

## Research Proposal

### Building a Fishery Ecosystem Plan for the U.S. Caribbean Region as a Guide for Implementing Ecosystem-based Fishery Management

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## **I. PROJECT NARRATIVE**

### **A. Project Description**

**Purpose:** To guide the development of a Fishery Ecosystem Plan for the U.S. Caribbean by defining management objectives and developing models that describe these marine ecosystems and help identify threats and factors that influence change across the region.

#### **Background**

During the fourth national scientific and statistical committee workshop in 2011, eight Science and Statistical Committee (SSC) members started a discussion directed at incorporating ecosystem considerations into the management of fisheries around the US (Seagraves & Collins 2012). Since then NOAA Fisheries developed a policy, roadmap and draft implementation plans to formalize its commitment to executing Ecosystem Based Fisheries Management (EBFM) across the Nation (Figure 1, National Marine Fisheries Service 2016). The main goal of the EBFM plan is to maintain ecosystem resiliency through six guiding principles. In the US Caribbean, the process needs to be multifaceted given the ecosystems are more complex due to the diverse array of habitats (i.e. seagrass beds, mangroves, coral reefs, pelagic and hard/soft sandy bottoms). Various Fisheries Management Councils (FMC) (e.g. Mid Atlantic, Pacific) have developed guidance documents to start an Ecosystem Approach to Fisheries Management (MAFMC 2016); however the Caribbean region has yet to start this process..

Current management of fisheries in the Caribbean is based on a species by species (or group of species) approach, with little (or no) consideration for the multi-specific nature of the problem (i.e. species in any fish assemblages are intrinsically and naturally correlated). Also, no consideration is given to the multivariable nature of potential drivers affecting/modulating fisheries resources and fish assemblages; and within this context, little consideration is given to the interaction between the two matrices of variables mentioned above (i.e. fish assemblages, and drivers) and the fisheries' socio-economic matrix (e.g. Cinner et al. 2016). Moreover, current methods developed for traditional stock assessment (i.e., those based on Maximum Sustainable Yield, MSY) have not performed well in tropical multi species fisheries associated with coral reef ecosystems (National Marine Fisheries Service 2016).

Fisheries-related data in the US Caribbean has traditionally been inadequate to run formal stock assessments. But even data-limited assessment methods require more information than is being acquired by currently existing sampling efforts. Regardless of potential critics to the process of data collection in the region, from an ecological point of view, tropical assemblages tend to be characterized by a wide-range of species. Under this scenario, it doesn't matter how intensive a sampling is, it will be very unlikely that we ever sample enough numbers of individuals for all commercially exploited species in order to run traditional stock assessments. Consequently, an alternative approach to assess fisheries in the Caribbean is necessary which takes advantage of the multitude of currently and existing data obtained from ongoing and other similar activities. Therefore, adopting an EBFM approach in the Caribbean is of utmost importance.

With this background in mind, it has been proposed that the development of a Fisheries Ecosystem Plan (FEP) is a necessary precursor to help guide regional efforts to move to an EBFM

(WPRFMC 2009; Levin et al 2018). A Caribbean FEP will provide the framework within which to account for ecosystem interactions including environmental, physical, socio-economic, ecological and anthropogenic factors and will produce the necessary information to guide the development of future management and assessment efforts, which by definition will adopt a multi-species approach. In addition, this FEP will be built upon existing efforts, particularly on those that have produced considerable amounts of data.

Based on the Lenfest's FEP implementation guide, there are four questions (and five steps) that need to be answered in order to develop an effective FEP (Lenfest 2016):

- 1) Where are we now? (Scientific question)
- 2) Where are we going? (Stakeholders/Societal question)
- 3) How will we get there? (Managerial question)
- 4) Did we make it? (Scientific question)

Out of those four questions, the present proposal specifically deals with the first one (i.e. where are we now?), while still providing the building blocks to address questions 2, 3, and 4. In this project, we will take a novel approach by not only modelling stakeholder's perceptions, but also empirical data collected around Puerto Rico and the US Virgin Islands. The comparison of both models will allow us to identify the major recurrent drivers and threats in the fisheries systems. In addition, comparing the two models will highlight the gaps between the stakeholder's perceptions and quantitative models. In order to answer the first question of the Lenfest FEP implementation guide (i.e. where are we?), the following objectives will be addressed:

- 1) To develop both a conceptual and quantitative model that describes the Caribbean ecosystem within a fisheries context based on stakeholder perceptions and data collected, respectively;
- 2) To select and estimate indicators of the performance of the model under different conditions (threats, impacts, human activities, etc.);
- 3) For a final product, we will work with stakeholders by integrating results from both models to identify the main indicators and threats potentially affecting the fisheries systems.

These three objectives will be achieved using two complementary approaches: a) compiling expert opinion from a diverse array of stakeholders to create conceptual models and b) quantitative approach to analyze existing information. As detailed below, both approaches will complement each other. Also, those three objectives will be achieved per management region, which in the Caribbean includes: Puerto Rico, St. Thomas/St. John and St. Croix.

### **Context:**

Stakeholders and managers in the region are aware that the current approach to managing stocks using status determination criteria such as annual catch limits, are insufficient for the region (National Marine Fisheries Service 2016). In particular, the Caribbean Fisheries Management Council (CFMC) has long recognized the need to move to an EBFM approach that will account for the intrinsic characteristics of the tropical fisheries in the US Caribbean (CFMC, 1994, 1996). The roadmap to achieve an EBFM outline for the region has been identified as one of the first objectives (objective 1B) to **develop** a Caribbean FEP (C-FEP) (Fig. 1). A FEP can be considered

as a first step towards alternative management based on an ecosystem approach and it is expected that it will guide the implementation of EBFM. In particular, the proposed work will provide a solid scientific foundation to guide FEP development by incorporating all available data that potentially determines and influences the structure, composition and function of the ecosystem and the fishery; in conjunction with expert opinion and traditional knowledge of stakeholders in the region. This will ultimately allow a paradigmatic change of management practices in the region.

This project will include direct contact with stakeholders at all stages of the project (identifying initial indicators/drivers, providing weights to relationships, ground truthing results from model, etc.) and the success of this project will depend on stakeholder participation. As part of the process proposed here, we will be producing two pieces of extra information that will not contribute as components of the FEP, but that managers will find particularly relevant due to the detailed review of the data available in the region. First, we will be conducting a gap analysis, to determine what information is still missing, to help managers achieve and implement an EBFM; and second, all databases used in this project will be made available (whenever permitted or authorizations are given) to the general public (very likely through the CFMC). Participation of managers in this project will be of paramount importance because the system that we are trying to understand and model is very heterogeneous in space and variable in time; as such, long-term predictive models will be difficult to create. Consequently, managerial decisions derived from the information generated here, will have to be flexible and constantly adapt (i.e. adaptive management) to the heterogeneous and variable nature of the fisheries system of the US Caribbean.

Finally, it is important to mention that the work proposed here will be done concomitantly and in close relationship with other projects and tasks currently being developed by the Caribbean task force to implement an EBFM approach. The task force membership includes members of a wide array of federal, regional institutions, NGOs and academia, the majority of whom have been included in this proposal (see key personnel section below). These tasks include a risk analysis (RA; adapted from Hobday et al.; 2017) for Caribbean fisheries and an ecosystem status report (ESR) for coral reefs in the Caribbean. These tasks will provide important information for the activities to be developed within the scope of the present proposal and will also receive relevant data from the questions answered here. In particular, CFMC will also organize stakeholder engagement opportunities throughout the development of the FEP, which may contribute information to this project and/or interact with results from this project.

Overall, answers to the research questions posed in this proposal (see below) and fulfillment of the proposed objectives, will also directly contribute to Lenfest's steps 2 to 4 (i.e. where are we going?, how are we getting there? and did we make it?). In particular, results of qualitative activity 2 (Figure 2) will help answer "where are we going"; as one of the main products of these activities is the identification of strategic management objectives. Similarly, results from qualitative step 3 will help answer "how are we getting there"; since the conceptual model will provide the main road map to achieve an FEP. Finally, results from the qualitative and quantitative (step 4), will provide the foundation blocks to answer "did we make it", because the monitoring and constant assessment of the selected indicators will allow managers to discern whether the management objectives have been met or not.



Figure 1. EBFM guiding principles pyramid, illustrating the interconnected and interdependent nature of these major principles (taken from NOAA NMFS 2016).

## Research Questions

In order to achieve the objectives listed above, the following general questions need to be answered for Puerto Rico, St. Thomas/St. John and St. Croix:

1. What is the perceived structure and connectedness of ecosystem components that represent each of the 3 management regions in the Caribbean as collected and analyzed from stakeholder perspectives?
2. What is the structure and connectedness of ecosystem components that represent each of the 3 management regions in the Caribbean as collected and analyzed from available biotic, abiotic, and socioeconomic data?
3. What are the relationships between the results stemming from the stakeholder perspectives and data-driven analyses of Caribbean ecosystems in each of the 3 management regions?

For each of those general questions the following specific questions will also be addressed:

*Development of a conceptual model based on stakeholder perceptions:*

1. What are the main components identified by stakeholders of the fishery and ecological systems in each of the management regions?
2. What are the main indicators and threats that the stakeholders identified as the most important?
3. Have the stakeholders perceived any temporal or spatial trend in the main components? If positive, what do they propose are the causes (i.e. drivers)?

*Development of a quantitative or structural model:* specific research questions in this category will greatly depend on the development of a conceptual model (questions above), as the conceptual model will generate relevant hypotheses to be tested using the quantitative approach. Nevertheless, and regardless of what those specific hypotheses are, the following questions will have to be answered to develop the quantitative model.

1. What are the temporal and spatial trends (and associated variability) of the following ecological and social data sources: a) fisheries independent surveys data, b) landings, c) Trip Interview Program (TIP), d) environmental variables (e.g. habitat, temperature, salinity, depth, etc.), e) socio-economic variables and f) anthropogenic/natural stressors?
2. For each one of the data sources described above, what are the main drivers (variables or group of variables) responsible for the patterns of spatial/temporal trends described above?
3. Are there correlations among trends of the different data sources?

*Validation and comparative study of the conceptual and quantitative models*

1. What are stakeholders' perceptions of both ecosystem components and their connections across the Caribbean and how do these perceptions compare to the quantitative analyses?
2. What are the gaps between the stakeholder perceptions and data analyses?
3. Is there a monitoring program that could be established which would include all variables identified above?

## **Research Methods and Analyses**

Research questions will be addressed following two parallel strategies (Figure 2) in order to achieve the three central objectives of this proposal (i.e. build both a **conceptual and quantitative model, identify main threats and indicators, and compare models**). These two sequences are mostly independent, however, information derived in qualitative step 3 will be necessary for quantitative steps 2 and 3 (Figure 2). Similarly, information generated in steps 4 will be concomitantly interchanged between the qualitative and the quantitative approach (Figure 2).

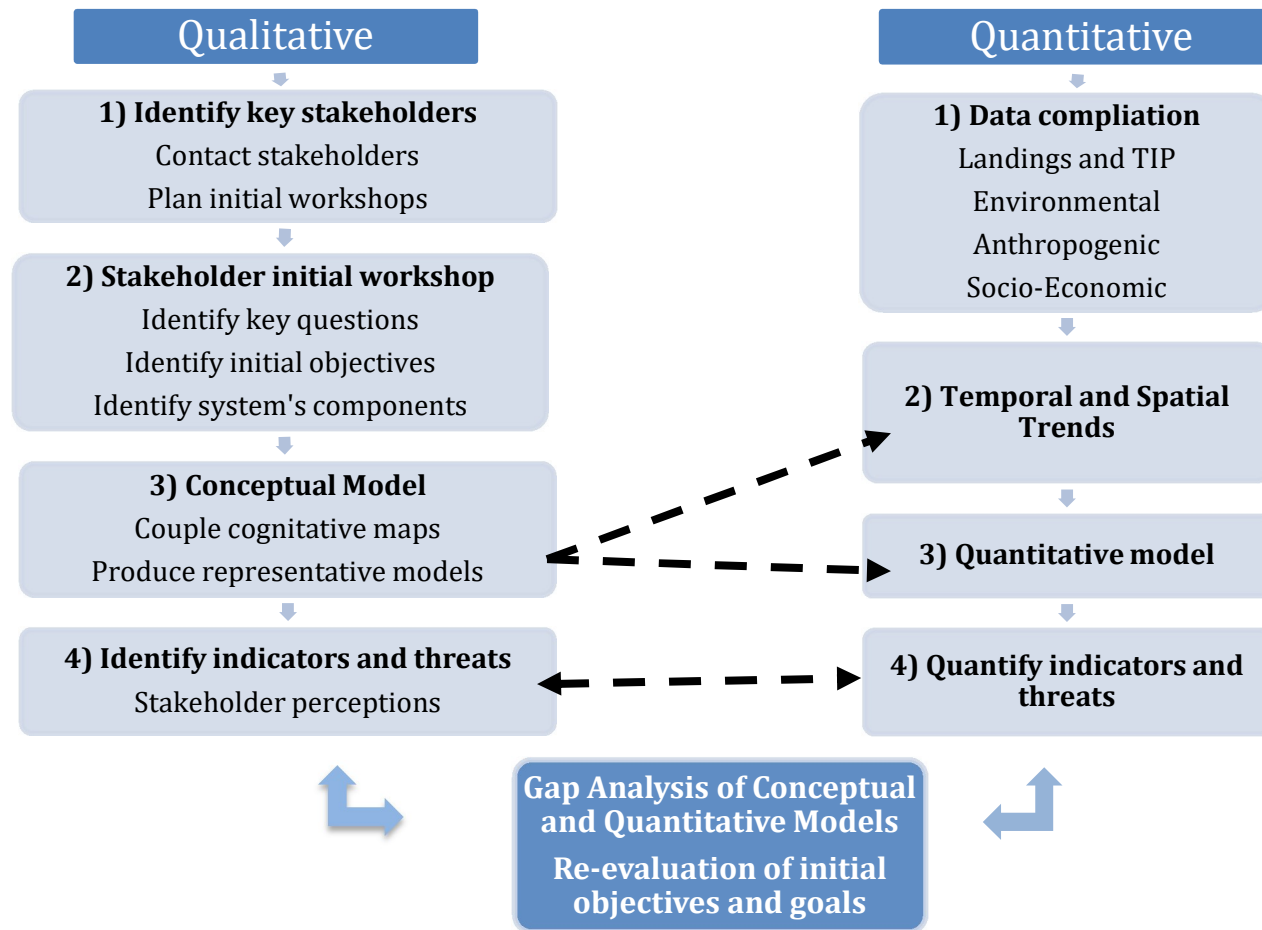


Figure 2. Flowchart showing main research steps for the qualitative (left) and quantitative approaches (right). Boxes across columns (i.e. processes) are not paired and do not have to occur concomitantly. However, dashed lines indicate information that will be transferred between the two processes.

*Qualitative approach:*

**1) Stakeholder engagement and planning:** The CFMC is developing an EBFM engagement strategy for the U.S. Caribbean region and activities described in this proposal will complement the efforts that the CFMC are already conducting. Those stakeholders identified as participants in that engagement strategy will be grouped according to their area of expertise and/or interest. All stakeholders will be contacted individually. This first planning step is crucial for the project as all interested and related parties must be included in the process, and redundant activities must be avoided. In this sense, members of various regional and federal agencies (NOAA, CFMC, DRNA, DPNR, etc.) have been included in the present proposal.

**2) Stakeholders Workshops:** In addition to workshops and meetings conducted by CFMC (such as the 2019 meetings of the SSC and DAP groups), we are proposing to conduct four initial workshop to cover all 3 management areas within the US Caribbean: 2 in Puerto Rico (Region East, San Juan and Region West, Cabo Rojo), 1 in St. Thomas/St. John and 1 in St. Croix (Table 1). Stakeholder groups will consist of (but are not limited to): Managers from DRNA and DPNR, members of the various federal agencies related to fisheries, NGOs (including those that have co-managing roles in the region), local and regional government, fishers, private sector, academia, and members of the public who have an interest in the issues addressed. These initial workshops will be used primarily to familiarize stakeholders with the objectives of the project and to initiate exchange of ideas between participants. During the initial workshops, general information about participants' characteristics, background, and interests will also be obtained through the use of short questionnaires. This information will be used to more appropriately plan and structure the approach used during the second round of workshops during which stakeholders will draw their cognitive maps (see below). Specific goals of the initial workshops are to: 1) present stakeholders with an unrelated example of a fuzzy cognitive map that will be used to explain the process and expected outputs of the qualitative approach; 2) collect information on stakeholders' characteristics and background (e.g. age, occupation), as well as interests driving participation in the project; 3) promote interaction among participants to facilitate collaborations and discussion in subsequent workshops. These initial steps are important in ensuring success of all subsequent steps of the qualitative approach which depend significantly on engagement by participating stakeholders and group collaboration. Key individuals interested in participating in the project but who are unable to attend these workshops will be individually contacted (in person or by phone) to receive all relevant information and provide their feedback which will be incorporated in the final output.

**3) Construct a conceptual model:**

The development of stakeholder driven conceptual models will be achieved through a multi-step fuzzy cognitive mapping approach based on Ozesmi and Ozesmi (2004). This method will allow for the organization and visualization of key system components and relationships among them based on stakeholders' perceptions and input. The construction of conceptual models will take place over a series of four one-day workshops to cover all management areas of the US Caribbean (same distribution as the first series of workshops, Table 1). The composition of these

workshops should ideally mirror the first series of workshops, thus all participants will be asked to attend both series upon first contact. The total number of workshop participants as well as their overall characteristics will influence the approach taken during the construction of the cognitive models, which can be conducted as an overall group approach, through the use of subgroups, or individually. Information about participants' background and interests obtained during the first round of workshops will be used to assess group heterogeneity and guide potential subgrouping of stakeholders for construction of the models based on similarity. The subgroup approach will be favored to maximize affinity and collaboration while minimizing potential negative group and power dynamics. Subgroups are also preferred over the individual approach to increase efficiency of data analysis (i.e. fewer maps) as well as encourage collaboration and discussions within the small groups.

During these workshops, stakeholders (most likely working in subgroups) will first be asked to identify and list on a large piece of paper the main ecosystem and fisheries components that are important to them (e.g. fish, coral). They will also be asked to compile a separate list of any elements they perceive as affecting or being affected in a positive or negative manner by the components in the first list (e.g. pollution, income, regulations). Open-ended questions will be formulated to guide this process. Participants will then be asked to draw circles representing all listed components in the center of the paper. From those central elements, they will draw lines representing relationships between variables. They will be asked to determine in order: 1) the direction (represented by arrows); 2) whether it is a positive or negative relationship (represented by positive and negative signs); and 3) the magnitude [on a scale of 1 to 3 (1=low; 2=medium; 3=strong)] (Ozesmi and Ozesmi, 2004). During the construction of the models, more variables not initially listed may be added to the diagram until participants agree they have exhausted all relevant system components.

All maps constructed by subgroups (and possibly individuals) will be averaged to develop one single conceptual model (i.e. social cognitive map) for each region, resulting in three final models. The averaging process will involve the construction of an adjacency matrix identifying all variables included in all maps and relationships between them. The number of times each variable appears in different maps will also be quantified to identify key variables common to multiple stakeholder subgroups. During construction of social cognitive maps for each region, conflicting connections (with opposite signs and different degrees of magnitude) will weaken causal relationships and agreement will strengthen them to form a consensus map (Ozesmi and Ozesmi, 2004). The use of subgroups based on stakeholder similarity will also allow us to potentially analyze averaged maps by stakeholder group for comparison. An important challenge when using information from a wide array of stakeholders, is the heterogeneity of concepts and their meaning. For example, two different stakeholders could use the words "catch" or "production" to refer to the same variable. Therefore, to ensure clarity during the map averaging and analyses, any concepts potentially duplicated in this manner will be standardized with the input of stakeholders during the workshops. The final averaged maps will be presented during a final series of workshops (same distribution as the 2 previous workshops, Table 1) to be validated and will also be presented and discussed in a three-day workshop at SERO's headquarters.

Final social cognitive maps will provide a powerful visual tool to help analyze and interpret stakeholder perceptions and will serve to develop specific hypotheses to be tested using the

quantitative approach which will further contribute to the validation process of the conceptual models. Moreover, further analyses through a graph theoretical approach, using social network software such as UCINET, will help us investigate aspects related to the nature and complexity of relationships between variables as understood by key stakeholders. These analyses will allow for a more systematic interpretation and application of the conceptual models by identifying key variables (e.g. centrality) and patterns of relationships (e.g. density, hierarchy). Results of these analyses can be used to assist in the interpretation of the outcomes of potential intervention simulation (e.g. new regulations, stock collapse). This approach will also contribute to the development of a baseline of information that can be used in future research investigating temporal and spatial changes in key components of Caribbean fisheries.

**4) Identify indicators and threats:** this activity will directly feed from the results of the risk analysis currently being done by NOAA Fisheries and through the quantitative approach. Those results (RA and quantitative step 4) will be summarized and presented to key stakeholders, experts and managers in order to complete a preliminary list of indicators and threats of the fisheries systems in the US Caribbean, as perceived by local stakeholders. This list will be compiled concomitantly with the quantitative list described in the latter section, however they will be compared after completion. This activity will be done by members of the C-EBFM task force but will feed into the structure of this proposal. In addition, the complete list will be widely distributed via electronic means for further comments.

Table 1. Summary of characteristics, objectives, and expected outcomes of proposed workshops.

| <b>Workshop Type</b>                                   | <b>Duration/Scope</b>        | <b>Objectives</b>                                                                                                                                            | <b>Expected Outcomes</b>                                                                                                     |
|--------------------------------------------------------|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Stakeholder Workshop 1:<br>Introduction to Project     | 1-day, 1 per region (4)      | 1) Explain and present conceptual model development and expected outputs; 2) Collect information on participants; 3) Promote interaction among participants. | 1) Information to guide subsequent workshops; 2) Increased level of interest and participation among stakeholders.           |
| Stakeholder Workshop 2:<br>Constructing Cognitive Maps | 1-day, 1 per region (4)      | Development of stakeholder driven conceptual models.                                                                                                         | Fuzzy cognitive maps by stakeholder subgroup/individual.                                                                     |
| Stakeholder Workshop 3:<br>Validating Outputs          | 1-day, 1 per region (4)      | Present and validate final social cognitive maps created by averaging multiple maps by region.                                                               | Information to finalize and improve final cognitive maps by region.                                                          |
| SERO Workshops                                         | 3-day, SERO headquarters (1) | Validate and discuss final cognitive maps by region.                                                                                                         | 1) Feedback on methodology; 2) Strategies to apply results of the map into future management plans for the Caribbean region. |

### *Quantitative approach:*

**1) Data compilation:** all analyses will be done with existing databases, consequently the first step will be to compile as many databases as possible related to the following types of information: 1) fisheries independent data, 2) fisheries dependent data (with emphasis on landings and TIP data), 3) natural environmental variables (including habitat), 4) anthropogenic stressors and 5) socio-economic (Table 2). This work will be based on efforts that the Caribbean EBFM task force has started and include (but not limited to) the databases and sources of information listed in the section *Data Sets* detailed below (Table 3). Table 3 is by no means a complete table of what is available and it is the intention of this project to expand that list. Consequently, an important component of this step is to identify and compile new sources of data that could contribute to this project. This data compilation will be done for all three management areas of the US Caribbean: Puerto Rico, St. Thomas/St. John and St. Croix. All analytical approaches described below will be performed per management area and they will take into consideration the various sampling designs used by the various sampling programs from which the data were derived. Data sources will be categorized into three main categories: Response variables, Predictor variables and Socio-Economic variables (Table 2). Socio-Economic was considered on its own as it will be considered as co-variables in the different models. Also, depending on the particular hypothesis been tested, it can be considered as a response or predictor variable. For example, market price can respond to a major natural impact (e.g. hurricane) but also drive structure and composition of catch.

Some databases consist of different sampling programs aiming at different suit of variables and that have different sampling designs. For example, SEAMAP-C database is composed by different sampling programs directed at different fish assemblages (e.g. snappers, conch, lobster, etc). Consequently, a data matrix will be produced per program and database and, as appropriate, it will be made public through the CFMC web page. A data matrix is a form of data presentation in which columns represent variables and lines represent cases or observations. Continuing with the SEAMAP-C example, a possible data matrix that can be extracted from the database; is one in which each column will represent a fish species and each line a sampling station and time. Each intersecting cell will represent the abundance of that particular fish species in that particular sampling station/time. Another data matrix that can be extracted from that database is one in which cells are filled with biomass instead of abundance. Overall, it is expected that various data matrices will be extracted from each database and that there will be various databases in each Type and Category (Table 2).

The compilation of data for the quantitative approach in itself constitutes an effort to address an existing gap of readily available information. Thus, uncertainty exists in terms data availability, consistency, and comparability. Due to a number of challenges that include cost and accessibility, this uncertainty is particularly poignant for Caribbean fisheries socio-economic data (Crosson and Hibbert 2016). In this study, it is anticipated that fisheries specific socio-economic data will be compiled from previous fishery census conducted in the region by Matos-Caraballo and Agar (2011) in Puerto Rico and by Kojis and Quinn (2011) in the USVI, and from other previous studies (e.g. Giffith and Valdes-Pizzini 2002, Kojis 2004, García-Quijano 2009, Matos-Caraballo 2009, Tonioli and Agar 2009, Valdes-Pizzini et al. 2010, Valdes-Pizzini et al. 2012, Griffith et al. 2013, García-Quijano et al. 2015, Crosson and Hibbert 2016, Seara et al. 2018).

Information will be compiled from published materials as well as by personal communication with social science researchers in the PIs and co-PI networks. Data is expected to provide the general makeup of fisheries participants in terms of general demographics (e.g. age, education), engagement and dependency on fisheries (aspects related to income and diversity of livelihood), as well as other aspects related to fishers' well-being when available. Appropriate levels of measurement, as well as spatial and temporal considerations will be determined and standardized within the constraints of the data obtained. Additionally, data from the national Census databases may be compiled to provide relevant information by municipality which can be useful in interpreting results of the quantitative approach.

Table 2. Categories, types and examples of databases. This table does not list all databases available.

| Category                   | Type                           | Examples                                                                                                                                                                       |
|----------------------------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Response Variables</b>  | <i>Fisheries Independent</i>   | -SEAMAP-C data: Abundance and Biomass of fish assemblages and some invertebrates.<br>-PR Coral Reef Monitoring Program (PRCRMP): Abundance and Biomass of fish assemblages     |
|                            | <i>Fisheries Dependent</i>     | -Landings: Abundance and Biomass of landings reported by fishers<br>-TIP: Abundance and Biomass of landings reported fisheries officials                                       |
| <b>Predictor Variables</b> | <i>Environmental</i>           | -CARICOOS: continuous reports on temperature, currents, winds and general oceanographic conditions.<br>-Puerto Rico Climate Change Council (PRCCC): Temperature and Turbidity. |
|                            | <i>Habitat</i>                 | -PRCRMP: Percentage cover of coral assemblages<br>-National Coral Reef Monitoring Program: Percentage cover of benthic assemblages (including corals)                          |
|                            | <i>Anthropogenic Stressors</i> | -National Water Quality Monitoring Council: Various parameters such as Turbidity, CDOM, Nutrients, etc. depending on specific site.                                            |
| <b>Socio-Economic</b>      | <i>Socio-Economic</i>          | -National Census databases                                                                                                                                                     |

**2) Description of trends (Temporal and/or Spatial):** the specific characteristics of the analyses to be performed will depend on the outcomes of qualitative step 3 (i.e. development of

conceptual model); however, and regardless of specific hypotheses derived from the conceptual model, it is of paramount importance to describe the spatial and temporal trends for each data matrix. As each data matrix is composed of many variables (e.g. the finfish data matrix of the SEAMAP-C database has abundance and biomass information on 63 species of fish across 81 stations repeatedly sampled for 11 years); description of trends will be done using multivariate analyses such as multivariate ordinations (e.g. Non-metric multidimensional Scaling (nMDS), Principal Coordinate Analyses (PCO)) and multivariate hypothesis testing procedures (PERMANOVA). From these analyses, we will be able to know whether the structure and composition of the entire fish assemblages (as collected by the SEAMAP project for example) has changed through time. If positive, we will also be able to quantify the magnitude of that change and identify whether those changes were similar across all locations/regions. Furthermore, when performing the same analyses across different data matrices (e.g. SEAMAP's fish abundance and PRCRMP fish abundance) we will be able to determine whether detected trends are similar across sampling programs. In addition to this multivariate approach, traditional univariate analyses (e.g. GLMs) will be done on the indicators identified by the stakeholders. For example, if total biomass of fish (resulting from adding all biomasses of all fish's species per sampling station/location) was selected as indicator by stakeholders (during step 2 and 3 of qualitative analyses); we will quantitatively describe the temporal trends of biomass through time. Similarly to the multivariate case, we will also identify whether those trends were similar or not in all location/regions. Other traditional univariate indicators that could be selected are: total number of species (richness), total biomass of commercially exploited species or average length of a particular species. Description of these temporal and spatial patterns is important because before any attempt is done to identify socio-ecological processes driving the fisheries system of the US Caribbean, we need to understand these natural temporal and spatial trends (Underwood 1997). The importance is further detailed at the end of this section with an example on the relationship between the qualitative and quantitative approach. Multivariate and univariate analyses will be done on all data matrices extracted from each type of database in all three categories (Table 2). These trends analyses in all data matrices will partially determine subsequent analytical strategies. In particular, it will help us to select the particular data matrices (in each category and type) that will be used in the following steps.

**3) Build the quantitative model:** This step mainly consists on correlating described trends across different categories of data (i.e. Response, Predictor and Socio-Economic variables). Unlike traditional correlations that relate two single variables (e.g. Total Biomass of Fish vs Turbidity), these will be done across all three categories and taking into account the multivariate structure of the data. In addition, these correlations will also take into consideration that within each category there are different types of data (e.g. Response variables could be of two types: Fisheries Independent and Fisheries Dependent). In doing so (collating all this together), it is likely that most of the considered variables within category will be co-varying, resulting (potentially) in spurious correlations, that will not only have negative statistical consequences (i.e., can reduce the statistical power of true relationships) but will also lead to confounded conclusions. It is also possible that a variable (or group of variables) within a particular type/category could be considered a response and a predictor variable within the model. For example habitat (evaluated as the structure and composition of benthic assemblages of coral reefs) could be considered a predictor for the structure and composition of fish assemblages; but could also be considered a response to the data matrix containing information on concentrations of heavy metals and turbidity. To deal with multi-

collinearity, we will use Structural Equation Modeling (e.g. Graham 2003, Grace 2006). Structural Equation Models allow the assessment of the significance of specific relationships given the effects of other variables and their potential collinearities, considering all three categories (response, predictor and socio economic) at the same time. This procedure will allow to quantitatively assess the relative importance of relationships among data sources. For example, we will be able to determine whether fish biomass is better correlated with temperature changes or with organic pollution; taking into consideration that other variables such as sedimentation or coral cover could also be important in the model. This information will be crucial to determine the strengths of the links proposed in the conceptual model or whether important links not identified by stakeholders might be missing.

**4) Identification of indicators and threats:** As a result of the previous steps, we will understand the degree of relationship among the three categories of data (e.g. predictor vs response variables). Furthermore, we will also understand the degree of relationship among types of data within each category (e.g. Independent vs Dependent Fisheries data). However, in order to identify particular **indicators** (i.e. individual response variables) within each data matrix, and **threats** (i.e. individual predictors variables affecting response variables), we need to perform pairwise correlations among individual data matrices (e.g. one data matrix in the response category vs one data matrix in the predictor category at a time). This task has the challenges however, that each data matrix has different resolutions, scales, extensions and were collected using different sampling designs. For example, the 81 stations used in the finfish program of the SEAMAP-C database, coincide only in a 22% (coincidence defined as those stations that were in the proximity of 1 km radius and sampled in the same year/season) with the stations used in the PRCRMP program to estimate percentage cover of benthic assemblages associated with coral reefs. Under this scenario, no direct comparison among different data matrices will be attempted. Instead, we will use the following approach: 1) after extracting and categorizing all data sets (Step 1 quantitative) and 2) describing spatial and temporal trends (Step 2 quantitative); 3) meta-analyses will be conducted using effect size of the different matrices (Koricheva et al., 2013) to determine overall temporal changes/trends per category (i.e. response, predictor and socio economic). Finally (4) overall trends will be correlated among pair of categories (specially response/predictor and biological/socio economic) using multivariate multiple correlations (Anderson et al 2008) and graphically displayed using constrained multivariate ordinations (Clarke & Gorley 2015).

#### *Relationship between the conceptual and quantitative models (validation and comparison)*

As part of the qualitative approach, main components of the ecological and fisheries systems will be identified (together with indicators and threats) by stakeholders. For example, in a recent exercise lead by NMFS/NOAA personnel and members of the C-EBFM task force (Dr. Tauna Rankin and Dr. Bill Arnold); Caribbean DAP and SSC members (about 60 people) were participating in three independent focus groups (26 – 28 March 2019) to develop Conceptual Models for the fisheries in Puerto Rico, St Thomas/St John and St. Croix respectively. During that time, all three groups (one per management region), identified the main components of their respective fisheries systems and stablished relationships among those components. Very interestingly, all three working groups independently concluded the same: “Contamination” (part of predictor variables) is the main problem driving/affecting fisheries (part of response variables)

in those three management regions, and as such "contamination" would be an important element of the Conceptual Models in the Caribbean. Now if that information is to be translated into some specific management plan or action; it is crucial that "contamination" is defined and quantified. To achieve this, quantitative analyses of the "anthropogenic stressor" data source will help in:

a) Identifying what particular type of contamination (i.e. heavy metals, organics, fertilizers, etc.) is important/relevant, where that "contamination" is (i.e. mapping), how much there is (i.e. concentrations) and what are the temporal trends in different locations/areas/reefs. This is what we have defined as step 2 of the quantitative approach: describe temporal and spatial trends. For this particular example, a potential source where we can extract this information has been identified: National Water Quality Monitoring Council. However, that information is not listed in Table 3, as it is in the form of reports (pdf). Consequently, data will have to be extracted from those reports to construct the necessary databases. As this is just an example, it is possible, that for some other elements identified by the stakeholders, the data necessary to perform the quantitative analyses is non-existent or not available. If this is the case, we will first attempt to use a proxy, for example estimating the distance to the nearest river as a proxy for contamination. If a proxy is not possible, then the lack of information will serve in our gap analysis and inform managers of the type of data that needs to be collected in future monitoring programs.

b) Once those trends are described (where, what, how much and when); we can correlate those trends of "contamination" with other components of the model that are directly relevant to the fisheries (e.g. catch, production, biomass, etc.) and the ecosystem (e.g. diversity, functional integrity, etc). This is what we have defined as step 3 of the quantitative approach: develop quantitative model. If there are correlations, then we can model that specific relationship (quantitative step 4) in order to inform managers about: i) Specific management actions in different location/regions, ii) Prioritize management actions and/or areas to apply those actions, and iii) Indicators to be used in future monitoring programs. If there are no correlations, stakeholders can be informed and decide whether the conceptual model need to be refined/adjusted or perhaps the data acquisition programs (in this case "contamination") need to be modified/adjusted.

In this particular example only "contamination" was used, but the quantitative approach proposed here will take into consideration the entire suit of predictor, response and socio-economic variables available. Considering that the Caribbean fisheries and ecosystem elements are a complex system, Structural Equation Meta-Models (SEMMs, Grace et al. 2010) will be used to represent general relationships among multiple theoretical constructs (from qualitative analyses) and model derive from data analysis (quantitative step 3: SEM). Overall, this iterative process between the qualitative and quantitative approach will allow to: 1) refine the conceptual model, 2) validate elements of the conceptual model that the stakeholders might disagree about, 3) reduce uncertainty in those elements of the model that stakeholders might be unsure about, and 4) identify important elements of the conceptual model that needs immediate research efforts.

Finally, this validation/comparison exercise will also help with re-evaluating the strategic objectives originally proposed by the stakeholders, which will ultimately feed into Lenfest's second step to develop an FEP (where are we going?). During a final series of workshops, we will present the results of the project, models, indicators and threats; in order to receive feedback from the stakeholders in relation to the strategic objectives. The key players will be the resource managers, not only those acting at the federal agencies (e.g. NOAA line office representatives), but also at the state level (e.g. DRNA, DPNR, management officers of protected areas, etc).

## Data Sources (Examples).

Table 3. Examples of datasets to be considered in this project. This list is not complete and it is expected that it will be expanded/complemented during the course of the project.

| <b>Fisheries Independent and habitat</b>    |                               |             |            |                                        |                                      |
|---------------------------------------------|-------------------------------|-------------|------------|----------------------------------------|--------------------------------------|
| Name                                        | Responsible                   | # Locations | Time spawn | Scale                                  | Type of data                         |
| SEAMAP - C                                  | Seagrant                      | 45-72       | 1999-2018  | Regional (PR, STJ, SCX)                | Fish Assemblages                     |
| PR Coral Monitoring Program                 | DRNA                          | 21-42       | 1999-2018  | Island (PR)                            | Benthic and Fish Assemblages         |
| USVI Coral Monitoring Program               | NOAA/DPNR                     | 25-32       | 2001-2017  | Island (USVI)                          | Benthic and Fish Assemblages         |
| CRES                                        | Dep. of Marine Sciences (UPR) | 27          | 2005-2010  | Local (La Parguera, SW Puerto Rico)    | Benthic and Fish Assemblages         |
| National Coral Reef Monitoring Program      | NOAA, NCCOS and SEFSC         | 120         | 2013-2018  | Regional (PR, STJ, SCX)                | Benthic and Fish Assemblages         |
| <b>Fisheries Dependent (i.e., Landings)</b> |                               |             |            |                                        |                                      |
| Fisheries Laboratory DRNA                   | DRNA                          | 50-75       | 1990-2016  | Regional (PR, STJ, SCX)                | Landings data                        |
| SEFSC                                       | NOAA                          | 50-75       | 1990-2016  | Regional (PR, STJ, SCX)                | Landings data                        |
| <b>TIP</b>                                  |                               |             |            |                                        |                                      |
| Fisheries Laboratory DRNA                   | DRNA                          | 40          | 2000-2016  | Island (PR)                            | Tip data                             |
| <b>Environmental</b>                        |                               |             |            |                                        |                                      |
| CARICOOS                                    | CARICOOS                      | variable    | 2008-2017  | Regional (PR, STJ, SCX)                | Various                              |
| PRCCC                                       | NOAA                          | variable    | 2013-2017  | Regional (PR, STJ, SCX)                | Various                              |
| CREWS                                       | NOAA/AOML                     | 2           | 2002-2014  | Local (La Parguera and Salt River Bay) | Atmospheric and Oceanographic        |
| NCRMP                                       | NOAA/AOML                     | variable    |            | Regional (PR, STJ, SCX)                | Various                              |
| <b>Socio-Economic</b>                       |                               |             |            |                                        |                                      |
| NCRMP                                       | NOAA/NCCOS                    | variable    | 2014-2017  | Regional (PR, STJ, SCX)                | Knowledge, attitudes and perceptions |
|                                             |                               |             |            |                                        |                                      |

## **Challenges.**

1. Infrastructure to run, house and share data, including the GIS layers for long-term storage and use: The proposed activities for this project include both quantitative and qualitative data. The quantitative and qualitative data that will be aggregated and compiled at the Caribbean Fisheries Management Council and ISER Caribe data server. All data types will be stored in .CSV format and .TXT for widest possible dissemination. In addition, we will share shape files through ArcGIS Open Data, which will allow anyone to download and redistribute our data freely. Raw data will be available one year after all deliverables are submitted for publication.
2. Access to data: Many fisheries and socio-economic data are located in grey literature, which may make it difficult to access the necessary data. All principal or co-principal investigators of the grey literature will be contacted via email and/or over the phone. All available transcribed data will be collated in CVS files. We will also visit any government institution to access additional public record files.
3. Proprietary issues with publishing data before it becomes public. Consent will be sought from all participants and copies of approved consent forms will be given to each participant indicating how the data collected will be used, stored and disposed. Signed participant consent forms will be kept by the investigators until all data is disposed. Additional data will consist of photographs of the community and community members taken with their consent for purposes of documentation. Additional consent forms will be created to explain the various uses of the pictures and the forms of dissemination. These photos will be used in the publications of the research and will not be used for profit.
4. Stakeholder buy-in: To assure stakeholder buy-in is successful, we will involve the stakeholders early in the project. At the beginning of each of the workshops, expectations or goals of each meeting will be discussed and agreed upon. Communication between PIs and stakeholders will be key and occurring throughout the project.

## **Consideration of Climate.**

Local demand and the environmental variability can affect the abundance of fish and the sustainability of the fisheries in the long term. However, the current fisheries management approach is not amenable to consideration of interactions between species, the habitat and/or the environment. This project will not only analyze species interactions, but also include climate considerations into fisheries management, particularly with respect to changing productivity. The very nature of an EBFM approach is to include climatic considerations (among other drivers) into the management of fisheries systems. In particular, predictions of effects of changes to pertinent environmental variables (e.g., wind speed and direction, dissolved oxygen, water temperature, etc.) on habitat distribution and condition will be used to quantitatively estimate changes to the productivity (i.e., distribution and abundance) of fishery resources dependent on those habitats. Results of other studies and assessment conducted by the Caribbean EBFM group (e.g. resilience assessment of Coral Reef in Puerto Rico and risk assessment) will be directly linked to the present study and will be used to understand the major risks to the ecosystem and potential actions to mitigate risk and enhance resilience to climate impacts.

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