950.825022	37767.43995	295632.6569	3978.186037	30410.24457	59194.5349	375817.2323	29364.39539
2015	63521.18251	2144.827852	41337.61763	303764.046	1621.044202	24707.83775	53877.37111	417017.1042	29085.38417
2016	64229.45462	1406.924765	38274.06113	350256.309	2713.445851	24565.28904	53175.87952	445158.3867	32376.52009
2017	47537.39845	1384.196581	32406.35	300054.5235	1431.62238	15205.10644	30593.71183	279658.3704	22927.20766
2018	62816.65603	1382.399807	39054.73866	393161.1447	791.700644	13273.31445	70587.11194	517112.2813	29515.97393
2019	65196.08469	894.014296	41291.12664	202132.2576	2319.20605	19318.25733	58075.37349	486291.2987	26354.41154
2020	34452.20231	258.202874	29880.95541	142150.5895	5934.00602	7427.210801	33947.57749	333718.0589	18904.89379
2021	61233.07228	237.598032	32954.60808	208208.6217	13053.28702	19805.80948	39105.85572	468631.2135	36998.63704

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1995	73667.60563	22683.09858	92504.22537	299750.7042	198029.5775	34881.69015	65407.04224	392446.4789	213345.0704
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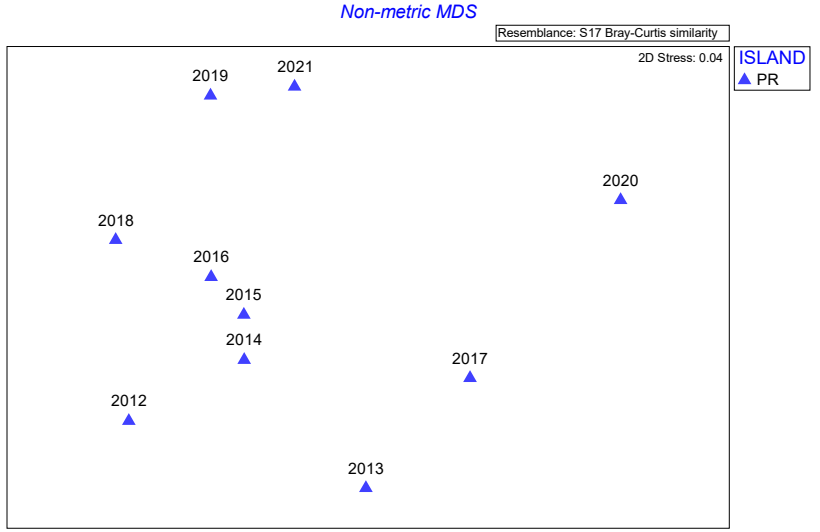
Dis/Similarity index (e.g. Bray-Curtis)
Non metric, No assumptions (e.g. lineal)
Data as it is, Simple

	1983	1984		.....		2020	2021
1983							
1984	92						
…	89	94					
…	64	70	72				
…	51	57	59	84			
…	58	64	66	80	80		
2020	67	73	75	83	71	83	
2021	62	68	70	81	77	80	85

Ordinations

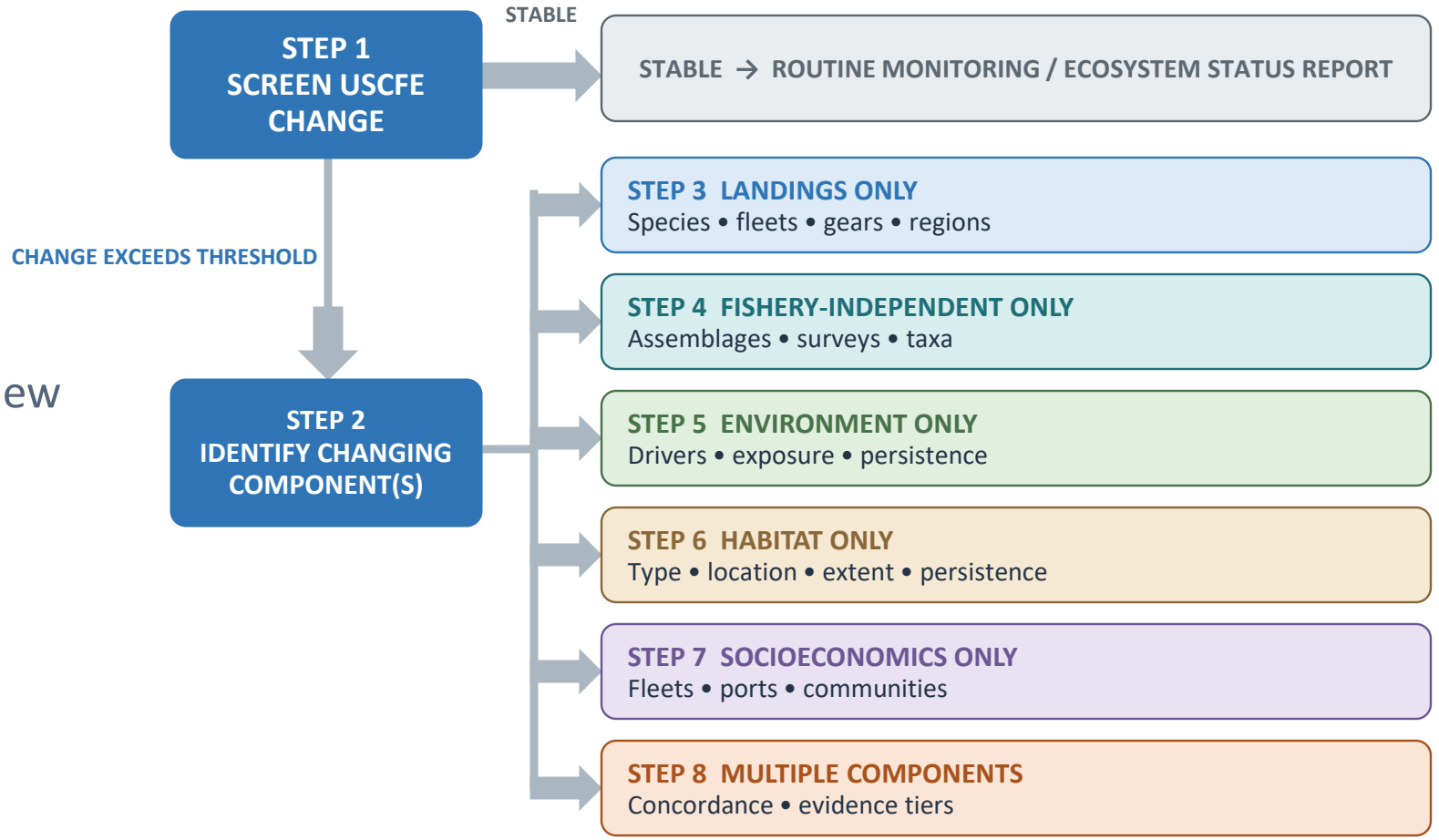


- Formal statistics:
  - Non-parametric,
  - No assumptions
  - More power

- Multiple correlations:
  - Environmental,
  - Fisheries independent
  - Habitat
  - Socio-economic

IMPLEMENTATION: EIGHT STEPS SEQUENCE

Every pathway ends with a documented interpretation, proportionate response, and review trigger.



STEP 1 — SCREEN EACH COMPONENT FOR CHANGE

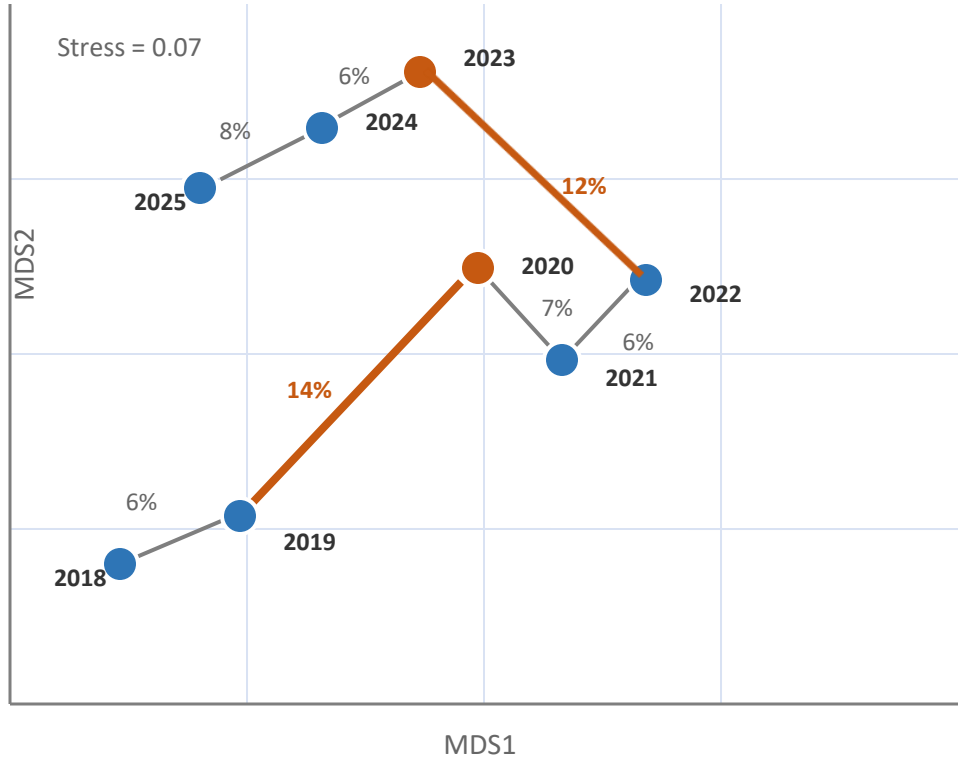
A. Bray–Curtis dissimilarity among years

Hypothetical values (%); adjacent-year triggers outlined

	2018	2019	2020	2021	2022	2023	2024	2025
2018	0							
2019	6	0						
2020	18	**14**	0					
2021	16	12	7	0				
2022	19	15	9	6	0			
2023	**24**	**21**	16	13	**12**	0		
2024	**22**	20	15	12	11	6	0	
2025	20	18	14	11	10	9	8	0

B. MDS trajectory of the same years

Distance between points represents multivariate dissimilarity



Interpretation: Small dissimilarities indicate similar composition; larger values indicate greater multivariate change. The screening threshold is a policy choice, not a universal ecological constant.

TWO DECISIONS DEFINE THE THRESHOLD

DEFINE THE TEMPORAL REFERENCE

What should the current year be compared with?

PREVIOUS YEAR

$D(X_t, X_{t-1})$

+ **Early warning of abrupt annual change**

– Sensitive to anomalous years

HISTORICAL CENTROID

$D(X_t, Cbaseline)$

+ **Stable multiyear reference**

– May detect gradual change less rapidly

BOTH

Annual + centroid distance

+ **Early detection + persistent/cumulative change**

= Uses two complementary indicators

ESTABLISH THE OPERATIONAL THRESHOLD

How should the threshold be established?

RETROSPECTIVE ANALYSES

Evaluate historical behavior and candidate values

SENSITIVITY TESTING

Test robustness across references, datasets, and values

CONSULTATION

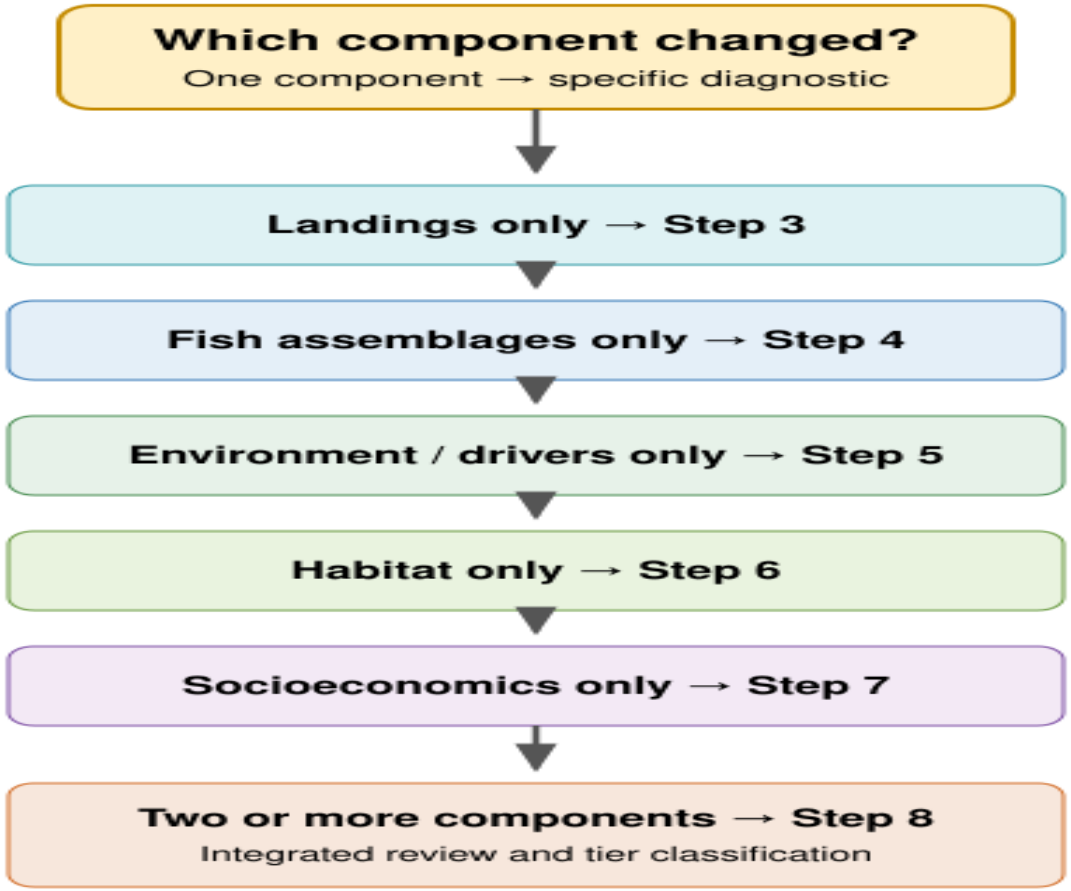
Scientists • managers • SSC • fishers • stakeholders

OPERATIONAL THRESHOLD(S)

May differ by component, dataset, or management area

10% | **Illustrative only — not a validated reference threshold and not an automatic management trigger.**

STEP 2 — SELECT THE DIAGNOSTIC PATHWAY



STEP 3 — DIAGNOSE A LANDINGS CHANGE

EVIDENCE

1 ANALYSIS

- Identify species or complexes, regions, gears, seasons, and fleets contributing to change
- Examine its direction and magnitude
- Determine whether the change persists

MEANING

2 MANAGEMENT INTERPRETATION

- Treat a landings-only signal first as a change in the fishery
- Catch may change without an equivalent stock change
- Examine reporting, effort, participation, access, markets, regulations, and infrastructure

ACTION

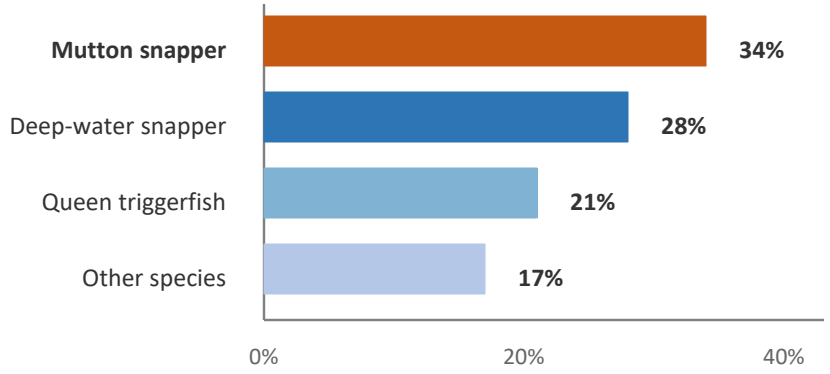
3 RESPONSE

- Validate data and fishery mechanisms
- Prepare a fisheries status report
- Review measures or data needs
- Assign assessment priority only when independent evidence and risk justify it

Contribution analyses identify what drives the detected change

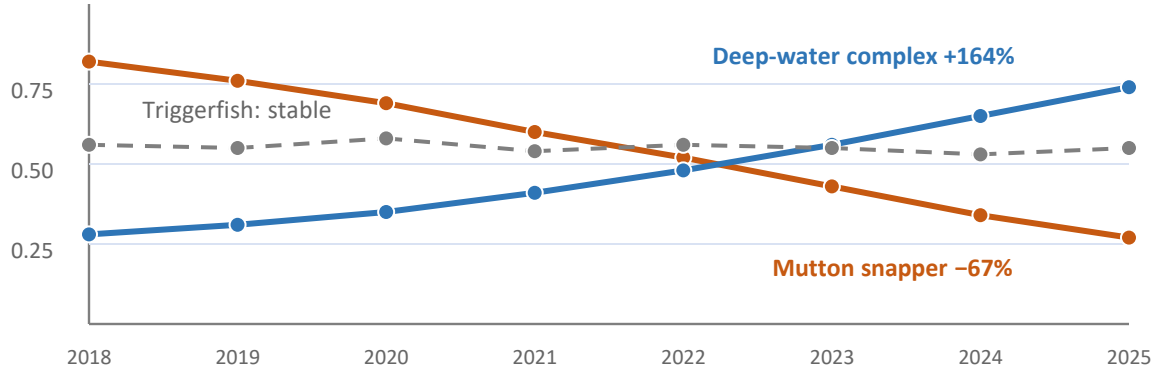
A. Species and complexes driving change

Contribution to Bray–Curtis dissimilarity (hypothetical)



B. Direction, magnitude, and persistence

Standardized landings relative to each taxon's historical maximum



C. Fishing region and gear contribution

Relative contribution to the detected change (%)

	North	East	South	West
Traps	4%	18%	15%	6%
Hook & line	5%	7%	8%	17%
Nets	3%	6%	8%	3%

Relative contributions across all cells sum to 100%

D. Diagnostic classification

Evidence carried forward to prioritization and management review

Taxon	Direction	Magnitude	Persistence	Primary stratum
Mutton snapper	Decrease	Large	8 years	E/S traps
Deep-water complex	Increase	Mod.–large	6 years	W hook & line
Queen triggerfish	No trend	Small	Stable	Multiple

Interpretation: A persistent mutton snapper decline is concentrated in eastern and southern trap landings, while the deep-water complex is increasing. Investigate the contrasting trajectories separately before inferring stock-abundance change.

STEP 4 — FISHERIES INDPENDENT DATA

EVIDENCE

1 ANALYSIS

- Evaluate each program within its design: NCRMP + SEAMAP-C (all units); PRCRMP (PR); TCRMP (STT/STJ + STX)
- Diagnose PR, STT/STJ, and STX separately; compare standardized rates—not raw data
- Classify one-program, discordant, or concordant signals; identify taxa, direction, extent, and persistence

MEANING

2 MANAGEMENT INTERPRETATION

- Treat fishery-independent-only change as an ecological diagnostic—not direct stock status
- Managed species may provide an early biological warning despite stable landings
- Non-target species or functional groups may signal altered ecosystem structure or function
- Concordance strengthens evidence; discordance retains uncertainty

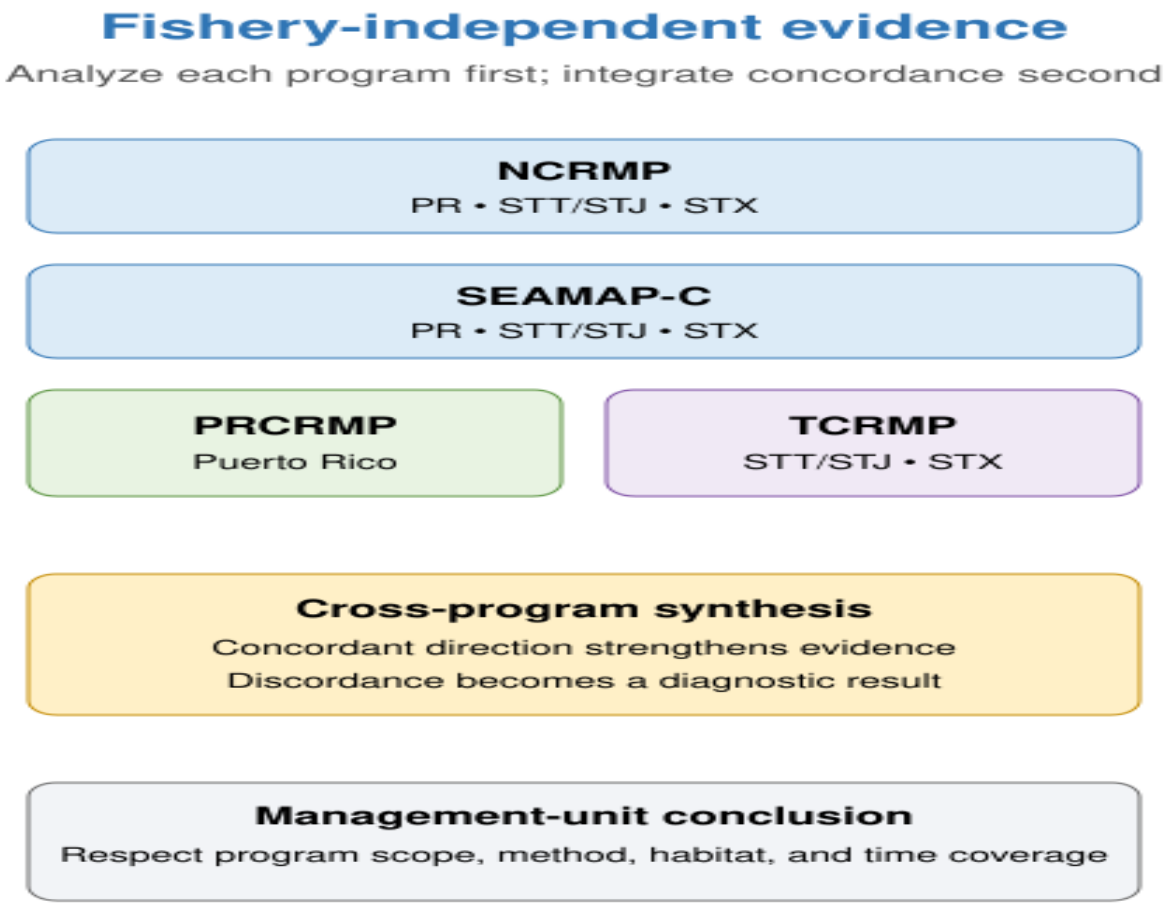
ACTION

3 RESPONSE

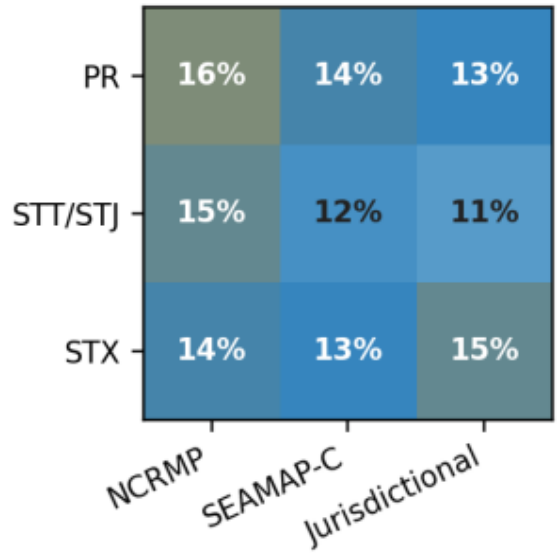
- Validate survey comparability and drivers
- Enhance monitoring; investigate effort, reporting, and measures
- Prioritize SSA or precautionary review when evidence is persistent, widespread, vulnerable, and corroborated
- Develop biodiversity, trophic, sentinel, and ecosystem indicators

STEP 4 — INTEGRATE SURVEY EVIDENCE

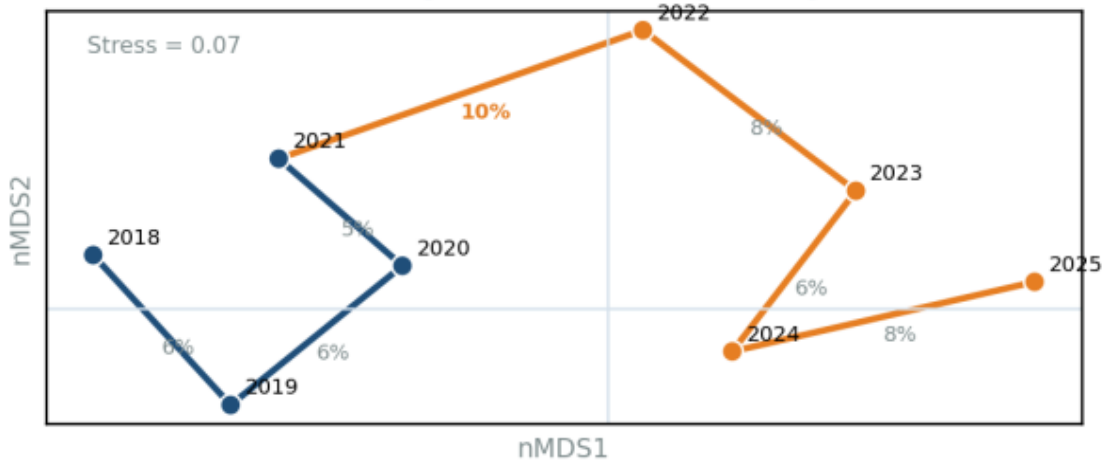
Analyze each program within its design and habitat scope; then compare direction, responsible taxa, space, and persistence by management unit.



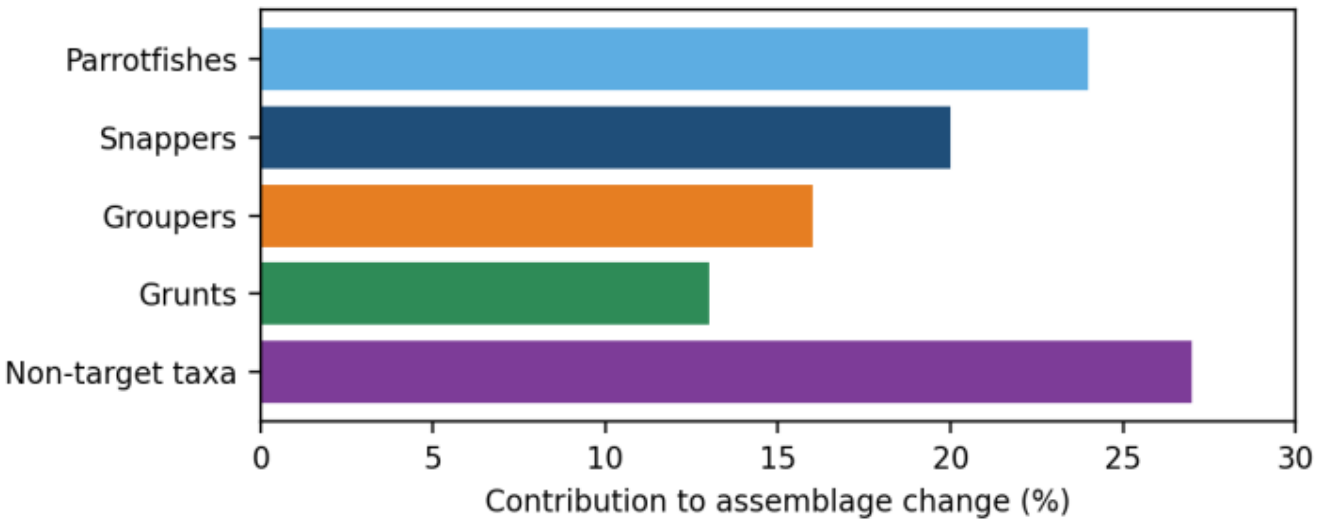
A. Change magnitude by survey and management unit



B. Temporal nMDS trajectory



C. Species/groups responsible



D. Cross-program synthesis

Evidence pattern	Management interpretation
One program	Validate; program diagnostic
Discordant programs	Evaluate methods and spatial heterogeneity
Concordant programs	Integrated biological review; prioritize SSA/risk review

Theoretical example — values do not represent empirical estimates for the U.S. Caribbean.

STEP 5 — DIAGNOSE ENVIRONMENTAL CHANGE

EVIDENCE

1 ANALYSIS

- Normalize variables and calculate Euclidean distances
- Identify responsible drivers—such as temperature, productivity, rainfall, storms, or pollution
- Evaluate direction, magnitude, spatial extent, and duration
- Classify change as episodic, cyclical, localized, or persistent

MEANING

2 MANAGEMENT INTERPRETATION

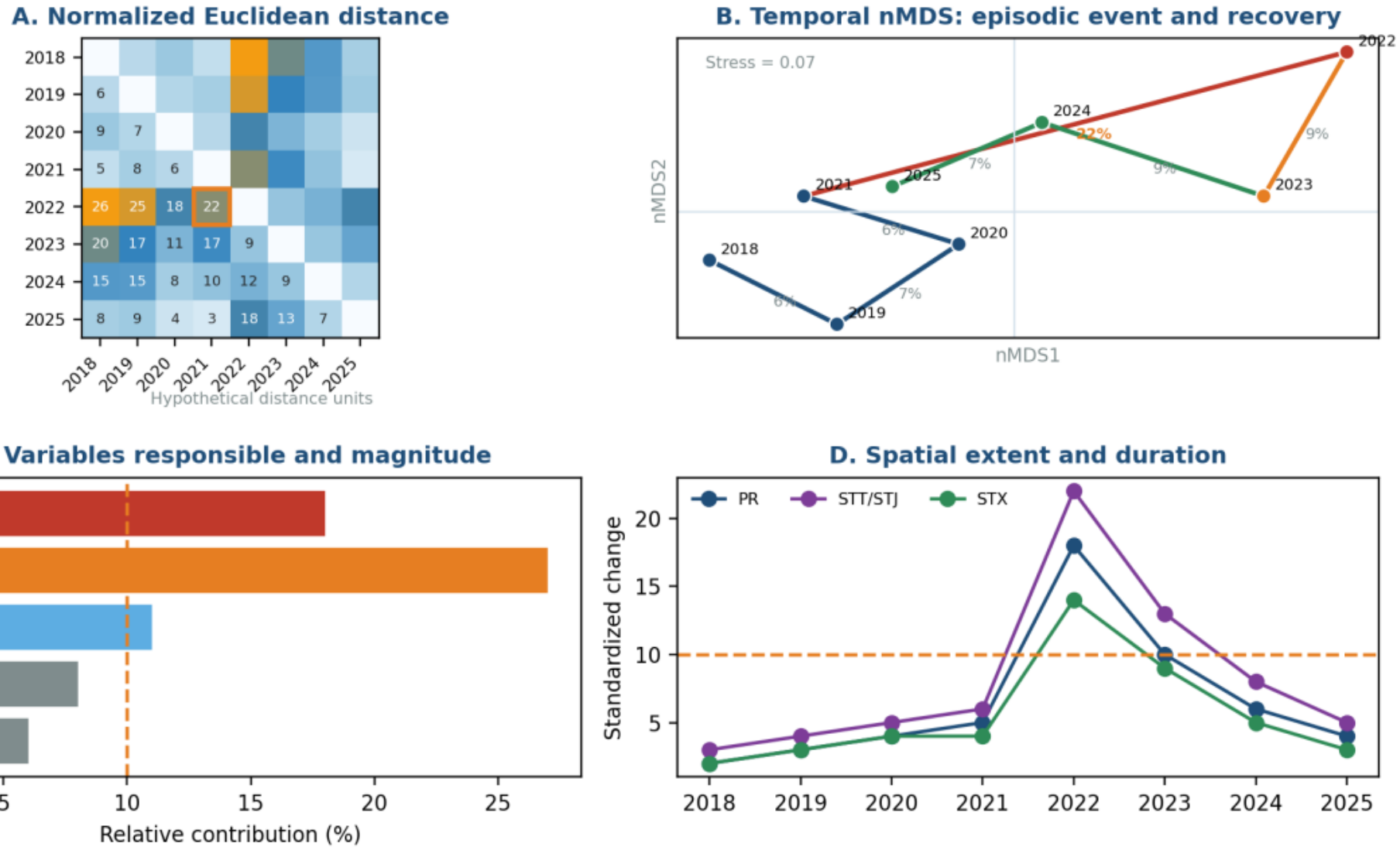
- Treat an environment-only change as an exposure and vulnerability warning—not evidence of stock decline
- Biological and fishery responses may lag behind the driver
- Determine which species, habitats, fisheries, and communities are most exposed and vulnerable

ACTION

3 RESPONSE

- Increase biological and fishery monitoring
- Conduct risk and vulnerability assessments
- Add environmental covariates to SSA/ERPs; consider precautionary buffers when risk is high
- Coordinate with environmental and coastal authorities

Environmental diagnostics distinguish episodic from persistent change



Theoretical example — values do not represent empirical estimates for the U.S. Caribbean.

STEP 6 — DIAGNOSE HABITAT CHANGE

EVIDENCE

1 ANALYSIS

- Quantify benthic composition, rugosity, and habitat heterogeneity
- Identify changed variables, direction, magnitude, extent, and persistence
- Map overlap with EFH, nursery and spawning areas, corridors, and fishing grounds
- Identify dependent species, functional groups, and fisheries

MEANING

2 MANAGEMENT INTERPRETATION

- Treat habitat-only change as a warning of altered ecosystem capacity
- Recruitment, survival, productivity, connectivity, and carrying capacity may change before fish or landings respond
- Evaluate ecological importance, reversibility, exposure, and vulnerability

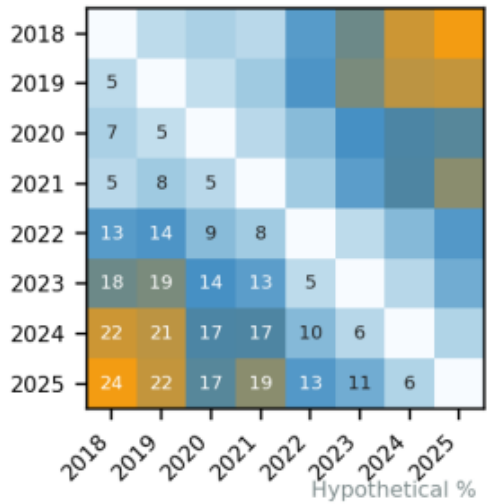
ACTION

3 RESPONSE

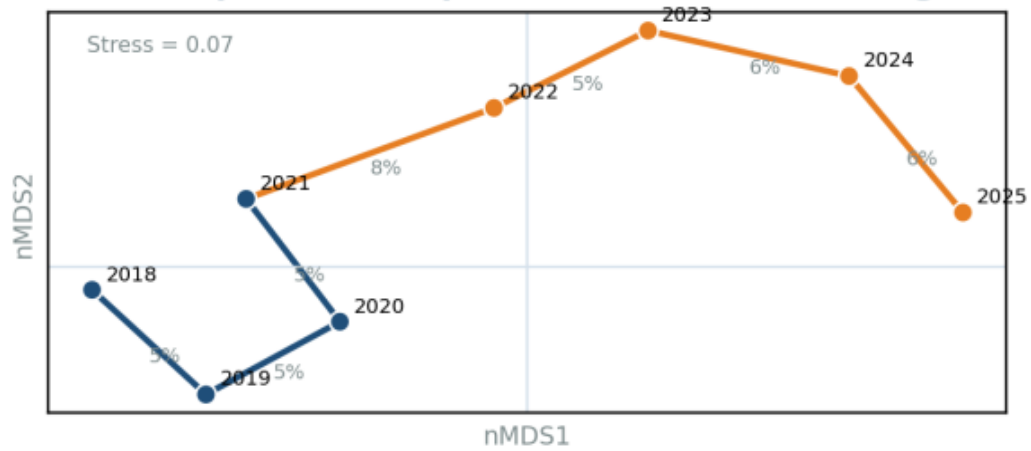
- Conduct an EFH review and incorporate habitat condition into risk assessments and SSA
- Protect nursery/spawning areas; modify habitat-damaging fishing practices
- Prioritize restoration and disturbance response
- Coordinate referrals on anchoring, development, pollution, and water quality

Habitat diagnostics identify condition, spatial footprint, and fisheries exposure

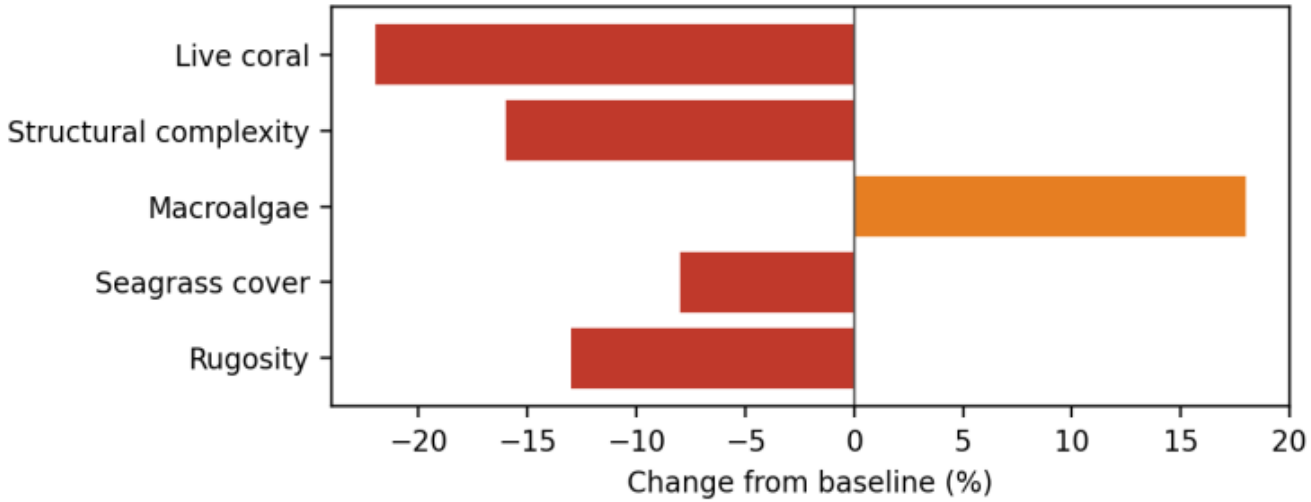
A. Habitat resemblance change



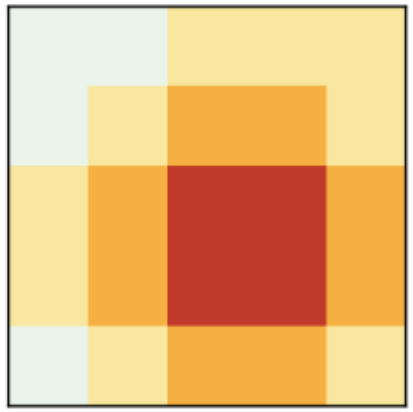
B. Temporal nMDS: persistent directional change



C. Habitat variables responsible



D. Spatial footprint and habitat importance



Localized → nursery/spawning/EFH overlap → broader response

Theoretical example — values do not represent empirical estimates for the U.S. Caribbean.

STEP 7 — DIAGNOSE SOCIOECONOMIC CHANGE

EVIDENCE

1 ANALYSIS

- Compile consistent time series; quantify direction, magnitude, and persistence
- Identify changed indicators and affected communities, ports, fleets, gears, and demographic groups
- Distinguish resource, regulatory, cost, market, infrastructure, access, or disturbance drivers
- Corroborate interpretations with LEK and stakeholder information

MEANING

2 MANAGEMENT INTERPRETATION

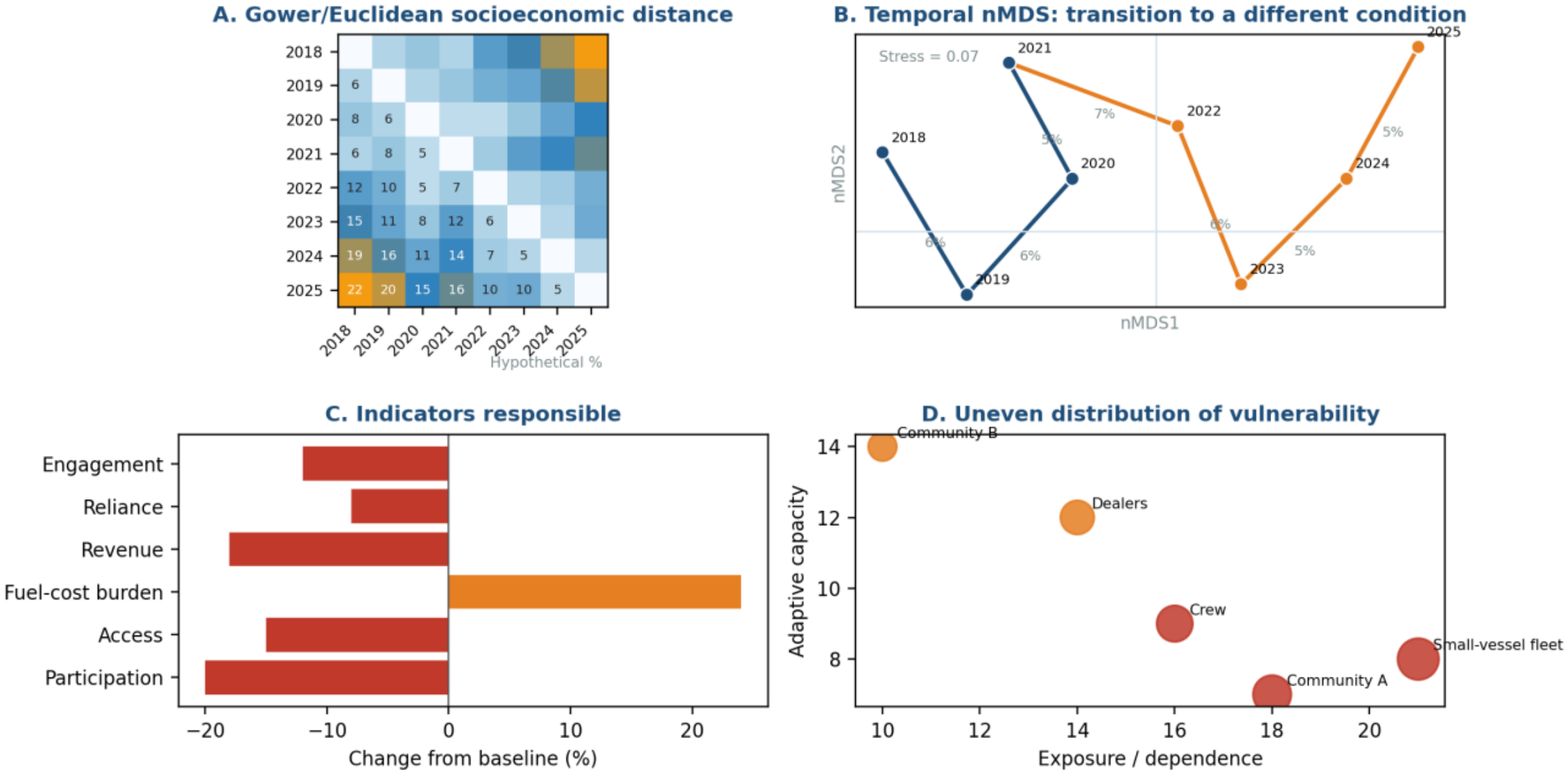
- Treat a socioeconomic-only change as a human-dimension signal—not necessarily biological deterioration
- It would not normally change a biological reference point
- It may change management feasibility, equity, timing, design, and distributional consequences

ACTION

3 RESPONSE

- Prepare an FPR and conduct social/economic impact analysis
- Adjust implementation schedules, access, or permits where appropriate
- Consider mitigation; protect subsistence and culturally important practices
- Review compliance and strengthen socioeconomic and LEK monitoring

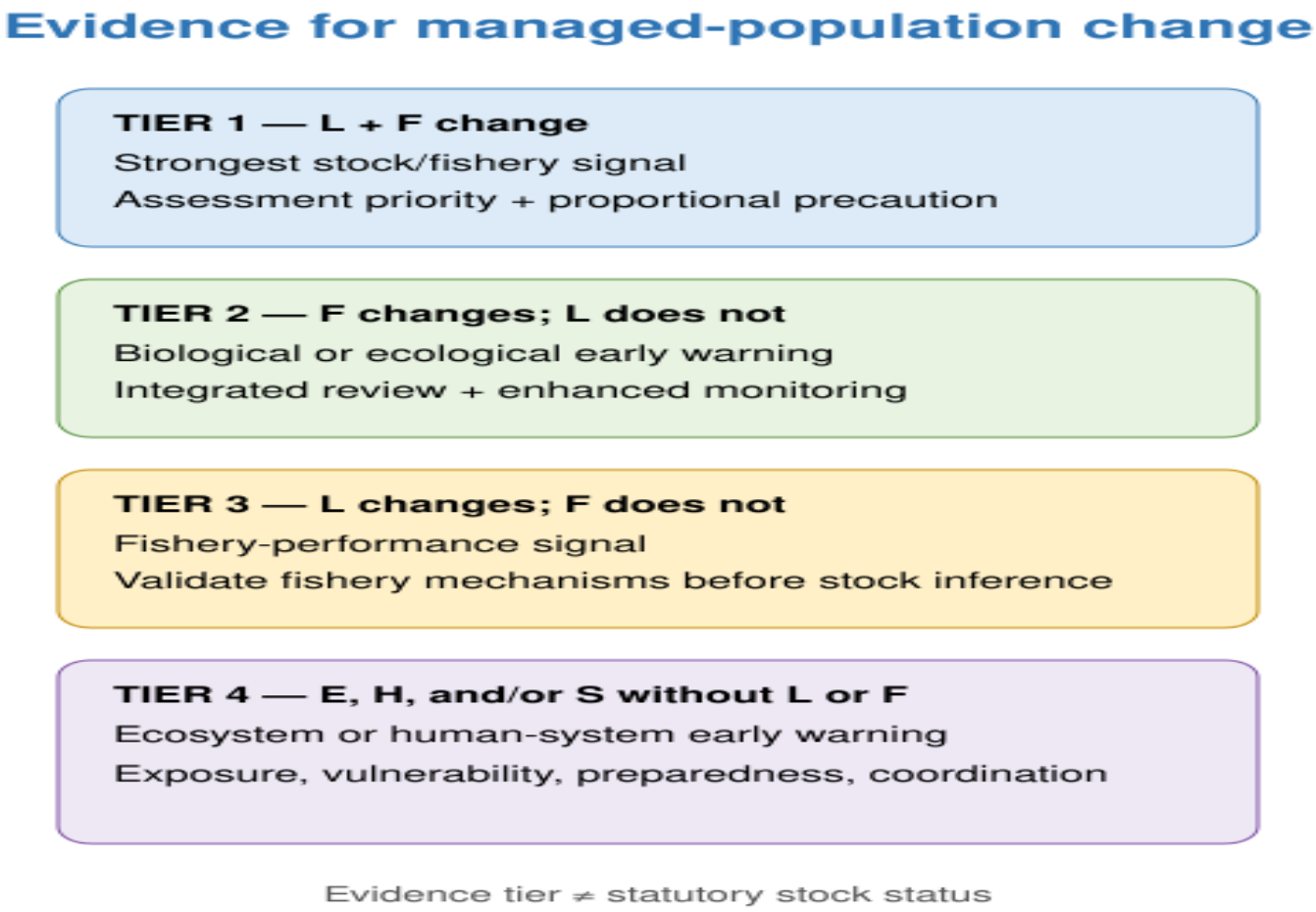
Socioeconomic diagnostics identify affected indicators, fleets, and communities



Theoretical example — values do not represent empirical estimates for the U.S. Caribbean.

STEP 8 — CLASSIFY THE L–F EVIDENCE COMBINATION

Landings (L) and fishery-independent assemblage evidence (F) define the direct evidence tier; environmental, habitat and socioeconomic changes refine mechanism, exposure and response.



STEP 8 — ORGANIZE MULTI-COMPONENT EVIDENCE

Tiers rank evidence for change in managed populations—not the importance of the signal to ecosystem management.

STRONGER DIRECT STOCK-RELATED EVIDENCE

WEAKER DIRECT EVIDENCE • STILL MANAGEMENT-RELEVANT

TIER 1

L + F

Strongest direct stock-related signal

L + F only
or + E/H/S

Assessment / precautionary review

TIER 2

F, not L

Biological early warning

F only
or + E/H/S

Biological review / monitoring

TIER 3

L, not F

Fishery-performance signal

L only
or + E/H/S

L + S important

Fishery diagnostic / risk review

TIER 4

E/H/S only

Ecosystem / human-system warning

E+H • E+S • H+S
or E+H+S

Exposure / vulnerability response

E = environment • H = habitat • S = socioeconomic
In Tiers 1–3, E/H/S add context and plausible mechanisms—not automatic causation.

STEP 8 — TIER 1: LANDINGS + SURVEY CHANGE

Signal: L + F, with or without E, H, and/or S | Strongest direct evidence for managed-population change

ANALYSIS

1 ANALYSIS

- Test L–F correspondence (RELATE), shared taxa, and direction
- Examine abundance, biomass, size structure, effort, regulations, markets, and reporting
- With E/H/S: test plausible mechanisms (BIOENV, DISTLM, SEM) and alternative hypotheses
- Integrate LEK and expert knowledge

INTERPRETATION

2 MANAGEMENT INTERPRETATION

- Strongest biologically meaningful managed-resource signal—but not proof of overfishing
- L + F only: stock-related change is plausible; mechanism remains unresolved
- +E/H: potential ecological drivers or indicators
- +S: possible driver, consequence, or management constraint

RESPONSE

3 RESPONSE

- Validate and monitor if recent; prioritize or initiate SSA if persistent
- High exposure/vulnerability: consider temporary precaution while assessment proceeds
- Confirmed fishing risk: review catch, effort, gear, season, or spatial measures
- +E/H: habitat/interagency action; +S: SIA/mitigation

STEP 8 — TIER 2: SURVEY CHANGE, LANDINGS STABLE

Signal: F, not L, with or without E, H, and/or S | Biological early warning with weaker fishery evidence

ANALYSIS

1 ANALYSIS

- Identify taxa, groups, life stages, and regions; separate managed from non-target species
- Standardize indicators for survey effort and test temporal lags
- Without E/H/S: examine survey–fishery mismatch, catchability, or fishery adaptation
- +E/H: test drivers/exposure; +S: test effort or operational explanations

INTERPRETATION

2 MANAGEMENT INTERPRETATION

- Biological or ecological warning not yet expressed in landings
- Managed-species change raises urgency; non-target change is primarily ecological
- Stable landings may reflect lag, effort, catchability, aggregation, or redistribution
- +E/H provides mechanisms; +S may explain how landings remain stable

RESPONSE

3 RESPONSE

- Conduct an integrated survey review and enhance monitoring
- Diagnose why landings remain stable; review survey–fishery spatial alignment
- +E/H: assess vulnerability and buffers; avoid increasing pressure in exposed areas
- +S: socioeconomic diagnostic, FPR, engagement, and SIA as appropriate

STEP 8 — TIER 3: LANDINGS CHANGE, SURVEY STABLE

Signal: L, not F, with or without E, H, and/or S | Fishery-performance signal with limited stock evidence

ANALYSIS

1 ANALYSIS

- Disaggregate landings by species, fleet, gear, port, region, and season; standardize for effort
- Examine markets, costs, access, regulations, reporting, and participation
- Without E/H/S: test fishery/reporting mechanisms and survey mismatch
- +E/H: test redistribution/catchability; +S: diagnose human–fishery mechanisms

INTERPRETATION

2 MANAGEMENT INTERPRETATION

- Treat first as change in fishery performance or behavior—not stock abundance
- Stable survey data weaken, but do not eliminate, biological concern
- +E/H effects may alter availability or precede survey response
- +S can indicate a substantial access, market, cost, infrastructure, or participation problem

RESPONSE

3 RESPONSE

- Validate landings; review survey coverage and power; use targeted/cooperative research
- Recent or uncertain: maintain measures and monitor
- +E/H: conduct exposure, redistribution, and catchability diagnostics
- +S: FPR, social diagnostic, or SIA; persistent unexplained decline → risk review/SSA

STEP 8 — TIER 4: E, H, AND/OR S CHANGE ONLY

Signal: one or more of E, H, and S; no change in L or F | Ecosystem/human-system warning—not stock-change evidence

ANALYSIS

1 ANALYSIS

- Apply the relevant component pathways; evaluate direction, magnitude, extent, and persistence
- Test E–H mechanisms and identify exposed managed resources
- Evaluate socioeconomic exposure, adaptive capacity, and consequences
- Distinguish E + H, E + S, H + S, and E + H + S combinations

INTERPRETATION

2 MANAGEMENT INTERPRETATION

- E + H: altered environmental forcing and habitat capacity
- E + S: operating conditions or communities may respond before biology
- H + S: access, infrastructure, fishing opportunity, or well-being may be affected
- E + H + S: broad exposure with human consequences; direct stock evidence remains weak

RESPONSE

3 RESPONSE

- Conduct exposure and vulnerability analyses
- Enhance biological and fishery monitoring to detect lagged effects
- Develop scenarios, preparedness actions, and review criteria
- Coordinate habitat, coastal, pollution, disaster, and socioeconomic responses across agencies

CONCLUSIONS: EVALUATION FIT

The method aligns strongly with ecosystem-level criteria while remaining complementary to stock assessment.

MULTIPLE-INDICATOR ECOSYSTEM DECISION SUPPORT
Screens change, identifies affected components, and guides proportionate responses

DATA USES

Combines available Caribbean landings, survey, environmental, habitat, and socioeconomic data

THEORETICAL BASIS

Uses established multivariate analyses in a transparent, documented sequence

ECOSYSTEM SCOPE

Evaluates multiple taxa, ecosystem structure, ocean conditions, and human dimensions

MANAGEMENT VALUE

Prioritizes monitoring, assessment, and response options for each management unit

Feasible for ecosystem screening and prioritization; operational readiness depends on calibration and data coverage.

CAVEATS: CONDITIONS FOR FEASIBILITY

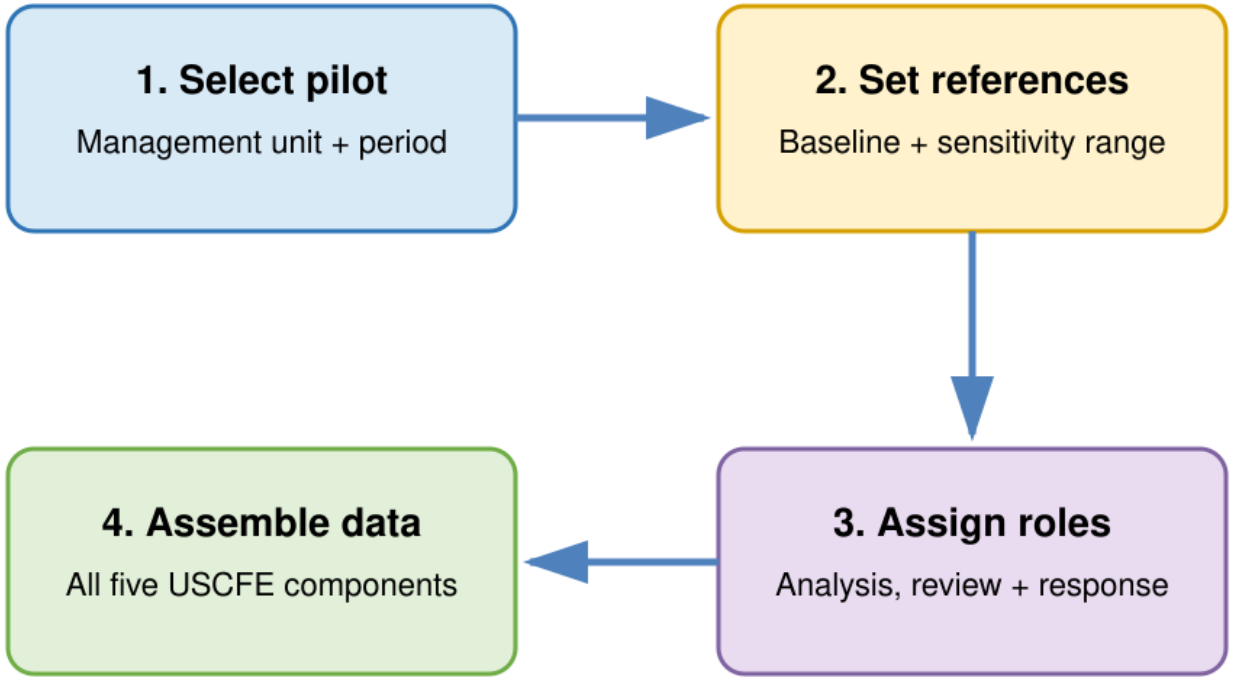
Readiness depends on data coverage, uncertainty treatment, actionable outputs, and implementation capacity.

LIMITATION		IMPLEMENTATION SAFEGUARD
DATA AVAILABILITY AND COVERAGE Coverage and resolution vary among components, surveys, years, and management units.	→	**GRADE CONFIDENCE BY DATASET** Analyze regions separately, document gaps, and lower confidence when coverage is incomplete.
SENSITIVITY AND UNCERTAINTY Baselines, thresholds, missing data, and correlations—not causal mechanisms—shape the signal.	→	**CALIBRATE BEFORE OPERATIONAL USE** Use retrospective analyses, sensitivity tests, and explicit uncertainty reporting.
CHANGE IS NOT A REFERENCE POINT Distances detect change but are not validated biological, ecosystem, or economic reference points.	→	**USE AS SCREENING, NOT A CONTROL RULE** Retain stock-assessment and regulatory processes for status determinations or harvest action.
PRACTICALITY AND GOVERNANCE Harmonization, recurring updates, expertise, and cross-agency responses require capacity.	→	**PILOT AND ASSIGN RESPONSIBILITIES** Define data owners, timelines, review criteria, referrals, and an adaptive update cycle.

Strongest for diagnosis and prioritization; weaker where coverage, causal evidence, or authority are limited.

TEST THE TOOL WITH A RETROSPECTIVE PILOT

- Start with one management unit and a period containing known ecosystem or fishery events; test rules without affecting current management.



QUESTIONS