An Operational EBFM Decision-Support Tool for the U.S. Caribbean

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A stepwise diagnostic framework linking multivariate ecosystem change to management interpretation and response

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SEDAR 103: U.S. Caribbean Application of Alternate Assessment Methods

Summary

Fisheries in the U.S. Caribbean are multispecies, multigear, spatially heterogeneous, and influenced by ecological, environmental, habitat, and human drivers. Yet most managed resources are assessed and regulated through single-species or stock-complex approaches, frequently under data-limited conditions. Cruz-Motta et al. (2026) demonstrated that multivariate analyses can describe spatial and temporal variation across five components of the U.S. Caribbean Fisheries Ecosystem (USCFE), identify the taxa and variables contributing to those patterns, and reveal potential drivers that differ among Puerto Rico (PR), St. Thomas/St. John (STT/STJ), and St. Croix (STX).

This working paper translates that analytical framework into a stepwise decision-support tool, within an adaptive management context. The process begins by screening five USCFE components for temporal change. The five components are fishery-dependent data (L), fishery-independent assemblage data (F), environmental and anthropogenic variables (E), habitat condition (H), and socioeconomic conditions (S). If one or more components exceed the screening threshold, the tool identifies which components changed and directs the assessment team to the appropriate component-specific or multi-component diagnostic pathway. Each pathway specifies data sources, analytical questions, management interpretation, and potential responses.

The tool is intended to guide annual or periodic screening, diagnosis, prioritization, and coordination. It does not estimate stock status, produce acceptable biological catches (ABCs) or annual catch limits (ACLs), establish causation, or replace a single-species assessment (SSA). In addition, modeling approaches here, are used to described current patterns and not to forecast or predict reference points, indexes and or conditions. Instead, it identifies when an SSA or another form of assessment may be warranted, which species or complexes should receive priority, what ecosystem information should accompany that assessment, and when monitoring, socioeconomic analysis, habitat action, or interagency coordination may be the more appropriate response. The illustrative 10% screening threshold is retained only to demonstrate the decision logic and must be calibrated and reviewed before operational use.

1. Introduction

The island-based fishery management plans recognize that PR, STT/STJ, and STX differ ecologically, environmentally, culturally, and socioeconomically. The multivariate description of the USCFE developed by Cruz-Motta et al. (2026) supports this area-specific approach as the three management units exhibited distinct ecosystem states, temporal trajectories, and potential drivers. At the same time, the region manages a large number of species with limited assessment and monitoring capacity. A practical decision-support process is therefore needed to identify where additional assessment, monitoring, or management attention can provide the greatest value from available resources.

The USCFE should not be treated as a homogeneous regional system. Its three management units—and the regions and fishing communities within them—differ in environmental exposure, habitat composition and condition, biological assemblages, fishing practices, markets, social dependence, and monitoring coverage. These differences can produce locally distinct or even opposing trajectories that become muted when observations are averaged across broad spatial units (Cruz-Motta et al., 2026; Seara et al., 2024; Heim et al., 2021). The decision-support tool treats this heterogeneity and diversity as management-relevant information: diagnoses are conducted at the finest defensible spatial scale and integrated only after data comparability and spatial correspondence have been evaluated.

Within this heterogeneous system, the five USCFE components may be connected through ecological, fishery, and human-system pathways (Figure 1). Environmental and anthropogenic drivers may affect habitat and biological assemblages; habitat and assemblage change may alter resource availability and catchability; landings affect livelihoods and markets; and fishing and coastal activities may feed back to biological, habitat, and environmental conditions. The proposed connections are hypotheses to evaluate rather than assumed causal relationships (Levin et al., 2009; Seara et al., 2024).

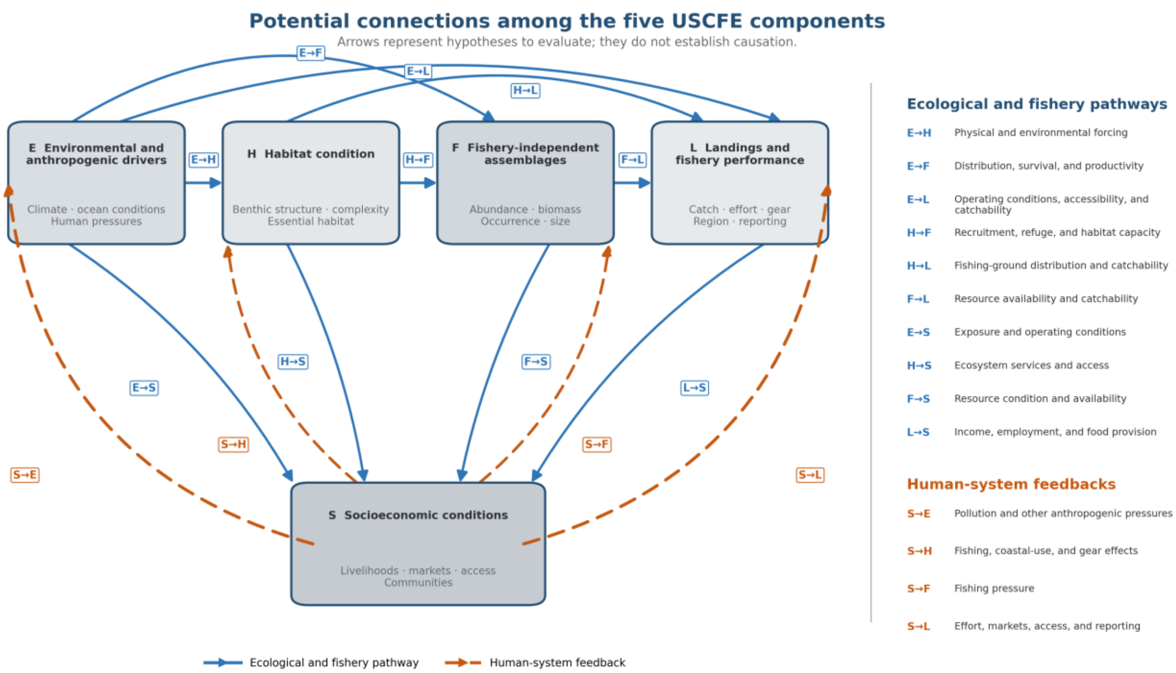

Figure 1. Conceptual connections among the five USCFE components. Solid blue arrows represent potential ecological and fishery pathways, whereas dashed orange arrows represent potential human-system feedbacks. Connections are hypotheses to be evaluated using temporal, spatial, and cross-component evidence; they do not establish causation.

NOAA Fisheries defines ecosystem-based fisheries management as a systematic approach to fisheries management in a geographically specified area that contributes to the resilience and sustainability of the ecosystem, recognizes physical, biological, economic, and social interactions, and seeks to optimize benefits among diverse societal goals (NOAA Fisheries, 2024a, 2024b). Consistent with that policy, this tool treats biological reference points as one possible management product rather than the sole endpoint. Changes in habitat, environmental exposure, ecological structure, fishing behavior, access, markets, or community vulnerability may warrant management attention even when the available evidence does not support a change in catch limits.

The framework also complements stakeholder-driven conceptual models developed for the U.S. Caribbean, which demonstrate that fishers, scientists, managers, and other groups perceive interacting ecological and human drivers differently (Seara et al., 2024). A transparent decision sequence provides a common structure for evaluating those different forms of evidence without treating correlation as causation or requiring every pathway to end in a regulatory action.

2. Objective and Scope

The objective is to conduct a comprehensive diagnosis of the USCFE within each management unit using a documented sequence of analytical steps, management interpretations, and potential responses. The tool is designed to answer the following operational 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?

The immediate output is therefore not an ACL or ABC. Depending on the pathway, the output may be routine monitoring, a data-quality investigation, enhanced sampling, an assessment priority, an integrated biological review, a socioeconomic or vulnerability analysis, a precautionary review, an evaluation of management measures, or referral to another authority, among many others. Some of the responses delineated in this tool, constitute analytical or management approaches that will be discussed on their own during SEDAR 103 (e.g. Socio-Ecological System Diagnostic, Ecosystem reference Points)). A complete list of possible analyses, diagnostics, assessments and management procedures is provided in the accompanying Glossary.

3. Operating Framework

3.1 Review cycle and management units

The process should begin when the information required for a new analytical cycle becomes available. In an annual implementation, the release of a new landings year would ordinarily initiate the cycle, while fishery-independent, habitat, environmental, and socioeconomic components would be updated according to their sampling schedules. For this purpose, a "year" or analytical cycle is the interval between successive releases of the principal annual dataset. When a component is not sampled annually, the tool should use the most defensible common review period and clearly identify temporal mismatches.

Analyses should be conducted separately for PR, STT/STJ, and STX, and at finer spatial scales (e.g. regions within management units) when sample size and design permit. Regional separation (whenever possible) is ideal because a management unit average/centroid can conceal local change, opposing trajectories, or differences in exposure and vulnerability (Heim et al., 2021)

3.2 Data inputs and analytical foundation

The tool organizes available information into five components: L, F, E, H, and S. Each component is represented by an observation-by-variable matrix or matrices and analyzed using transformations, standardization, and a distance or dissimilarity measure appropriate to the data. Bray–Curtis dissimilarity is generally suitable for biological/ecological structure/composition and landings matrices, whereas normalized Euclidean distance is generally suitable for continuous environmental, anthropogenic, habitat, or socioeconomic variables; Gower distance may be considered when socioeconomic data contain mixed variable types (Legendre and Legendre, 2012).

The core analytical products include resemblance matrices, temporal non-metric multidimensional scaling (nMDS), tests or effect-size descriptors of multivariate separation, decomposition of dissimilarities, coherent-species analyses, univariate trajectories, and methods that evaluate correspondence among matrices or constrain multivariate patterns using explanatory variables. The appropriate combination may include ANOSIM, PERMANOVA, SIMPER, RELATE, BIOENV/BVSTEP, DISTLM, CAP, or equivalent procedures (See Glosary). These methods diagnose patterns and associations; they do not by themselves demonstrate a causal mechanism.

3.3 Data-quality and comparability prerequisites

Although data quality is not a separate branch in the eight-step tree, every analytical cycle requires a documented quality and comparability review before Step 1 is interpreted. The assessment team should evaluate completeness, sampling effort, taxonomic consistency, changes in reporting or survey methods, spatial coverage, temporal resolution, detection limits, and the comparability of observations across datasets. A signal attributable to a method or reporting change should be corrected, qualified, or converted into a data-improvement priority rather than treated as ecosystem change.

For cross-component analyses, observation units must be aligned. For example, if L contains more years than F, the comparison should use the common years or an explicitly justified temporal aggregation. The information lost through alignment, and any differences in survey footprint or habitat coverage, must be recorded as limitations.

3.4 Relationship to assessment and management

The decision tree presented here is a screening and prioritization framework that complements, but does not replace, accepted stock-assessment and management procedures. Where L and F provide concordant evidence for a managed species or complex, the tool can elevate that resource for an SSA or alternate assessment and provide hypotheses, covariates, spatial context, and uncertainty for the assessment team. Where evidence instead indicates habitat degradation, environmental exposure, socioeconomic stress, or an ecological change dominated by non-target species, the appropriate response may lie outside an SSA and, in some cases, outside CFMC jurisdiction.

Any proposed change in catch, effort, gear, season, area, access, or other regulatory measure would continue through the CFMC, NMFS, territorial, scientific-review, and statutory processes. The decision-support tool identifies what deserves review and why; it does not authorize the final action.

4. Decision-Support Sequence

The operational tool comprises eight sequential steps. Steps 1 and 2 screen for change and identify the affected component or components; Steps 3–7 provide component-specific diagnostics; and Step 8 integrates evidence when two or more components change.

Step 1. Screen for temporal change

> **Decision rule:** If all USCFE components show temporal change below the selected screening threshold (illustratively, 10%), continue routine monitoring. If any component exceeds the threshold, proceed to Step 2.

Explanation:

The magnitude of temporal change is estimated using a distance or dissimilarity measure appropriate for each data type. Bray–Curtis dissimilarity is commonly used for biological assemblage and fisheries data because it is not influenced by joint absences (Clarke, 1993; Clarke and Gorley, 2015). Euclidean distance is generally appropriate for normalized environmental, anthropogenic, and socioeconomic variables. Because numerous distance and dissimilarity measures are available, the most appropriate metric should be selected by the assessment team based on the characteristics of each dataset and reviewed in consultation with the Scientific and Statistical Committee (SSC) (Legendre and Legendre, 2012). The selected metric, data transformation, standardization, and baseline period should be specified before conducting the assessment. Dissimilarity and distance matrices can be evaluated using non-parametric procedures such as ANOSIM and permutation-based multivariate procedures such as PERMANOVA (Anderson, 2001; Clarke and Gorley, 2015). Details of the suite of multivariate analyses that can be performed are provided by Cruz-Motta et al. (2026).

When change is expressed across multiple correlated variables, a single multivariate analysis can be more informative and powerful than separate univariate analysis (Anderson and Santana-Garcon, 2015). In a multispecies analysis, evaluating the assemblage as a whole also avoids conducting a separate analysis for every species and the associated multiple-testing problem (Clarke, 1993; Legendre and Legendre, 2012).

Figure 2 provides a theoretical example of how the Step 1 screening rule can be evaluated using a Bray–Curtis dissimilarity matrix and the corresponding temporal nMDS trajectory.

Bray–Curtis dissimilarities identify magnitude of change and triggers Step 2

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

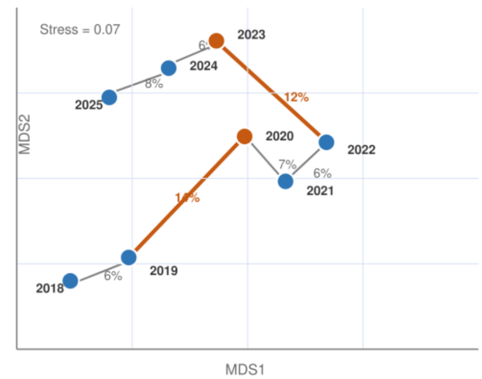

Figure 2. Hypothetical Step 1 screening example. Panel A shows Bray–Curtis dissimilarity among years, with adjacent-year changes exceeding the illustrative 10% threshold highlighted. Panel B shows the temporal nMDS trajectory derived from the same resemblance matrix. Values are illustrative and are not empirical estimates for the U.S. Caribbean fisheries ecosystem.

Questions requiring discussion for all steps

What should constitute the temporal reference?

Should the 10% threshold be evaluated relative to:

1.1. The immediately preceding year: A comparison with the previous year would provide an early-warning indicator of abrupt annual change but could be sensitive to anomalous years.

2.2. A predefined historical reference period, represented by its multivariate centroid: comparison with a predefined multiyear centroid would provide a more stable reference but might detect gradual change less rapidly.

3.3. Both: annual dissimilarity for early detection and distance from the historical centroid to evaluate persistent or cumulative change.

1. **How should the threshold be established?**

The 10% threshold used in this working paper is illustrative and should not be interpreted as a validated reference threshold or an automatic management trigger. An operational threshold should be developed through retrospective analyses, sensitivity testing, and consultation with scientists, managers, the SSC, fishers, and other relevant stakeholders. Different thresholds may ultimately be appropriate for different ecosystem components, datasets, or management areas.

Step 2. Identify the component or components showing change

For each component, determine whether the estimated temporal change exceeds the selected screening threshold:

1. ***Only fishery-dependent data (landings) show change*:** proceed to Step 3.
2. ***Only fishery-independent data (the entire surveyed fish assemblage) show change:*** proceed to Step 4.
3. **Only environmental and/or anthropogenic variables show change:** proceed to Step 5.
4. **Only habitat structure and composition show change:** proceed to Step 6.
5. **Only socioeconomic variables show change:** proceed to Step 7.
6. **Two or more components show change:** proceed to Step 8

Step 3. Only fishery-dependent data change (L)

3.1 Data sources

Catch reports by fishers (landings) and TIP. These datasets are provided by territorial agencies to SEFSC.

3.2 Analytical approach

1. 1. For landings data, use coherent-species analyses and decomposition of dissimilarities to identify the species or species complexes responsible for the multivariate change.
2. 2. Examine species-specific time series to determine: the direction of change; its magnitude; whether it is abrupt or gradual; whether it is persistent; and whether it is concentrated in a particular fishing region.
3. 3. Disaggregate the data by gear, and/or fishing region when sample sizes permit.
4. 4. Correlate with TIP data.

Figure 3 illustrates how a landings-only signal can be decomposed to identify the taxa, trajectories, fishing regions, and gears contributing to the detected change.

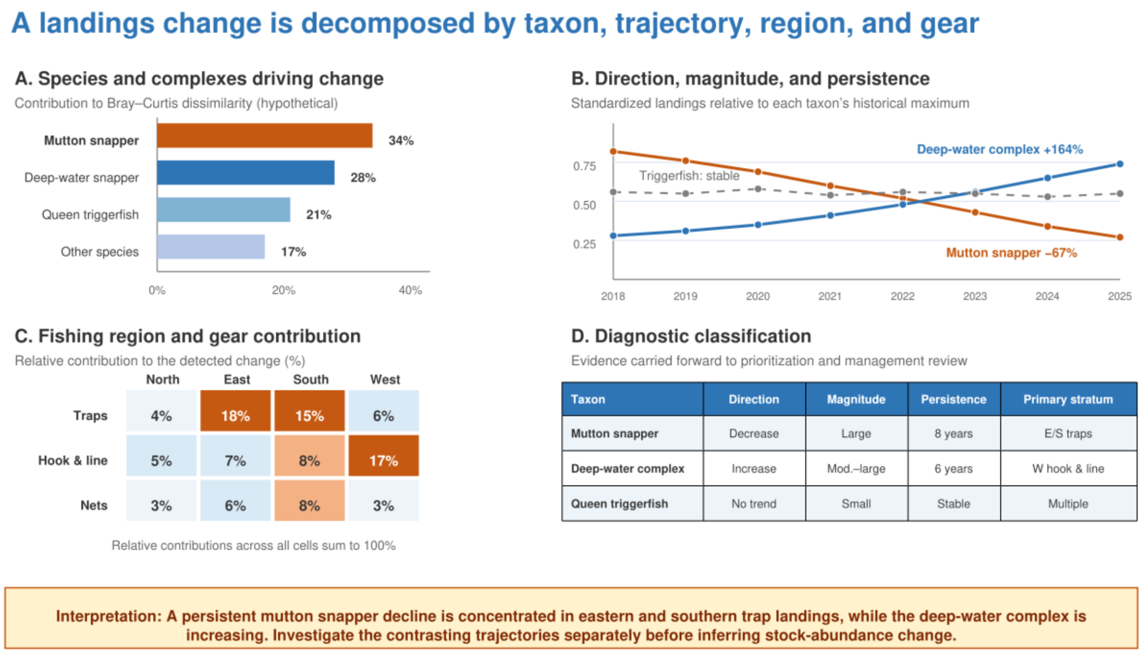

Figure 3. Hypothetical Step 3 landings diagnostic. The example combines taxon-level contributions to Bray–Curtis dissimilarity, standardized temporal trajectories, relative contributions by fishing region and gear, and a diagnostic classification of direction, magnitude, and persistence. All values and taxa are illustrative.

3.3 Management interpretation

A change in landings alone should initially be interpreted as a fishery-performance signal rather than direct evidence of a change in stock abundance. The signal may reflect changes in fishing effort, gear use, access, fisher behavior, port sampling or reporting, markets and other socioeconomic conditions, or regulations. Because landings and catch-per-unit-effort are jointly influenced by abundance, catchability, fishing practices, management, and reporting, additional diagnostic information is required before the change can be attributed to stock status (Harley et al., 2001; Maunder and Punt, 2004).

3.4 Potential responses

Potential responses at this level include:

1. 1. Prioritization and identification of species for potential future SSAs.
2. 2. Investigate effort
3. 3. Investigate reporting/enhance monitoring
4. 4. Investigate management measures

These diagnostics can help direct limited assessment resources toward the species or complexes for which an SSA or alternate assessment is most warranted.

Step 4. Only fishery-independent assemblages change (F)

4.1 Data sources

PRCRMP, TCRMP, NCRMP and SEAMAP-C. Others that can be applied for specific regions, management areas and time periods. Also recreational fisheries data can be evaluated.

4.2 Analytical approach

This pathway examines the entire surveyed assemblage, including commercially important and non-target species. Each fishery-independent monitoring program should first be assessed independently using standardized, temporally consistent data and analytical techniques comparable to those in Step 3.2. Determine whether the detected change is survey-specific or supported by multiple programs within comparable spatial, habitat, taxonomic, and temporal domains. Analyses may be conducted at several spatial scales: by management unit (PR, STT/STJ, and STX), by region within each management unit, and by smaller areas within regions when the design and data permit. When multiple stations are sampled within a management unit or region, temporal comparisons may be based on the corresponding multivariate centroids, provided the sampling design remains comparable. Potential outcomes:

Outcome 4A - Only one program shows change: validate the signal and conduct a program-specific diagnostic.

Outcome 4B - Programs change discordantly: evaluate spatial heterogeneity and methodological comparability/standardization before recommending management action.

Outcome 4C - Multiple programs change concordantly: the concordant evidence supports an integrated diagnostic of broader biological change. The integrated diagnostic compares standardized rates of change across programs rather than pooling raw observations from surveys with different methods. The integrated diagnostic will determine:

1. 1. Overall magnitude of change
2. 2. Direction of change
3. 3. Spatial extent if data can be disaggregated at smaller spatial scale.
4. 4. Identify the species responsible for the assemblage change.
5. 5. Group species identified in 4 according to:
    1. a) commercial importance;
    2. b) trophic or functional role;

2. c) vulnerability;

6. 6. Determine whether changes are related to: biomass, abundance, occurrence or size structure.

Analytical approaches 1, 2 and 4 are similar to those applied in step 3.

Figure 4 illustrates how evidence from NCRMP, SEAMAP-C, PRCRMP, and TCRMP can be evaluated within management units and then synthesized across programs.

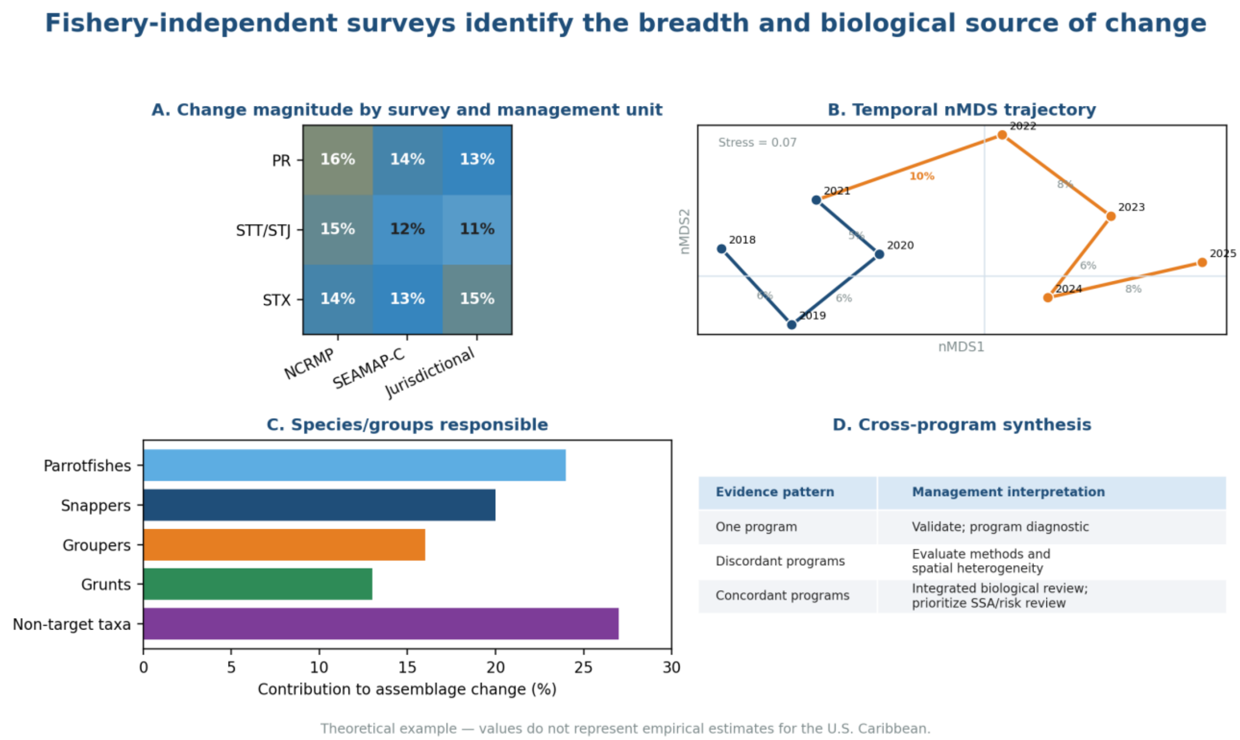

Figure 4. Hypothetical Step 4 integrated fishery-independent diagnostic. Panels show program-by-management-unit change, a connected temporal nMDS trajectory, species or functional groups contributing to change, and the corresponding cross-program interpretation. Values are illustrative.

4.3 Management interpretation

In general, changes detected only in fishery-independent assemblage data should be interpreted as ecological diagnostic signals rather than direct evidence of stock status. If the signal involves a managed species, stable landings could be maintained temporarily by changes in effort, fishing location, catchability, or fisher behavior and therefore may not contradict the fishery-independent signal. If non-target species or functional groups are responsible, it may indicate alteration of ecosystem structure or function, including changes in prey availability, predator abundance, competition, species distributions, among others. The management relevance depends on the ecological relationships between the affected non-target species and the managed resources. Also, if a strong, persistent decline in a vulnerable or functionally important group could support a precautionary review before the change becomes evident in commercial landings. A precautionary review is a structured evaluation initiated when a persistent, widespread, or biologically consequential change in species or group of species (either of commercial or ecological importance) is identified only in the fisheries independent data, but available evidence is insufficient to support a definitive management conclusion (Link, 2005; Levin et al., 2009; Shin et al., 2010).

4.4 Potential responses

1. 1. Prioritization and identification of species for SSA.
2. 2. Investigate effort
3. 3. Investigate reporting/enhance monitoring
4. 4. Investigate management measures
5. 5. Evaluate biodiversity and functional indicators;
6. 6. Examining trophic or multispecies consequences;
7. 7. Identifying sentinel species;
8. 8. Developing ecosystem-level indicators.

Note: Responses 1 to 4 are similar to responses in step 3.

Step 5. Only environmental and/or anthropogenic variables change (E)

5.1 Data sources

The environmental database requires routine updating. Cruz-Motta et al. (undr review) compiled 19 environmental variables from publicly available datasets. These variables were grouped into: 1) Static, those that do not change in time, for example distance to the nearest river and 2) Variable: those that change through time, for example Sea Surface Temperature (SST). This data set is compiled for each sampling station where there is fishery independent data. The variables and compilation procedures are detailed in Cruz-Motta et al. (under review). Caveat: The current compilation extends through 2022 and should be updated to match the temporal coverage of landings and fishery-independent data.

5.2 Analytical approach

The analytical tools are similar to those used in Steps 3 and 4. The principal differences are the distance metric among observations—typically Euclidean distance—and the procedures used to normalize and standardize the data. Because the variables have different units and ranges, normalization is required before analysis. The analysis will identify:

1. Overall magnitude of change
2. Direction of change
3. Spatial extent if data can be disaggregated at smaller spatial scale.

4. Whether the change is:
    1. episodic, such as a hurricane or heatwave;
    2. cyclical;
    3. spatially localized; or
    4. persistent and directional.
5. The variables responsible for change: for example, SST, productivity, turbidity, rainfall, storms, pollution index, or population.

Figure 5 illustrates the diagnostic attributes used to distinguish environmental events from persistent directional change.

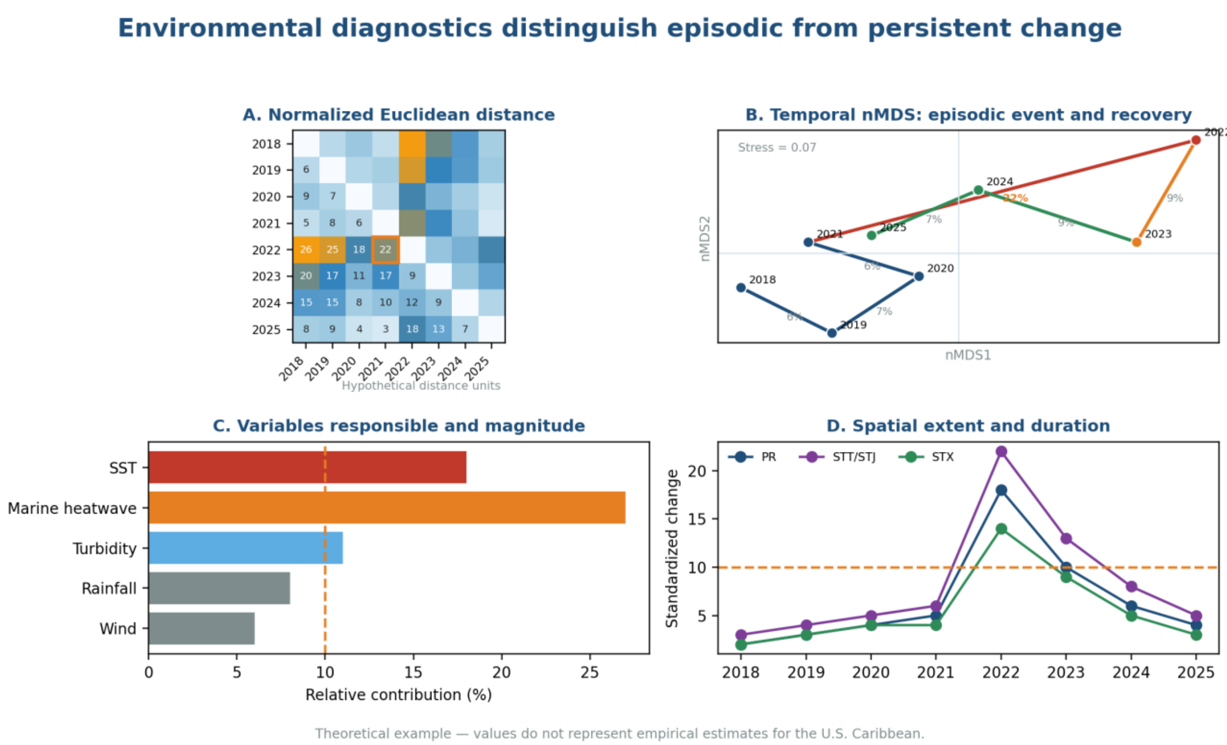

Figure 5. Hypothetical Step 5 environmental diagnostic. Normalized Euclidean distances and temporal nMDS are paired with variable contributions and management-unit trajectories to evaluate direction, magnitude, spatial extent, duration, and episodic versus persistent behavior. Values are illustrative.

5.3 Management interpretation

Environmental change alone will trigger a risk assessment and vulnerability analysis rather than changes to reference points or catch limits. The objective of the risk assessment will be to determine risks posed by changes in the specific variables identified in the analysis to the ecosystem, groups of species and fisheries. The vulnerability analysis will identify, habitats, species or group of species and fishing communities most vulnerable to changes in variables identified by the analysis. The absence of an immediate biological response should not be interpreted as absence of risk because ecological responses may be delayed (Hare et al., 2016; Holsman et al., 2019).

5.4 Potential responses

1. Increase biological and fishery monitoring
2. Identify vulnerable species, habitats, or fishing communities;
3. If SSAs are conducted, consider additional temporary precautionary buffers to reference points when risks and/or vulnerability are high;
4. Incorporate environmental covariates (identified by this analysis) into SSAs;
5. Use these covariates to develop Ecosystem Reference Points (ERPs) and
6. Develop or update an Ecosystem Status Report (ESR)
7. Depending on the identified variable, coordinate and liaise with other environmental and coastal-management authorities.

Step 6. Only habitat changes (H)

6.1 Data sources

PRCRMP, TCRMP, NCRMP (Benthic assemblages)

6.2 Analytical approach

The analyses are similar to those in Section 4.2, but the response matrix represents the structure and composition of benthic assemblages. Variables are relative percentage cover of larger taxonomic and/or functional groups, such as (but not limited to): hard coral, macroalgae, encrusting octocorals, branching octocorals, sponges, CCA and others. This database also contains information on rugosity and habitat heterogeneity. The analysis will:

1. Estimate magnitude of change
2. Describe direction of change
3. Identify scale of change and whether the change affects nursery habitat, spawning areas, essential fish habitat, migration corridors (if known), or fishing grounds.
4. Which habitat variables are responsible for the observed change.
5. Identify which fish species or group of species, functional groups, and fisheries depend on the affected habitat.

Figure 6 illustrates how habitat change can be linked to the variables responsible, its persistence, spatial footprint, and overlap with fisheries-relevant habitat.

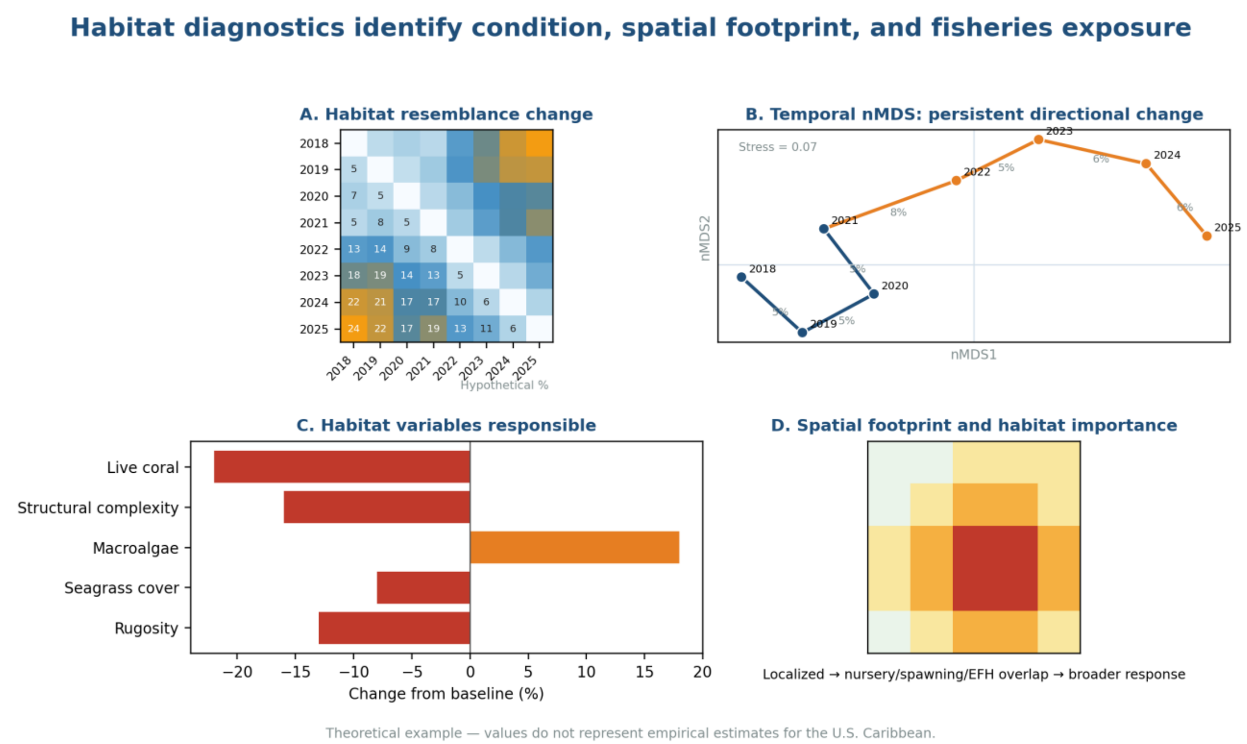

Figure 6. Hypothetical Step 6 habitat diagnostic. The example combines multivariate habitat change, a connected temporal nMDS trajectory, variable-specific changes, and a theoretical spatial footprint indicating potential overlap with nursery, spawning, or essential fish habitat. Values are illustrative.

6.3 Management interpretation

A habitat-only signal is a warning of altered ecosystem capacity and may indicate future effects on recruitment, survival, productivity, connectivity, and carrying capacity before changes become detectable in fish populations or landings. The management interpretation will depend on the direction, magnitude, spatial extent, persistence, ecological importance, and reversibility of the habitat change, as well as the exposure and vulnerability of managed species. Because many habitat stressors and interventions fall partly or entirely outside CFMC jurisdiction, the principal management output may be a formal referral or coordinated response involving territorial agencies, NOAA habitat programs, EPA, coastal-zone programs, protected-area managers, or other authorities (Gratwicke and Speight, 2005; Levin et al., 2009; NOAA Fisheries, 2022).

6.4 Potential responses

1. EFH review;
2. Spatial protection or modification of fishing practices that damage habitat;
3. Identify Restoration or disturbance-response priorities;
4. Protection of nursery or spawning habitat;
5. Anchoring, coastal-development, pollution, or water-quality interventions; and

6. Incorporation of habitat condition into future risk assessments, buffering and/or SSA.

Step 7. Only socioeconomic conditions change (S)

7.1 Data sources

Multiple socioeconomic studies are available for the region, including community profiles, social-indicator products, and fishery-specific analyses (Clay and Colburn, 2020; NOAA Fisheries, 2026). However, these studies have not been compiled into single databases with consistent observations across multiple and continuous years.

7.2 Analytical approach

The complete time-series analysis cannot yet be implemented because the available socioeconomic observations are not compiled consistently across years. If those data are assembled, analyses similar to those in Step 5 should:

1. Estimate magnitude of change
2. Describe direction of change
3. Identify which indicators changed, such as (but not limited to) fishery engagement, reliance, vulnerability, income, employment, costs, market access, fleet participation, food security, or perceptions of resource status.
4. Identify which communities, ports, fleets, gears, or demographic groups are affected.
5. Whether the change reflects:
    1. resource conditions;
    2. management regulations;
    3. fuel or operating costs;
    4. market disruption;
    5. infrastructure loss;
    6. demographic change;
    7. access restrictions; or
    8. an external disturbance.
6. Whether the change is temporary, persistent, or unevenly distributed.
7. Whether LEK or stakeholder information supports the interpretation.

Figure 7 illustrates how socioeconomic change can be separated into indicator contributions and uneven effects among fleets and communities.

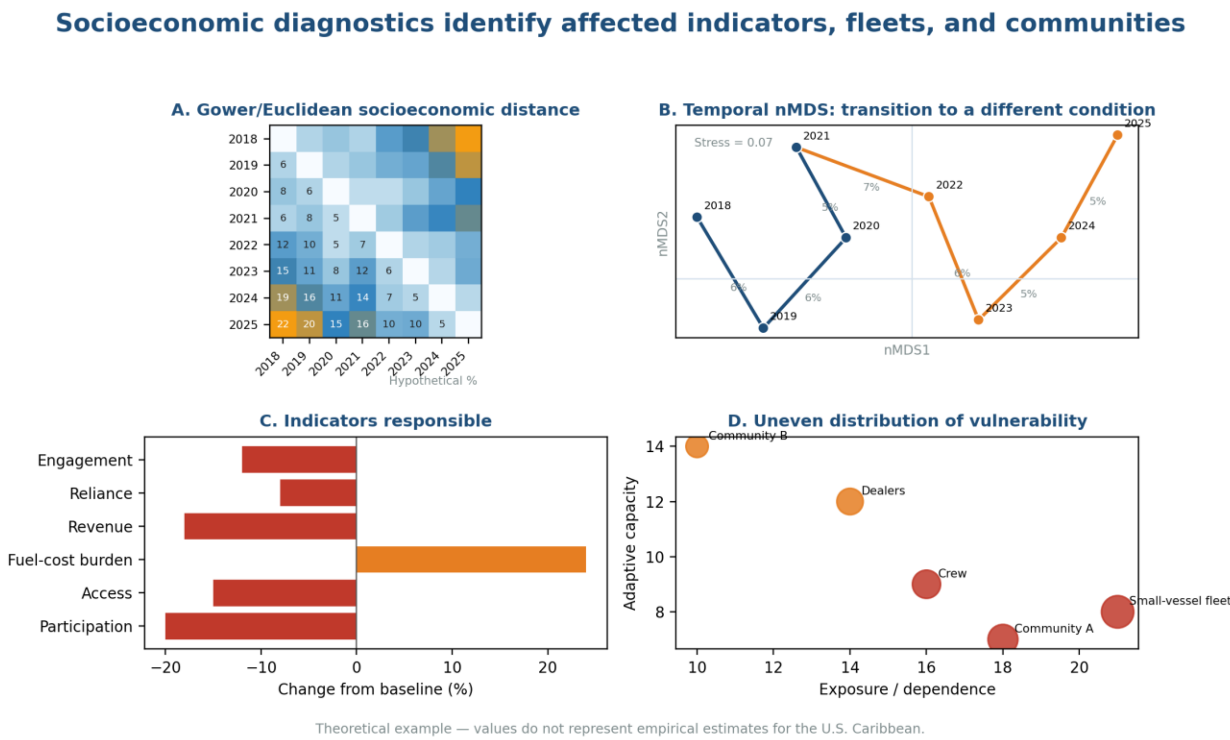

Figure 7. Hypothetical Step 7 socioeconomic diagnostic. Gower or normalized Euclidean distances and temporal nMDS identify a transition in socioeconomic condition; indicator changes and an exposure–adaptive-capacity plot identify the groups most affected. Values are illustrative.

7.3 Management interpretation

A socioeconomic-only signal represents change in the human dimension of the fishery and should not, by itself, be interpreted as biological or ecosystem deterioration. The change may reflect markets, operating costs, access, participation, labor, infrastructure, regulations, demographics, community vulnerability, or data-reporting effects. A socioeconomic change alone would not normally justify changing a biological reference point. It may, however, affect the choice, design, timing, and distributional consequences of a management action. A socioeconomic signal should prompt evaluation of whether current management remains practical, equitable, and consistent with community objectives (Clay and Colburn, 2020; NOAA Fisheries, 2024c).

7.4 Potential responses

1. Perform a Fishery Performance Report (FPR) which will integrate quantitative socioeconomic indicators with stakeholder observations
2. Perform a social and/or economic impact analysis;
3. Evaluate the modification of management implementation schedules;
4. Improved access or permit flexibility where legally appropriate;
5. Mitigation assistance;
6. Protection of subsistence or culturally important fishing practices;

7. Review of enforcement and compliance implications; and

8. Systematic collection of socioeconomic and LEK information.

Step 8. Two or more components change

This pathway indicates a USCFE change detectable in more than one component, regardless of whether the components showing change interact or whether a causal relationship can be demonstrated. Since there are five components, there are 26 possible combinations involving two or more components. Consequently, listing all 26 as independent decision-tree branches would become difficult to manage. In this sense, four tiers were developed here. **Data sources** for all scenarios are the same as those mentioned in all previous steps. The analytical approaches detailed below should be conducted in addition to those described above for each component that changed.

Figure 8 summarizes the evidence hierarchy and the principal management endpoint for each multiple-component pathway.

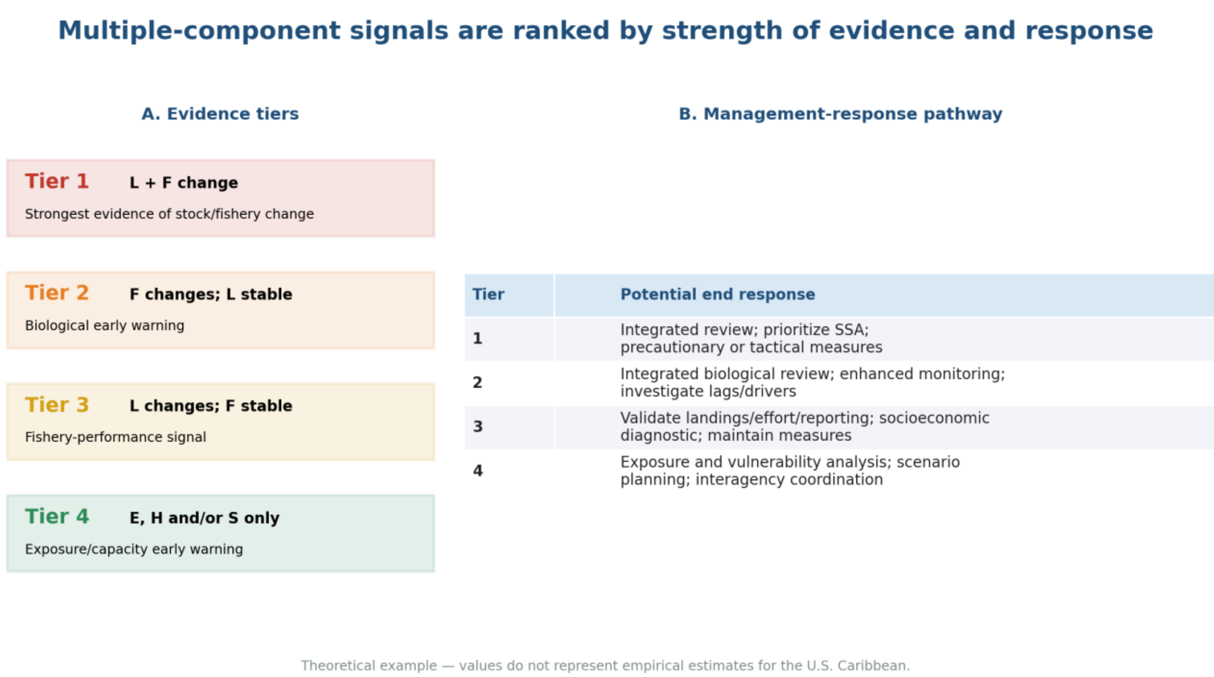

Figure 8. Step 8 evidence-tier and response synthesis. Tier 1 provides the strongest evidence of stock and fishery change; Tiers 2–4 progressively emphasize biological early warning, fishery-performance diagnostics, and ecosystem or human-system exposure. Responses should be proportional to persistence, magnitude, vulnerability, and uncertainty.

Tier 1 (Step 8.1). L and F change

This tier includes any combination in which landings (L) and fishery-independent data (F) change, ranging from L + F only to all five components. This is the strongest outcome suggesting change in one or more managed populations.

8.1.1 Analytical approach

1. Identify whether patterns of temporal variation are correlated between L and F. This is done using RELATE.
2. Identify whether the same species drive changes in L and F. This is done through coherent-species analyses and decomposition of dissimilarities. And determine whether both signals have the same direction.
3. Conduct the analyses above independently for abundance, biomass, and size structure.
4. Analyze whether fishing effort, regulations, markets, or reporting could explain part of the landings change;
5. If another component changes in addition to L and F, evaluate whether environmental (E), habitat (H), or socioeconomic (S) patterns provide plausible mechanisms or context for the observed L and F changes. Appropriate methods may include BIOENV, DISTLM, constrained ordination, or structural equation modeling when the data and design support them.
6. Develop and compare alternative hypotheses for the correlations identified among components.
7. Integrate quantitative results with LEK, and expert judgment.
8. Comparability requirement: Cross-component analyses must use matched observations. If L contains more years than F, the analysis should use the common years or an explicitly justified aggregation. The resulting loss of temporal information must be documented.

Figure 9 illustrates how BIOENV and a constrained multivariate ordination can be used together to identify plausible environmental correlates of the landings signal.

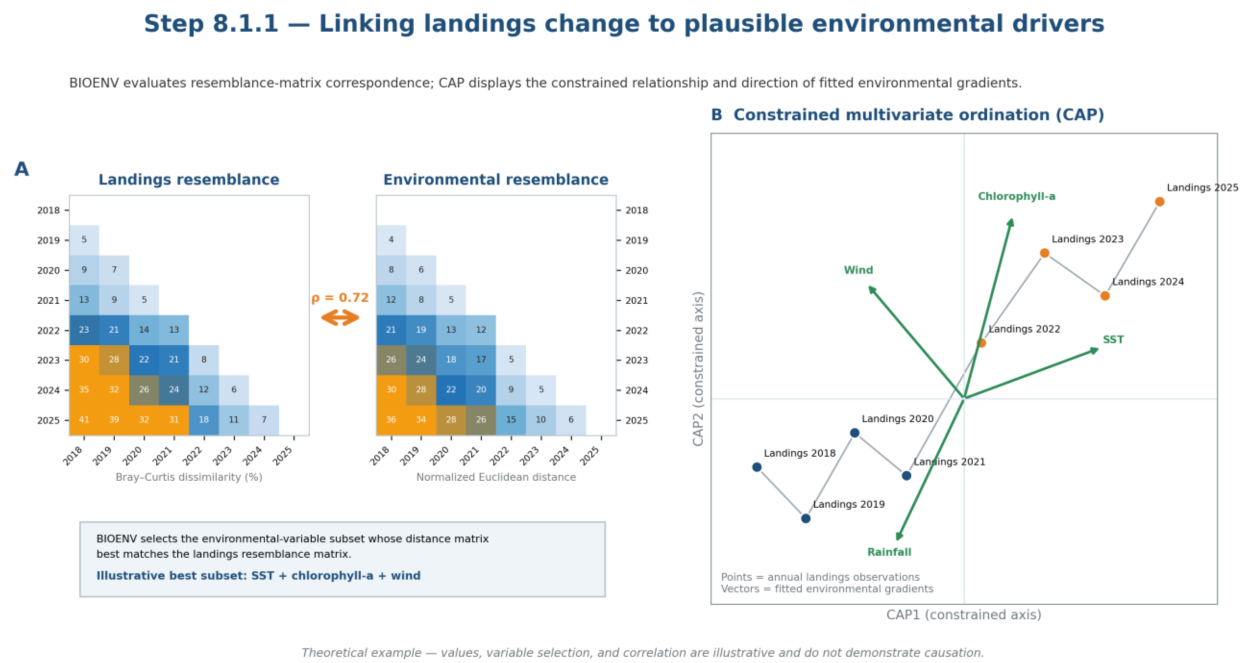

Figure 9. Hypothetical Step 8.1.1 BIOENV and constrained-ordination diagnostic. Panel A compares the Bray–Curtis resemblance matrix for annual landings observations with a normalized Euclidean-distance matrix for the environmental variables. BIOENV identifies the environmental-variable subset producing the strongest rank correspondence between matrices. Panel B presents a constrained multivariate ordination (CAP) in which annual landings observations are displayed as points and fitted environmental variables as vectors. Vector direction indicates the direction of increasing values and vector length indicates the relative strength of association with the constrained ordination. Values, variable selection, and correlation are illustrative and do not demonstrate causation.

8.1.2 Management interpretation

Concordant L and F changes provide the strongest evidence that the detected pattern may represent a biologically meaningful change in managed resources. The result does not automatically establish that overfishing is occurring or that a stock is overfished, whoever it identifies which species or species complex has to be prioritized. As such, this outcome should trigger a species- or complex-specific review and may justify assessment prioritization and eventually an SSA on selected species. If E and/or H also change, potential drivers of change can be identified and proposed as indicators. They can also be parametrized and included in the SSAs. If S is also changing, it may represent either a potential driver or a consequence of changes in L and F (Levin et al., 2009; Samhouri et al., 2014).

8.1.3 Potential responses

Specific responses will depend on the analytical results. Table 1 provides illustrative responses for selected Tier 1 conditions.

Table 1. Illustrative Tier 1 response options

Tier 1 condition	Potential response
Change is recent or uncertain	Validate data and enhance monitoring,
Persistent but moderate change	Prioritize species for future SSA
Persistent decline in managed species	Initiate SSA on identified managed species
Widespread decline with high vulnerability	Implement immediate precautionary measures while SSA is completed.
Assessment confirms fishing-related risk	Modify catch, effort, gear, seasonal, or spatial measures
Environment or habitat is the main driver	Combine any measure above with habitat or interagency action
Severe socioeconomic consequences	Conduct an SIA and develop mitigation measures
Multiple species and functional groups change	Conduct an integrated ecosystem review rather than only a SSA

Tier 2 (Step 8.2). F changes, but L does not

This tier provides moderate-to-strong evidence of biological or ecological change, but weaker evidence that it has affected the fishery.

8.2.1 Analytical approach

1. Identify species, functional groups, life stages (if possible), and regions responsible.
2. Determine whether managed or non-target species drive the change.
3. Compare survey changes with effort-standardized fishery indicators.
4. Test for temporal lags between biological change and landings.
5. If E and/or H also change, evaluate environmental and habitat correspondence and identify potential drivers.
6. If S changes, determine whether socioeconomic conditions explain stable landings or reveal increased effort or operational adaptation; apply the relevant analyses from Step 7.

8.2.2 Management interpretation

A persistent fishery-independent change may represent an early biological warning that has not yet propagated to landings. If managed species drive the signal, this step may approach the previous step in management importance. If non-target species drive it, the interpretation is primarily ecological and can serve as a guide to direct ecological research applied to fisheries in the region. In general this step does not establish that fishing is causing changes in managed species. If E and/or H are also changing it might also identify potential drivers of change which could give context to the management actions. If S is changing, it could provide explanations of stable landings (Link, 2005; Shin et al., 2010).

8.2.3 Potential responses

1. As per step 4, proceed to an integrated biological review across fishery independent datasets.
2. Identify reasons for stable landings, which might include (but not limited to):
    1. Fishing effort increased to maintain catch;
    2. Fishers shifted locations or depths;
    3. Catchability increased because fish aggregated;
    4. Fishers changed gears or target species;
    5. Imports or markets altered fishing behavior;
    6. Regulations constrained reported landings;
    7. Species-complex reporting concealed species-specific decline;
    8. Landings are aggregated across management units;
    9. Survey and fishery spatial domains do not overlap;
    10. Biological change has not yet reached harvestable size classes;
    11. Landings respond with a temporal lag;
    12. Reporting quality changed.
3. If E and/or H are also changing:
    1. Determine vulnerability or adaptive capacity of species responsible for change.
    2. Avoid increasing fishing pressure or modify buffers in areas of greater exposure to potential E and H drivers.
4. If S is changing:
    1. Conduct Socioeconomic diagnostic.
    2. Prepare or update a Fishery Performance Report.
    3. Engage affected fishers, dealers, and communities.
    4. Evaluate distributional effects among management units, fleets, gears, and communities.
    5. Conduct an SIA if management alternatives are considered.

Tier 3 (Step 8.3). L changes, but F does not

This tier provides evidence of fishery change but limited evidence of stock change.

8.3.1 Analytical approach

1. Identify species, fleets, gears, ports, regions, and seasons responsible.
2. Standardize landings by available measures of effort.
3. Examine prices, markets, operating costs, access, and participation.
4. Evaluate changes in regulations and reporting.
5. Determine whether environmental or habitat changes altered distribution or catchability.
6. Investigate possible mismatches between survey coverage and fishing grounds.

8.3.2 Management interpretation

The combined signal indicates a change in fishery performance or behavior but does not independently establish a change in stock abundance. Management should initially focus on identifying fishery, socioeconomic, regulatory, environmental, or habitat mechanisms before considering stock-related restrictions. Changes in landings may result from fishing effort, regulations, market demand or prices, access to fishing grounds, infrastructure, reporting, or gear or target switching. If E and/or H also change, those effects may not yet be detectable as assemblage changes in F. Of particular importance are changes in S. L + S without F may indicate a human-fishery problem requiring management attention despite relatively weak evidence of stock change (Harley et al., 2001; Maunder and Punt, 2004).

8.3.3 Potential responses

1. Validate and disaggregate landings by species, management unit, gear, region, season, and sector.
2. Evaluate changes in fishing effort, participation, reporting, regulations, markets, prices, access, and infrastructure.
3. Assess the statistical power and spatial coverage of fishery-independent surveys for the species, habitats, depths, and fishing grounds involved.
4. Conduct targeted or cooperative research where fishery and survey domains do not overlap.
5. If E and/or H also change, evaluate whether redistribution, aggregation, habitat effects, or altered catchability explain the landings signal.
6. If S also changes, prepare or update a Fishery Performance Report and conduct a socioeconomic diagnostic; conduct an SIA if management alternatives are proposed.
7. Maintain existing measures and enhance monitoring when the change is recent or uncertain.
8. If a persistent decline remains unexplained, prioritize a species-specific risk analysis or SSA and avoid increasing fishing pressure until uncertainty is reduced.

Particularly important combination - L + S: Landings and socioeconomic change without fishery-independent change may indicate reduced participation or effort, market disruption, infrastructure loss, increased operating costs, changed access, or regulatory effects.

Tier 4 (Step 8.4). E, H, and/or S change without L or F

This tier provides the weakest direct evidence of stock change but potentially important evidence of changing ecosystem exposure, capacity, or community vulnerability. The absence of a currently detected biological response should not be interpreted as absence of risk.

8.4.1 Analytical approach

1. As per the component-specific pathways. Determine direction, magnitude, spatial extent, and persistence.
2. Evaluate whether environmental and habitat changes are mechanistically related.
3. Identify managed species potentially exposed to changes in E and H.
4. When S changes, evaluate potential consequences to S due to changes in E and H.

8.4.2 Management interpretation

Any combination of changes in these components (E, H and S) represent an ecosystem or human-system early warning rather than direct evidence of stock change. Specific interpretations will depend on the combination of components that are changing (Levin et al., 2009; Samhouri et al., 2014).

1. **E + H:** Environmental forcing may be altering habitat condition or ecosystem capacity.
2. **E + S:** Environmental conditions may be affecting fishing communities or operations before biological effects are detectable.
3. **H + S:** Habitat change may be affecting access, operations, infrastructure, or community well-being
4. **E + H + S:** Broad ecosystem exposure with potential human consequences, but no detectable biological or landings response yet

8.4.3 Potential responses

1. Perform an exposure and vulnerability analysis.
2. Enhance biological monitoring.
3. Perform scenario development.
4. Start interagency coordination.

5. Applications of the Method

5.1 Hypothetical application

Assume that the annual diagnostic for STT/STJ shows landings dissimilarity above the selected screening threshold. The signal persists during a second cycle, and fishery-independent monitoring shows a concordant decline in a commercially important predator. Decomposition of dissimilarities and coherent-species analyses identify mutton snapper as a principal contributor; species-specific trajectories show declining biomass; habitat data indicate a concurrent increase in macroalgae; and systematically collected LEK reports reduced availability in specific fishing regions.

1. The data-quality review confirms that the result is not explained by changes in reporting, survey methods, taxonomic treatment, or spatial coverage.

2. Because both L and F change, the case enters Tier 1 (Step 8.1); H provides additional context.
3. The team evaluates whether the same species, direction, years, and spatial domains drive the L and F patterns and whether fishing effort or reporting could explain part of the signal.
4. Mutton snapper is evaluated for assessment priority using fishery importance, contribution to change, vulnerability, ecological role, available data, and assessment feasibility.
5. The immediate output is an SSA with explicit ecosystem covariates and spatial hypotheses—not an automatic ACL reduction.

This example illustrates the relationship between the EBFM tool and an SSA: the tool identifies where attention is warranted and supplies ecosystem context, while the assessment estimates stock status and informs any catch-limit process.

5.2 Governance and implementation

A pilot implementation could be embedded within the CFMC Fishery Ecosystem Plan and synchronized with an annual or biennial ecosystem-status review. The analytical team would prepare component-specific outputs and a decision record for each management unit. A technical review involving CFMC, NMFS, territorial agencies, relevant monitoring programs, social scientists, the SSC, and stakeholder representatives would evaluate the assessment as currently done if a SSA is conducted.

The decision record should identify the review period, spatial unit, datasets, transformations, resemblance measures, baseline, threshold, data-quality findings, affected components, species or variables responsible, evidence tier, LEK or stakeholder evidence, uncertainty, competing explanations, jurisdiction, selected response, responsible body, and re-evaluation date. Recording dissenting interpretations is important when evidence is partially concordant or management consequences are substantial. Repeating the process creates an adaptive-management record through which thresholds, indicators, and responses can be evaluated and revised (Edmondson and Fanning, 2022).

6. Caveats and Safeguards

The following limitations define how the tool should be interpreted and implemented:

1. Pattern-based inference: multivariate analyses identify temporal and spatial patterns and associations, not causal mechanisms. Drivers should be described as plausible or potential until targeted analyses support stronger inference.
2. No forecasting: the present framework does not predict future stock, fishery, or ecosystem states. Prospective evaluation of candidate strategies requires management strategy evaluation or another operating-model approach.

3. Threshold sensitivity: results may depend on the screening threshold and temporal reference. Candidate thresholds and baseline definitions should be evaluated retrospectively and through sensitivity analyses before formal adoption.
4. Data inconsistency: changes in program design, sampling effort, spatial footprint, reporting, or taxonomy can generate apparent change. Each cycle requires a documented data-quality and comparability review.
5. Unequal temporal resolution: socioeconomic and some ecological datasets are sparse or nonannual. Analyses must use defensible common periods and report information lost through temporal alignment.
6. Jurisdiction: habitat, pollution, coastal-development, restoration, and some social responses may fall outside Council authority. The output should identify the responsible authority and coordination mechanism rather than imply Council control.
7. Institutional capacity: routine application will require analytical time, standardized data delivery, documented review roles, and possibly changes to existing schedules. A retrospective pilot should precede formal implementation.
8. Assessments teams not currently trained to perform some of the analysis listed in this decision tool.
9. Some pathways need to be evaluated within the MSA and might require to be adapted to such legislation.

7. Recommended SEDAR 103 Discussion Items

1. Confirm the role of the tool as screening, diagnosis, and prioritization support rather than a replacement for accepted stock assessments. Note that most of the branches do not lead to a SSA.
2. Select the initial review frequency and temporal-reference strategy for each management unit and component.
3. Define a process for calibrating component-specific screening thresholds and for evaluating persistence, magnitude, and independent confirmation.
4. Determine minimum data-quality and comparability standards, including how changes in landings reporting, TIP, and monitoring-program methods will be handled.
5. Agree on how species or complexes will be prioritized for SSA or alternate assessment using contribution to change, fishery importance, vulnerability/risk, LEK, ecological role, data availability, and assessment feasibility.
6. Identify a pilot management unit and retrospective period for testing the complete eight-step sequence.

8. Conclusions

The proposed decision-support tool provides an operational bridge between ecosystem description and management application. Its principal value is not a new model of stock dynamics, but a transparent and repeatable method for detecting change, diagnosing the affected component or components, integrating diverse evidence, prioritizing limited analytical resources, and directing each issue toward the appropriate assessment or management pathway. This proposed tool also acknowledge the heterogeneity and diversity of the USCFE and takes into consideration not only the managed resources, but also the context in which these resources operate.

The framework can be piloted immediately as a screening and triage process, provided that thresholds remain provisional, data quality and comparability are reviewed, and regulatory decisions continue through the applicable assessment and management standards. Repeated implementation can support management-unit-specific ecosystem indicators and, where scientifically justified, the longer-term development of ecosystem-level reference points (Morrison et al., 2024). Application of this framework guide decisions that not necessarily have to finish in a SSA. Finally, the accumulated diagnostic record could ultimately inform operating models, management strategy evaluation, socio-economic decisions and adaptive ecosystem-level strategies while preserving the essential role of SSAs for estimating stock status.

References

Anderson, M. J. (2001). A new method for non-parametric multivariate analysis of variance. Austral Ecology, 26, 32–46. https://doi.org/10.1111/j.1442-9993.2001.01070.pp.x

Anderson, M. J., and Santana-Garcon, J. (2015). Measures of precision for dissimilarity-based multivariate analysis of ecological communities. Ecology Letters, 18, 66–73. https://doi.org/10.1111/ele.12385

Appeldoorn, R. S. (2011). Reef resources, the fog of fisheries and ecosystem-based management. In L. Fanning, R. Mahon, and P. McConney (Eds.), Towards Marine Ecosystem-Based Management in the Wider Caribbean (pp. 147–156). Amsterdam University Press.

Clarke, K. R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18, 117–143. https://doi.org/10.1111/j.1442-9993.1993.tb00438.x

Clarke, K. R., and Gorley, R. N. (2015). PRIMER v7: User Manual/Tutorial. PRIMER-E.

Clay, P. M., and Colburn, L. L. (2020). A Practitioner's Handbook for Fisheries Social Impact Assessment. NOAA Technical Memorandum NMFS-F/SPO-212. https://doi.org/10.25923/xm1m-x732

Cruz-Motta, J. J., 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.

Edmondson, E., and Fanning, L. (2022). Implementing adaptive management within a fisheries management context: Gaps, challenges, and ways forward. Sustainability, 14, 7249. https://doi.org/10.3390/su14127249

Gaichas, S. K., et al. (2018). Implementing ecosystem approaches to fishery management: Risk assessment in the U.S. Mid-Atlantic. Frontiers in Marine Science, 5, 442. https://doi.org/10.3389/fmars.2018.00442

Gratwicke, B., and Speight, M. R. (2005). The relationship between fish species richness, abundance and habitat complexity in a range of shallow tropical marine habitats. Journal of Fish Biology, 66, 650–667. https://doi.org/10.1111/j.0022-1112.2005.00629.x

Hare, J. A., Morrison, W. E., Nelson, M. W., et al. (2016). A vulnerability assessment of fish and invertebrates to climate change on the Northeast U.S. Continental Shelf. PLOS ONE, 11, e0146756. https://doi.org/10.1371/journal.pone.0146756

Harley, S. J., Myers, R. A., and Dunn, A. (2001). Is catch-per-unit-effort proportional to abundance? Canadian Journal of Fisheries and Aquatic Sciences, 58, 1760–1772. https://doi.org/10.1139/f01-112

Heim, K. C., Thorne, L. H., Warren, J. D., Link, J. S., & Nye, J. A. (2021). Marine ecosystem indicators are sensitive to ecosystem boundaries and spatial scale. *Ecological Indicators, 125*, 107522. https://doi.org/10.1016/j.ecolind.2021.107522

Holsman, K. K., Hazen, E. L., Haynie, A., et al. (2019). Towards climate resiliency in fisheries management. ICES Journal of Marine Science, 76, 1368–1378. https://doi.org/10.1093/icesjms/fsz031

Legendre, P., and Legendre, L. (2012). Numerical Ecology (3rd English ed.). Elsevier.

Levin, P. S., Fogarty, M. J., Murawski, S. A., and Fluharty, D. (2009). Integrated ecosystem assessments: Developing the scientific basis for ecosystem-based management of the ocean. PLOS Biology, 7, e1000014. https://doi.org/10.1371/journal.pbio.1000014

Link, J. S. (2005). Translating ecosystem indicators into decision criteria. ICES Journal of Marine Science, 62, 569–576. https://doi.org/10.1016/j.icesjms.2004.12.015

Marshall, K. N., et al. (2018). Ecosystem-based fisheries management for social-ecological systems: Renewing the focus in the United States with next-generation fishery ecosystem plans. Conservation Letters, 11, e12367. https://doi.org/10.1111/conl.12367

Maunder, M. N., and Punt, A. E. (2004). Standardizing catch and effort data: A review of recent approaches. Fisheries Research, 70, 141–159. https://doi.org/10.1016/j.fishres.2004.08.002

Morrison, W. E., Oakes, S. A., Karp, M. A., Appelman, M. H., and Link, J. S. (2024). Ecosystem-level reference points: Moving toward ecosystem-based fisheries management. Marine and Coastal Fisheries, 16, e10285. https://doi.org/10.1002/mcf2.10285

NOAA Fisheries. (2022). Essential Fish Habitat Consultation Guidance. https://www.fisheries.noaa.gov/national/habitat-conservation/essential-fish-habitat-consultations

NOAA Fisheries. (2024a). Ecosystem-Based Fisheries Management Policy. https://www.fisheries.noaa.gov/s3/2024-02/Revised-EBFM-Policy-FINAL-2.12.24-508-signed-JC.pdf

NOAA Fisheries. (2024b). Ecosystem-Based Fisheries Management Road Map. https://www.fisheries.noaa.gov/resource/document/ecosystem-based-fisheries-management-road-map

NOAA Fisheries. (2024c). Guidance for Conducting Economic and Social Analyses of Regulatory Actions. https://www.fisheries.noaa.gov/national/laws-policies/guidance-conducting-economic-and-social-analyses-regulatory-actions

NOAA Fisheries. (2026). Community Social Vulnerability Indicators: Supporting Information. https://www.fisheries.noaa.gov/national/socioeconomics/community-social-vulnerability-indicators-supporting-information

Peterson, C. D., and Walter, J. F., III. (2023). Southeast Fisheries Science Center Management Strategy Evaluation Strategic Plan. NOAA Technical Memorandum NMFS-SEFSC-766.

Samhouri, J. F., Haupt, A. J., Levin, P. S., Link, J. S., and Shuford, R. (2014). Lessons learned from developing integrated ecosystem assessments to inform marine ecosystem-based management in the USA. ICES Journal of Marine Science, 71, 1205–1215. https://doi.org/10.1093/icesjms/fst141

Seara, T., Williams, S. M., Acevedo, K., Garcia-Moliner, G., Tzadik, O., Duval, M., and Cruz-Motta, J. J. (2024). Development and analyses of stakeholder-driven conceptual models to support implementation of ecosystem-based fisheries management in the U.S. Caribbean. PLOS ONE, 19, e0304101. https://doi.org/10.1371/journal.pone.0304101

Shin, Y.-J., Bundy, A., Shannon, L. J., et al. (2010). Can simple be useful and reliable? Using ecological indicators to represent and compare the states of marine ecosystems. ICES Journal of Marine Science, 67, 717–731. https://doi.org/10.1093/icesjms/fsp287