Summary of Collaborative Meeting #2 for a Meta-Analysis of Water Quality, Fish, and Benthic Data within the Kristin Jacobs Coral Reef Ecosystem Conservation Area

Florida Department of Environmental Protection
Coral Reef Conservation Program

Southeast Florida Coral Reef Initiative

Fishing, Diving, and Other Uses Focus Area
Local Action Strategy Project #51

Summary of Collaborative Meeting #2 for a Meta-Analysis of Water Quality, Fish, and Benthic Data within the Kristin Jacobs Coral Reef Ecosystem Conservation Area

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FDOU-51: A Meta-analysis of Water Quality, Fish, and Benthic Data within the Kristin Jacobs Coral Reef Ecosystem Conservation Area

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EXECUTIVE SUMMARY

The Southeast Florida Coral Reef Initiative (SEFCRI) has developed a series of local action strategies (LAS) to be completed for the Kristin Jacobs Coral Reef Ecosystem Conservation Area (Coral ECA), which are divided into five focus areas: fishing, diving, and other uses (FDOU); land-based sources of pollution; marine industry and coastal construction impacts; reef resilience; and awareness and appreciation. The FDOU focus area's LAS project #51 (FDOU-51), *A Meta-Analysis of Water Quality, Fish, and Benthic Data*, has the goal of conducting a holistic analysis of the three Coal ECA subsystems (water quality, fish, and benthic habitat) to identify patterns and trends within and among them. Additionally, this project seeks to frame these analyses within the scope of selected resource management and research priorities, and it will also identify knowledge gaps within the Coral ECA to help better inform future data collection or research and management efforts. Phase-I of FDOU-51 is directed toward data discovery and the scoping of priorities to be explored in the ultimate meta-analyses of the Coral ECA. The FDOU-51 project team operates within the framework of conceptual models previously developed to describe the south Florida coastal ecosystem and its related subsystems, and also attempts to incorporate aspects of ecosystem-based management (EBM) and the DPSER (*drivers*, *pressures*, *states*, *ecosystem services*, and *responses*) model for data organization.

As FDOU-51 seeks to frame its analyses within the scope of previously defined management and research priorities, a systematic review of the Coral ECA's subsystems and their data was performed by stakeholders in Collaborative Meeting #1 (CM_1) to fully develop those questions of interest. Phase-I of FDOU-51 attempts to narrow the scope of work for the project, prioritize the questions Coral ECA stakeholders want answered, identify the relevant data to address them, and, ultimately, will lead to a proposed analytical framework for use in Phase-II of this LAS project. This report details the efforts and results of Collaborative Meeting #2 (CM_2) conducted over two half-day sessions on May 18 & 23, 2022. At CM_2, the invited participants were charged with determining the analytical needs and likelihood of success for the highest priority research objectives developed to address the immediate needs of the Coral ECA and identified by stakeholders participating in CM_1.

In order to perform feasibility analyses and develop analytical plans for the selected research priorities, CM_2 was organized around one general deliverable that comprised five overall goals. The primary objective was to review the five research ideas that were developed during CM_1 and which were subsequently reviewed by SEFCRI's technical advisory committee (TAC) prior to CM_2. In that review, the TAC was engaged to help consolidate several ideas from stakeholders into slightly more general "research themes" that could better suit the goals of FDOU-51, and also to develop a first draft of those themes' vision statements. The remaining goals for CM_2 all pertain to, and were repeated for, each individual research theme (RT_i) assessed by the group, specifically:

a. Finalize the underlying research ideas and vision statement;

b. Determine the metrics of success for the theme;

c. Identify an appropriate analytical framework, methods, data requirements, and data-syntheses considerations;

d. Outline a general analytical process.

Thus, the final deliverable for CM_2 was a compilation of *a.-d.* for each research theme that the assembled stakeholders formally discussed.

The five research themes that were first vetted by the SEFCRI TAC, and which were subsequently presented to CM_2's participants, were all reviewed thoroughly, and proper consideration of the ultimate aims of FDOU-51 were given. After preliminary discussions regarding the fates of RT_4 and RT_5 were completed, the final slate of themes #1-4F and their respective visions captured the contemporary concerns of the Coral ECA that were not only important to stakeholders, but also analytically feasible given the data and information available at present. Thus, by pragmatically refocusing each research theme through the lens of their core deliverables and the methods and data required to achieve them, their likelihood of success increases. The final vision statements are as follows:

RT_1: "*To investigate the diversity, abundance, and size composition trends in fish resources on natural habitats within the Coral ECA. Examine any relationships between changes to water quality and/or benthic habitat. Identify fish species/functional groups indicative of different environmental conditions.*"

RT_2: "*To define the key environmental conditions that associate with benthic assemblages. Determine which benthic species are most indicative of water quality regimes in the Coral ECA.*"

RT_3: "*Examine the varying rugosity and geomorphology of reefs in the Coral ECA, and determine how this impacts the capacity of the system to provide risk-mitigation services to adjacent coastal communities. Estimate any relationships between reef rugosity and fish assemblages and benthic composition.*"

RT_{4F}: "*Investigate the response of the Coral ECA's benthic communities (i.e., resilience and resistance) to coastal construction and sedimentation.*"

Overall, the collaborative meeting was a success in determining the feasibility of performing the studies defined by the research themes. The agenda called for four completed MURAL virtual whiteboards that detailed the goals laid out in *a.-d.* above, and which was fully achieved for RT_1 and RT_2. The two remaining themes ultimately lacked an outline for their analyses' flows, but given the overall similarity between these themes and the fully completed ones with respect to their deliverables and the methods used to

achieve them, they would likely not be too difficult to create prior to beginning the analyses.

While the primary objectives for this collaborative meeting were ostensibly met, there remain unanswered questions related to these results that will need to be addressed prior to the start of Phase-II of FDOU-51. The first, and most important, is the determination of which of the research themes addressed here are most appropriate to move forward with. Furthermore, given that RT_2 only included two of three Coral ECA subsystems, that theme would either need to be disqualified or incorporated into another of the themes. The vision, deliverables, and methods of RT_1 are similar enough to RT_2 that this would be the obvious candidate for pairing, however this would add considerable time and effort to RT_1.

Another area where more progress must be made is with respect to determining precisely which parameters would need to be included in each theme's analysis to fulfill the requirements set forth in the vision statement and to produce the core deliverables. For example, rugosity-focused studies would likely prioritize water quality and hydrological conditions that would increase or decrease the erosion, dissolution, or deterioration rates of the physical reef structures when assembling the set of predictors thought to affect rugosity; whereas other studies would define their respective suites of relevant water quality parameters differently. Therefore, relevant parameter lists for the selected research theme must be fully developed prior to the start of Phase-II.

These conversations reinforced many recommendations from CM_1 that various aspects of the monitoring programs should be augmented to include contemporary considerations. This was most noticeable with respect to the fish subsystem as there is only one fishery-independent monitoring (FIM) program currently collecting fish data throughout the entire Coral ECA, and it only surveys data bi-annually. The participants all agreed that more, and more frequent, FIM sampling throughout the region would benefit the management and understanding of the living marine resources, particularly since the fishery-dependent monitoring (FDM) data are not adequately spatially resolved, nor do they capture all fishing modes accurately and, essentially, FDM data cannot be used for this region alone.

The other subsystem that contains relatively large data and knowledge gaps that were revisited in CM_2 was the water quality subsystem. Participants once again noted that the method detection limits were problematic and may limit the scales of inference, or even the usability of certain parameters' data. They also reiterated that additional water quality analytes, such as contaminant levels, and more finely resolved turbidity and sedimentation data would be crucial to performing RT_3 and RT_{4F} adequately, along with detailed *in situ* hydrological information. Further, data collections for a subset of water quality variables that could be measured using flow-through systems while in transit between full-observation stations were also mentioned again in this meeting.

Lastly, the benthic subsystem is the most completely surveyed and monitored subsystem within the Coral ECA and, therefore, has the fewest monitoring gaps. However, there were

still areas where participants echoed improvements called for in previous meetings. These included the addition of finer taxonomic resolution with respect to non-coral community members of the benthic subsystem, particularly macroalgae and sponges, as well as some reef structural parameters, such as measures of erosion and accretion rates, and porosity estimations for the underlying substrate.

Collaborative Meeting #2 for FDOU-51 was a success, and it produced four detailed analytical plans for describing the connections between the three subsystems of the Coral ECA. These themes can offer greater insight into the contemporary issues that are known to affect the system and its resources, and a selection of one or more of them will adequately complete the goals of this LAS project. Thus, to close out Phase-I of this project, the questions stated above in the Future Work section must be answered and, using these results as an outline, the final proposal will be developed for work to be completed in Phase-II of FDOU-51.

ACKNOWLEDGEMENTS

This work was the product of collaboration among data providers, analysts, researchers, and other stakeholders working throughout the Kristin Jacobs Coral Reef Ecosystem Conservation Area (Coral ECA). In particular, I would like to thank Katie Lizza, the Fishing, Diving, and Other Uses (FDOU) Coordinator from the Florida Department of Environmental Protection's Coral Reef Conservation Program, who was immensely helpful in the organization of resources and logistics, as well as in the production of this virtual collaborative meeting for the FDOU-51 project. Others who were also instrumental to this effort include Mollie Sinnott for project guidance. Additional thanks go out to all of the people who volunteered their time to attend the FDOU-51 collaborative meetings and participate in these activities – it would *not* have been possible without your expertise and input! Finally, I'd like to acknowledge the FDOU-51 Project Team who have provided advice and guidance along the way in preparation for these collaborative meetings and this report. I truly appreciate all of the people that have helped bring this portion of the project together.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
CAP	Canonical Analysis of Principal Coordinates
Coral ECA	Kristin Jacobs Coral Reef Ecosystem Conservation Area
CM_i	Collaborative Meeting *i*
CRCP	Coral Reef Conservation Program
DBHYDRO	SFWMD Hydrographic Database
dbRDA	Distance-based Redundancy Analysis
DEP	Florida Department of Environmental Protection
DPSER	Drivers, Pressures, States, Ecosystem Services, and Responses
DRM	Disturbance Response Monitoring
EBM	Ecosystem-Based Management
ECA-WQA	Coral Ecosystem Conservation Area Water Quality Assessment
eDNA	Environmental Deoxyribonucleic Acid
EPA	U.S. Environmental Protection Agency

FDM	Fisheries Dependent Monitoring
FDOU	Fishing, Diving and Other Uses
FDOU-51	FDOU LAS Project #51
FIM	Fisheries Independent Monitoring
FRT	Florida Reef Tract
FWC	Florida Fish and Wildlife Conservation Commission
GIS	Geographic Information System
HB	House Bill
ICA	Inlet Contributing Area
IndVal	Species Indicator Value
LAS	Local Action Strategy
LBSP	Land-Based Sources of Pollution
LiDAR	Light Detection and Ranging
MANOVA	Multivariate Analysis of Variance
MICCI	Maritime Industry and Coastal Construction Impacts
MRIP	Marine Recreational Information Program
NAS	National Academies of Science
NCRMP	National Coral Reef Monitoring Program
NCRMP	National Coral Reef Monitoring Program – Climate and Carbonate Chemistry
NCRMP	National Coral Reef Monitoring Program – Reef Visual Census
NOAA	National Oceanic and Atmospheric Administration
PERMANOVA	Permutation-based Multivariate Analysis of Variance
PERMDISP	Permutation-based Multivariate Dispersion
RDA	Redundancy Analysis
RT_i	Research Theme *i*
SCTLD	Stony Coral Tissue Loss Disease
SECOORA	Southeast Coastal Ocean Observing Regional Association
SECREMP	Southeast Florida Coral Reef Evaluation and Monitoring Project
SEFCRI	Southeast Florida Coral Reef Initiative
SFWMD	South Florida Water Management District
STORET	STOrage and RETreieval Data Warehouse
TAC	Technical Advisory Committee
USGS	U.S. Geological Survey
WIN	Water Information Network
WQP	Water Quality Portal

1. INTRODUCTION

1.1. Project Background

The Southeast Florida Coral Reef Ecosystem Conservation Area was officially established on July 1, 2018 after HB 53 passed the House on Jan. 25, 2018 and then subsequently passed the Senate on Feb. 7, 2018 (Florida-Senate 2018). This area was renamed the Kristin Jacobs Coral Reef Ecosystem Conservation Area (Coral ECA) on July 1, 2021, and includes the sovereign submerged lands and state waters offshore of Martin, Palm Beach, Broward and Miami-Dade Counties. The Coral ECA extends from its northern boundary at St. Lucie Inlet southward to the northern extent of Biscayne National Park at its southern boundary (Figure 1). Although these boundaries were only recently established, collaborative action and research among marine resource professionals, scientists, and stakeholders from government agencies and other organizations has been ongoing within the area since at least 2003 when the Southeast Florida Coral Reef Initiative (SEFCRI) was formalized (DEP 2004).

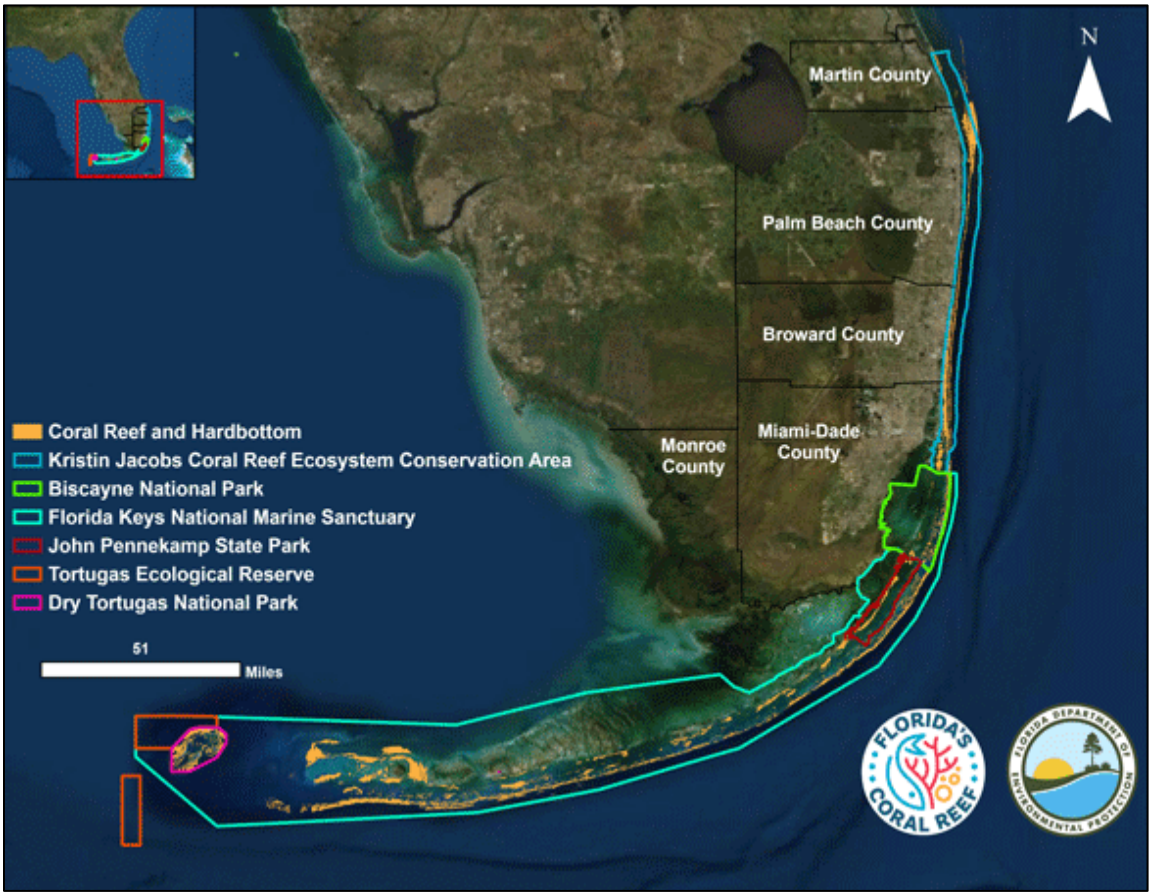

Figure 5. Map of the Florida Reef Tract's Subdivisions. The Kristin Jacobs Coral Reef Ecosystem Conservation Area (northern-most, dark blue outline) is the focus of this study.

The SEFCRI Team comprises 64 stakeholders and was formed to develop local action strategies (LAS) to protect the coral reef resources in the northern portion of the Florida Reef Tract (FRT), and which spans approximately 160 km linear coastline (Banks et al. 2007, Finkl & Andrews 2008). These LAS are short-term, locally driven projects, or roadmaps for cooperative action among federal, state, and non-governmental partners, that identify and implement priority actions needed to assess or reduce key threats to coral reef resources in the Coral ECA (DEP 2004). The Florida Department of Environmental Protection (DEP) Coral Reef Conservation Program (CRCP) was established in 2004 to support and manage the SEFCRI Team and overall progress towards completion of LAS projects (DEP 2004). The SEFCRI Team identified five focus areas for immediate local action to address threats to the Coral ECA, and included, (*i*) land-based sources of pollution (LBSP), (*ii*) maritime industry and coastal construction impacts (MICCI), (*iii*) fishing, diving, and other uses (FDOU), (*iv*) lack of awareness and appreciation, and (*v*) reef resilience. Each of these focus areas have specific LAS projects that are implemented and managed by DEP coordinators within the CRCP.

One LAS project, *FDOU-51*: *A Meta-Analysis of Water Quality, Fish, and Benthic Data*, has the goal of conducting a holistic analysis of these three Coal ECA subsystems to identify patterns and trends within and among them. Additionally, this project seeks to frame these analyses within the scope of selected resource management and research priorities, and it will also identify knowledge gaps within the Coral ECA to help better inform future data collection or research and management efforts. Phase-I of FDOU-51 is directed toward data discovery and the scoping of priorities to be explored in the ultimate meta-analyses of the Coral ECA.

The FDOU-51 project team operates within the framework of conceptual models previously developed to describe the south Florida coastal ecosystem and its related subsystems (Fletcher et al. 2013), and also attempts to incorporate aspects of ecosystem-based management (EBM; Christensen et al. 1996; Lubchenco & Sutley 2010) and the DPSER (*drivers*, *pressures*, *states*, *ecosystem services*, and *responses*) model for data organization (Bowen & Riley 2003, Tscherning et al. 2012, Kelble et al. 2013). Thus, after partitioning the Coral ECA into the three primary subsystems of interest to FDOU-51: (*i*) water quality, (*ii*) fishes, and (*iii*) benthic coral and hardbottom habitats, a data discovery process was undertaken to catalog relevant data sources that could inform holistic analyses of the Coral ECA (Kilborn 2022).

As FDOU-51 seeks to frame its analyses within the scope of previously defined management and research priorities, a systematic review of the Coral ECA's subsystems and their data was performed by stakeholders in Collaborative Meeting #1 (CM_1) to fully develop those questions of interest (Kilborn & Lizza 2022). In addition to consolidating data and system-level stakeholder priorities, CM_1 also elucidated several knowledge and data gaps within the monitoring system for the Coral ECA, and which will help inform

future improvements to research, data collection, and management efforts of this unique ecosystem. The stakeholder pool for CM_1 included county, state, federal, and academic data providers, statistical experts, resource managers, and members of the SEFCRI Project Team (Kilborn & Lizza 2022).

Phase-I of FDOU-51 seeks to narrow the scope of work for the project, prioritize the questions Coral ECA stakeholders want answered, identify the relevant data to address them, and, ultimately, will lead to a proposed analytical framework for use in Phase-II of this LAS project. This report details the efforts and results of Collaborative Meeting #2 (CM_2) conducted over two half-day sessions on May 18 & 23, 2022. At CM_2, the invited participants were charged with determining the analytical needs and likelihood of success for the highest priority research objectives developed to address the immediate needs of the Coral ECA and identified by stakeholders participating in CM_1 (Kilborn & Lizza 2022).

1.2. Collaborative Meeting #2 Objectives

In order to perform feasibility analyses and develop analytical plans for the selected research priorities, CM_2 was organized around one general deliverable that comprised five overall goals. The primary objective was to review the five research ideas that were developed during CM_1 and which were subsequently reviewed by SEFCRI's technical advisory committee (TAC) prior to CM_2. In that review, the TAC was engaged to help consolidate several ideas from stakeholders into slightly more general "research themes" that could better suit the goals of FDOU-51, and also to develop a first draft of those themes' vision statements. The remaining goals for CM_2 all pertain to, and were repeated for, each individual research theme assessed by the group, specifically:

a. Finalize the underlying research ideas and vision statement;
b. Determine the metrics of success for the theme;
c. Identify an appropriate analytical framework, methods, data requirements, and data-syntheses considerations;
d. Outline a general analytical process.

Thus, the final deliverable for CM_2 was a compilation of *a.-d.* for each research theme that the assembled stakeholders formally discussed.

2. METHODS

2.1. Collaborative Meeting Format

The content under review encompassed five research themes and, thus, each day generally consisted of the same activities performed multiple times, but with a different thematic focus for each iteration. The five themes, after consideration by the TAC, were broadly defined as follows to begin CM_2:

1. Beta-diversity of fishes and fish catches as indicators of Coral ECA water quality, fish, and benthic health, structure, and function.

2. Water quality effects on the fish and benthic subsystems. Characterize indicator species and keystone attributes with the greatest impacts. Specific focus on sedimentation and spatial considerations. Identify benthic indicators of "health".
3. Core coral reef population dynamics and functional ecosystem services: larval supply, recruitment success, and resilient area mapping; changes to rugosity and overall coastal risk mitigation services from the reef.
4. Coral disease sources and impacts. Particular focus on land-based sources of pollution (LBSP), dredging, and stony coral tissue-loss disease (SCTLD).
5. Defining a "healthy" coral reef ecosystem. Define eutrophication thresholds and assess acute vs. chronic impacts of water quality changes in the Coral ECA.

The first day of CM_2 dealt with research themes #1 and #2 (RT_1, RT_2), and the second day focused on the last three. One unique aspect of day two's agenda was that research themes #4 and #5 (RT_4, RT_5) were subjected to preliminary conversations among the meeting participants to determine which of the two should be formally subjected to objectives *a.-d.* outlined above. Thus, the meeting facilitator led a discussion after the completion of RT_1-RT_3 to make this determination prior to proceeding. Nominally, this was done to account for the actualities of the limited time available to complete all of the meeting's tasks, but it was also related to the relatively narrow focus of those two themes, and which may not have been fully indicative of the "spirit" of the FDOU-51 project's goals. Given that the ultimate charge of FDOU-51 is to perform holistic analyses of the three subsystems that the Coral ECA comprises – water quality, fish, and benthic habitats – some refocusing of all of the research themes was required.

2.2. MURAL Interactive Whiteboards

The meeting facilitator led the group through a series of activities using the MURAL virtual whiteboard interface (https://www.mural.co) that were designed to direct the development of the research themes in accordance with the goals and objectives outlined above. Thus, each theme had a pre-filled MURAL whiteboard (or "MURAL"; Figure 2) that participants could access via a weblink provided in the Zoom virtual meeting chat. Each theme's MURAL template included details specific to the theme's underlying research ideas and the TAC's advice, and was allocated 1 hour and 30 minutes to complete. The final MURAL, however, was only allotted 1 hour, due to the vision statement development being included in the preliminary discussion facilitated using Microsoft PowerPoint (see details below).

Each theme's MURAL activity was composed of seven sections, and the first two of which included a review of the specific research ideas proposed by attendees of CM_1 that underly the theme, along with a reworking of the suggested vision statement provided by the TAC. The next two sections included brainstorming sessions where participants suggested ideas

and metrics that could be used to define (*i*) "success" and (*ii*) the scope of deliverables for each theme. The definition of success section also included a vote

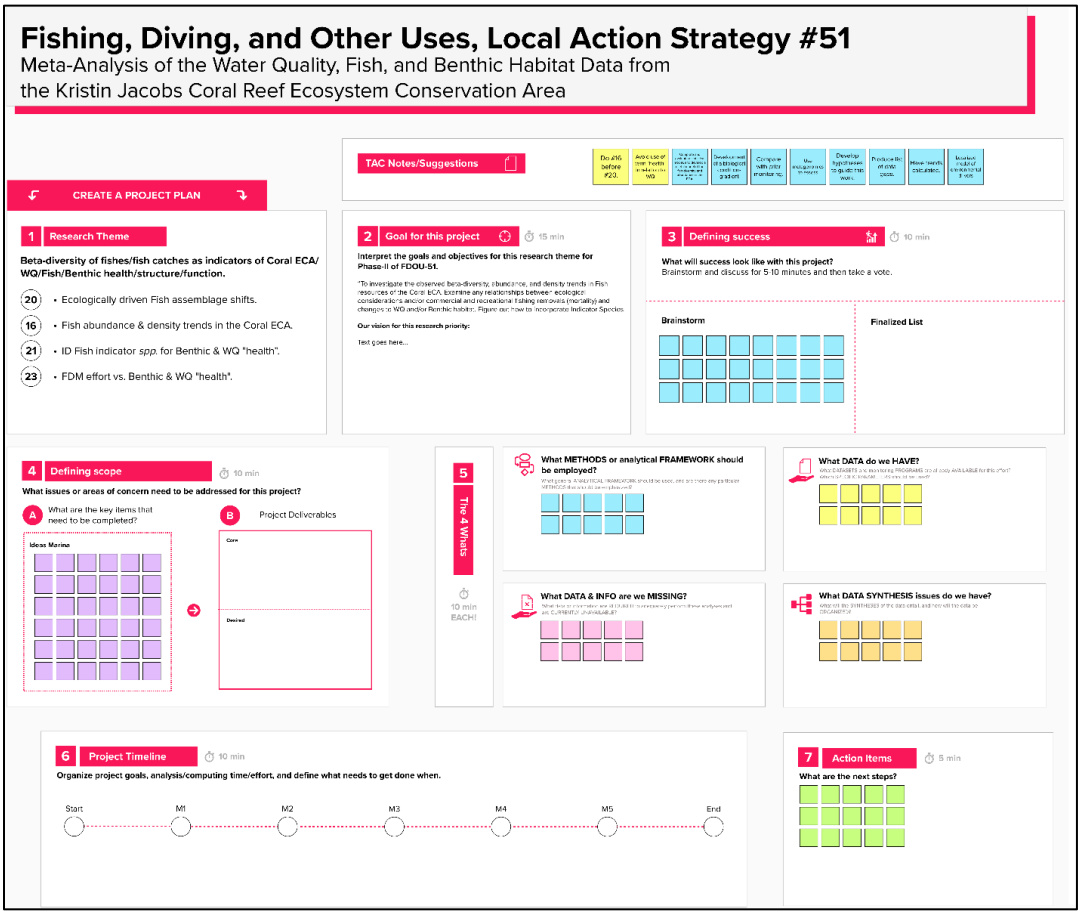

Figure 6. MURAL Virtual Whiteboard Template. An example (specific to RT_1) that shows the various elements of the collaborative MURAL virtual whiteboard activity used by meeting participants to develop each research theme.

where participants were allowed to signal which two ideas they felt were ranked in the top tier for that research theme. The next section, labelled "The 4 Whats", covers four areas specifically related to the choice of analytical frameworks and methods, along with data-specific considerations. In particular, it covers the following questions:

1. **What methods or analytical framework should be employed?** What general analytical framework should be used, and are there any particular methods that should be emphasized?
2. **What data do we have?** What datasets and monitoring programs are already available for this effort? Which specific parameters should be used?
3. **What data and information are we missing?** What data or information are required to adequately perform these analyses that are not currently available?

4. **What data synthesis issues do we have?** What will the synthesis of the data entail, and how will the data be organized?

Lastly, the final two sections in each MURAL were designed to capture an outline of the project's analytical process flow, as well as action items, or next steps, to be addressed upon its completion.

2.1. Microsoft PowerPoint Presentations

Throughout CM_2 the facilitator led two pre-prepared Microsoft PowerPoint presentations for the meeting participants over the course of the two days, and one of which also included the preliminary group discussion activity alluded to previously. The first presentation kicked off the series of meetings and included a group welcome, participant introductions, and shared meeting expectations, as well as a review of the agenda, scope of work, and deliverables. Group norms were established by the facilitator, which included the preference for cameras to be on, participants to share ideas verbally, and minimal use of the text chat. It was established that this would be a working meeting and active participation was necessary to achieve the meeting's goals and objectives.

In addition to logistical considerations, the first presentation also outlined the five research themes and underlying ideas that they comprised. Their placement on the importance vs. feasibility diagram (Figure 3) was presented and discussed, and the ideas' connections that lead to their ultimate groupings were also outlined for the group. Finally, a detailed description of the MURAL activities to be used in developing the themes was also given.

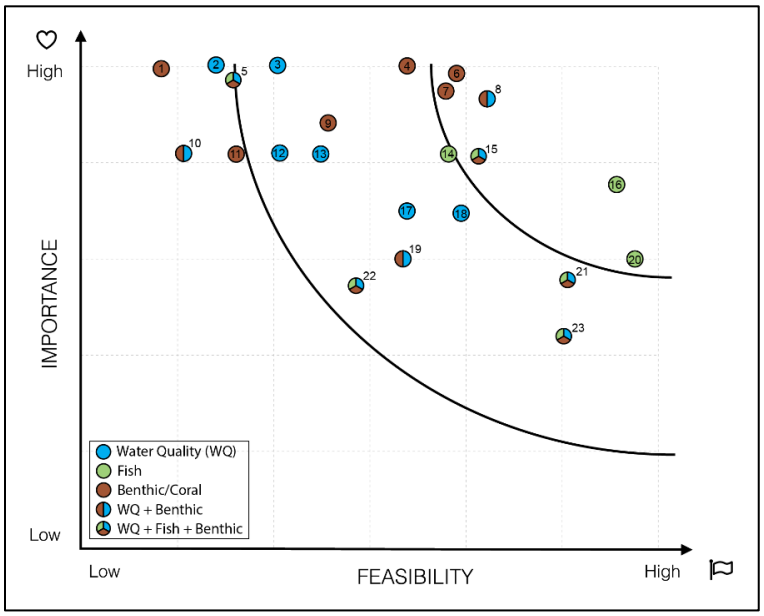

Figure 7. Importance vs. Feasibility Diagram. Ordination of the research and management ideas developed in CM_1, and which formed the underlying basis for each research theme explored in CM_2. Each idea was placed along the vertical axis depending on the relative importance of the idea to the Coral ECA in general, and along the horizontal axis by gauging each idea's feasibility of successful completion. All final locations were determined by group consensus after discussions.

The second presentation took place in the latter half of CM_2's second day, and focused on the preliminary discussion of RT_4 and RT_5. This conversation began with a description of the themes' underlying ideas and their juxtaposition within Figure 3 (Figure 4), and then followed through to an interpretation of their relative feasibilities. Finally, an ultimate research theme for the group to formally work up was decided upon, the list of individual ideas included within it was refined, and a final vision statement was developed. The vision statement was then carried forward into the MURAL activity to develop the details of the finalized fourth research theme (RT_{4F}).

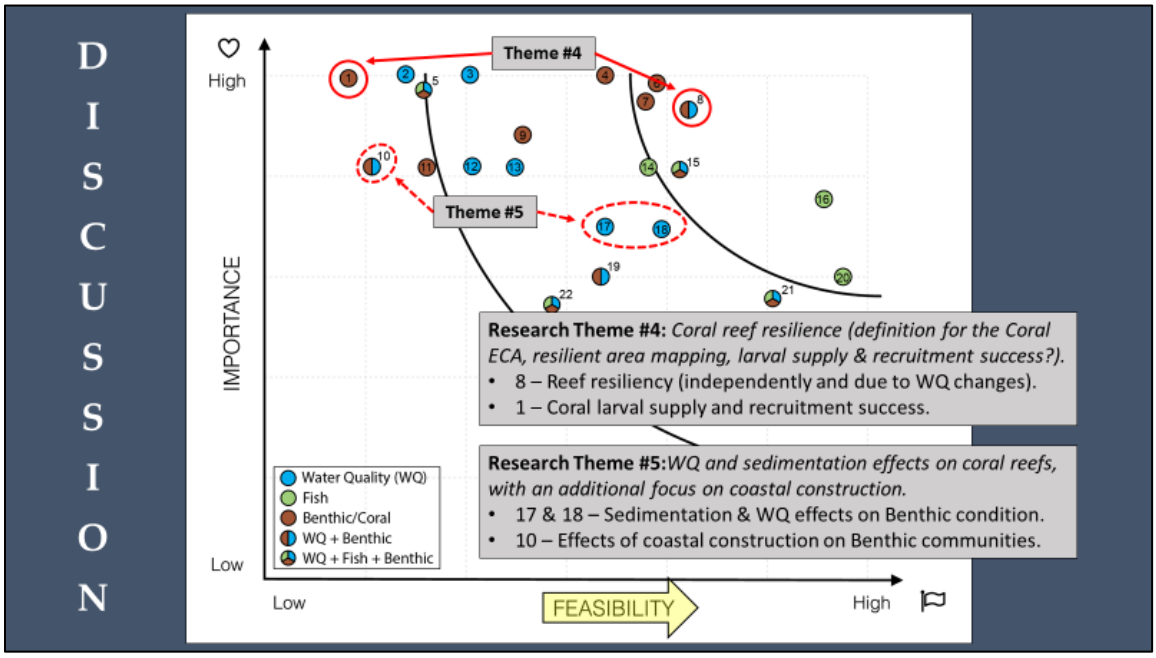

Figure 8. PowerPoint Slide to Compare Research Themes #4 & #5. Presentation slide used to help orient meeting participants to the differences in the underlying research ideas that comprise RT_4 & RT_5. This was used to help facilitate a discussion to determine which theme would be formally developed further.

3. RESULTS & DISCUSSION

3.1. Determination of Research Theme #4F

After discussion by the group, it was determined that there were several reasons to combine certain aspects of both RT_4 and RT_5 and to remove others. The group unanimously agreed to reorganize the underlying research ideas into a new research theme (RT_{4F}). First, since RT_2 explores the relationship between water quality and benthic communities and condition, these aspects (#8 and #18, Figure 4) were removed from the final theme (Table 1). Next, specific investigation of coral larval supply and recruitment success, while deemed to be important to reef resilience and condition, was also removed from the final theme due to data paucity concerns. Thus, the final form of the fourth research theme formally treated by the meeting's attendees was a combination of research ideas #8, #10, and #17, and was focused on understanding benthic resilience and resistance to both coastal construction and sedimentation (Table 1).

Table 6. Research Themes' Focus, Vision, and Underlying Ideas. The specific focus allocated to each research theme explored by the participants of CM_2, and their respective vision statements both as recommended by the TAC and in the final form developed by the attendees. The research ideas presented are those generated by participants of CM_1 and their numerical identifier corresponds with the colored circles depicted in Figure 3 and Figure 4. Any text that is stricken through represent specific portions of a thematic focus or idea that was ultimately removed from the final product.

Thematic Focus	Vision Statements	Research Ideas
RT_1 Focus: ~~Beta~~ Diversity of fishes ~~and fish catches~~ as indicators of Coral ECA water quality, fish, and/or benthic health, structure, and function.	**TAC:** *"To investigate the observed beta-diversity, abundance, and density trends in fish resources of the Coral ECA. Examine any relationships between ecological considerations and/or commercial and recreational fishing removals (mortality) and changes to water quality and/or benthic habitat. Figure out how to incorporate indicator species."* **Final:** *"To investigate the diversity, abundance, and size composition trends in fish resources on natural habitats within the Coral ECA. Examine any relationships between changes to water quality and/or benthic habitat. Identify fish species/functional groups indicative of different environmental conditions."*	**#20:** Ecologically driven fish assemblage shifts. **#16:** Fish abundance and density trends in the Coral ECA. **#21:** Identify fish indicator species for benthic and water quality "health". ~~**#23:** Fisheries dependent monitoring effort versus benthic and water quality "heath".~~
RT_2 Focus: Water quality effects on the ~~fish and~~ benthic subsystem~~s~~. Characterize indicator species/keystone attributes with the greatest impacts. Specific focus on spatial considerations. Identify benthic "condition" indicators.	**TAC:** *"To define the "keystone" water quality attributes that predict the "condition" of both fish and benthic assemblages. Determine which fish and benthic spp. are most indicative of "healthy" water quality."* **Final:** *"To define the key environmental conditions that associate with benthic assemblages. Determine which benthic species are most indicative of water quality regimes in the Coral ECA."*	**#15:** Characterize "keystone" water quality attributes with greatest impact to high ~~fish abundance density, and~~ diversity, along with high coral cover and relief in space. **#14:** Identify benthic indicator species or groups of interest. **#19:** Determine metrics for key benthic habitat or water quality to assess the health of the benthic habitat.

Table 1 Research Themes' Focus, Vision, and Underlying Ideas (Continued).

Thematic Focus	Vision Statements	Research Ideas
RT_3 Focus: Coral reef rugosity and the services that it provides (1) to the reef, and (2) to the adjacent coastal communities (e.g., storm risk mitigation, other?).	**TAC:** *"Examine the capacity of the system to provide risk-mitigation services to the adjacent coastal communities, and determine if there is any relationship with rugosity to these services. Estimate any general service provided by rugosity to the reef system."* **Final:** *"Examine the varying rugosity and geomorphology of reefs in the Coral ECA, and determine how this impacts the capacity of the system to provide risk-mitigation services to adjacent coastal communities. Estimate any relationships between reef rugosity and fish assemblages and benthic composition."*	**#6:** Reefs as a coastal risk-mediation service over time. **#7:** Role of rugosity on reefs.
RT_4 Focus: Coral reef resilience (definition for the Coral ECA, resilient area mapping, larval supply & recruitment success?).	**TAC:** *"Within the Coral ECA, investigate the resilience of the reef system to general threats, including water quality changes. Explore coral larval supply and recruitment in the Coral ECA and their impact to the questions above."*	**#8:** Reef resiliency (independently and due to water quality changes). **#1:** Coral larval supply and recruitment success.
RT_5 Focus: Water quality and sedimentation effects on coral reefs, with an additional focus on coastal construction.	**TAC:** *"Investigate the effects on water quality of coastal construction (including sedimentation), both inshore and nearshore, and, in turn, on the adjacent benthic habitats and communities of the Coral ECA."*	**#17:** Sedimentation effects on corals. **#18:** Water quality impacts on coral condition – spatial analysis (e.g., near inlets and outfalls vs. background). **#10:** Effects of coastal construction on benthic communities.
RT_{4F} Focus: Benthic resilience and resistance to coastal construction and sedimentation.	**Final:** *"Investigate the response of the Coral ECA's benthic communities (i.e., resilience and resistance) to coastal construction and sedimentation."*	**#8:** Reef resiliency (independently and due to water quality changes). **#17:** Sedimentation effects on corals. **#10:** Effects of coastal construction on benthic communities.

3.1. Thematic Overview of the Final Research Themes

Each of the research themes discussed had its own focus, however, they were all drawn from ideas generated during CM_1 and were meant to be indicative of the primary objective of FDOU-51 – to produce a holistic assessment of the three subsystems that comprise the Coral ECA. Thus, at the outset of the meeting, the majority of the themes were sufficiently broad enough in scope to fulfill these requirements (Table 1). As the themes were explored, however, the scope of work and depth of the data considerations for each became clearer, and some themes were ultimately restructured based on the outcomes from others' progress (e.g., RT_2's development with respect to the final deliverable from RT_1; Table 1). Therefore, when the agenda order for the themes' activities was created, those themes that included a broader set of research ideas spanning all three subsystems were treated before those with more specific research questions. Furthermore, the relative position of the underlying ideas along the feasibility axis from Figure 3 was also considered, and earlier scheduling given to those themes with greater assumed feasibility at CM_2's outset.

Generally, all of the themes discussed (Table 1) were largely focused on determining the natural organizational structure of resources within the three subsystems, and then investigating which aspects of one or the other might have some control over the structural patterns identified. That this thread repeated throughout all of the themes is not unexpected given its consistency with the scope of objectives and the spirit of FDOU-51. For example, RT_1 would investigate the variability in fish diversity, abundance, and size composition by mediating through patterns and trends discovered over space or time in both the water quality and benthic habitat considerations. Whereas RT_2, on the other hand, would explore the patterns in specific environmental and water conditions that may determine changes to benthic communities' structure and function. The original intent of RT_2 was to include both fish and benthic habitats, but was reduced only to benthic habitat due to the fact that the fish:environment and fish:benthos relationships will be explored in RT_1.

For RT_3, the underlying ideas remain relevant to the entire Coral ECA, however they focus in on the specific effects of variability in reef rugosity and geomorphology on coastal risk-mitigation services (e.g., storm protection), and resident fish and benthic assemblages' organization. Likewise, RT_{4F} prioritizes the investigation of the effects of coastal construction and sedimentation on the resilience and resistance capacities of adjacent reef resources. Thus, while all of the themes are spatially and temporally relevant to the entire Coral ECA, they do exist along a relative gradient of ecological generality. Themes #1 and #2 both have very broad applicability to the general understanding of changes to the Coral ECA and its subsystems over space and time (as well as how they relate to one another), whereas the other two are much more specialized toward specific (i.e., rugosity, resilience, resistance) or modern (i.e., ecosystem services, coastal construction) ideas.

With the exception of RT_3, all of the themes also seek to identify various suites of indicators that could be used to not only capture the multidimensional status, structure, and function

of a system of interest, but also of any ecological subdivisions that might be detected (e.g., regimes). With RT_1 and RT_2, this involves determining which fish or coral species or functional groups, and water quality or environmental parameters, respectively, best capture the changes in Coral ECA subsystems over both space and time. In the case of RT_{4F}, on the other hand, the definition of relative regime states, and the indicator attributes that account for them, is applied to the coastal construction pressures (e.g., beach renourishment, hotel construction) to determine the differential levels of risk that they pose to the Coral ECA's benthic subsystem. Additionally, where higher levels of resilience or resistance are noted, the indicator species associated with those areas would be determined.

3.2. Successful Outcomes and Deliverables

Brainstorming for research themes #1-4F produced a total of 7, 11, 9, and 11 individual ideas for how to define success for each particular theme (Appendix 1), respectively, and a total of 4, 5, 3, and 8 were retained after voting (Appendix 1, Table 2). The selected measures of success were all directly related to the scope and vision set for each theme, but were more specific to tangible outcomes such as statistical relationships or clear definitions. Furthermore, since these ideas were also carried forward into the conversation about defining the core and desired deliverables for each project, they helped to determine the specific products or outcomes that would be most useful for managers and stakeholders seeking to utilize the final results of FDOU-51.

Table 7. Definitions of Success for each Research Theme. The brainstorming ideas that passed the voting threshold to be used as definitions of success for each of the four research themes developed in CM_2. They are presented in descending order based on number of votes received (see Appendix 1 for full vote tallies).

Theme	Definition of Success
RT_1	• Statistically significant relationship between fish and benthic and/or water quality metrics. • Determine which species serve as indicator species on a regional/spatial scale. • Identify ecological correlates of the diversity, abundance, size-composition (of selected species) of the fishes in the Coral ECA. • Produce a list of indicator fish species relevant to specific management concerns in the Coral ECA.
RT_2	• To identify key traits of quality benthic habitat to determine benchmarks for other areas. • Identify which fish and benthic species survive what water quality parameter levels. • Identification of key environmental drivers of heath of benthic organisms (corals, sponges, gorgonians etc.). • Evaluate models that include both direct measures of water quality and proxy variables (e.g., distance to outfalls, ICA flows) on corals & other members of the benthic assemblage. • Use empirical observations to develop metrics of condition, e.g. turf algae, attached macroalgae.

Table 2. Definitions of Success for each Research Theme (continued).

Theme	Definition of Success
RT_3	• Development of a model that relates rugosity and other aspects of three-dimensional reef structure to ecosystem services provided by reefs, especially regulating (e.g., risk-reduction) and supporting (e.g., larval recruitment, fish assemblages) services. • Determine whether the presence of the nearshore/inner reef habitats provide added shoreline protection from wave action. • Determine if additional targeted rugosity and structure can increase risk-mitigation services.
RT_{4F}	• Clearly defining resilience/resistance for the Coral ECA. • Apply risk level for different benthic communities depending on proximity to and types of coastal construction. • Identify spatiotemporal patterns in coral condition related to sedimentation and coastal construction. • Improve understanding of impact area (e.g., distance from source) to benthic communities from construction activities. • Spatially identifying areas that may be more resilient or resistant. • Improved understanding of how stressors from coastal construction projects add to or interact with (i.e., synergistic effects) other stressors to the reef community. • Identify spatiotemporal relationships between the distribution of benthic and fish to construction and sedimentation data . • Identify locations less impacted by coastal construction (specifically lower partial and whole coral colony mortality).

3.2.1. Deliverables for Research Themes #1 and #2

Given the overlap in the scope of these two themes, the set of relevant deliverables are ultimately very similar to one another, albeit with slightly different foci. For both themes, considerable effort will be required to determine the scales of inquiry that are most appropriate to frame the response system (RT_1 = fish, RT_2 = water quality, benthos). This is captured in their core deliverables (Table 3) and will need to be one of the first aspects of the analyses completed in order to lay a foundation for the hierarchical application of methods. Spatial (or temporal) scale determinations are critical to identifying indicator species (fish, coral, or other benthos) or water quality regime states, and all of which are also encompassed in the core deliverables for these themes.

Conversations about RT_2 also led to the idea of not only finding benthic indicators for the various habitat regimes that may exist within the Coral ECA, but also specifically determining if there were certain species that associated themselves with relatively "poor" water quality or degraded environmental conditions, and potentially developing some form of biotic integrity index. Lastly, two more "desired" deliverables (i.e., those that would be welcome, but which are not required for success) for RT_1 were assigned but which would ultimately apply to any themes that investigate multivariate structures using constrained methods – ordination and dimension reduction diagrams, and confidence interval ($\geq$ 95%) figures to depict significant relationships.

Table 8. Core and Desired Deliverables for each Research Theme. The final sets of core and desired deliverables determined for each of the four research themes developed in CM_2.

Theme	Core Deliverables	Desired Deliverables
RT_1	• Scale determinations. • Direct habitat considerations. • Water quality considerations. • Indicator species & functional groups.	• Multivariate ordinations of data. • Confidence interval (95%) figures depicting all significant relationships.
RT_2	• Determine the spatial differences with respect to benthic habitat composition. • Identify water quality regimes or regime states over the Coral ECA. • Determine the spatial differences in water quality. • Indicator species that are indicators of poor water quality or other environmental conditions (e.g., sponges, macroalgae). • Index of biotic integrity.	
RT_3	• Examine rugosity changes over time and determine if it is changing or has changed. • Identify the risk-mediation services provided to coasts by reefs. • Identify changes to risk-services over time and compare with changes to reef morphology. • Hydrodynamic modeling of different geomorphologies combined with different rugosities. • Determine fish assemblages associated with various 'levels' of rugosity and geomorphology. • Find spatial areas where rugosity is similar or the same. • Perform a GIS spatial join between existing rugosity measurements and new coral recruit and juvenile abundances.	
RT_{4F}	• Determining whether coral condition varies with distance from construction activities. • Identify coastal construction "types" and their relative pressures. • Create a table with "types" of construction as well as the duration of pressure and risk for benthic communities. • Identify locations with higher density/diversity of juvenile corals (below a threshold size) and investigate how these relate to construction.	• Maps showing high risk areas. • Determine biological communities or assemblages most at risk. • Updating permitting requirements and BMPs [assumed to mean "best management practices"] for coastal construction projects.

3.2.2. Deliverables for Research Theme #3

This research theme examines the role of rugosity in the provision of risk-mediation and other ecosystem services, and the deliverables are specific to this focus (Table 3). However, in terms of functional deliverables, they are very similar to those described for the previous themes. For example, after broadly defining which risk-mediation services are of interest, the analyses will seek to identify the temporal scales over which these services change. Furthermore, the same questions will need to be considered for the spatial domain and,

thus, the higher-level questions lead back to complex systems of indicators and how their dynamics and variability are organized over space and time. This theme also includes deliverables similar to those described for RT_1, and which entail the description of fish communities and indicator species, but in this case focuses on those that best capture the variability associated with changing rugosity levels. Two additional deliverable areas were related to incorporating modeling frameworks, specifically, creating some form of hydrodynamic model for the Coral ECA that accounts for reef geomorphology and rugosity attributes, and using geographic information systems (GIS) to create spatially-explicit models that join rugosity with coral recruitment and juvenile abundance.

3.2.3. Deliverables for Research Theme #4

Given that RT_{4F} is focused closely on coastal construction, these deliverables are heavily geared toward the definition and identification of the "types" of construction events that take place within the Coral ECA that are relevant to local benthic communities (Table 3). For example, the definitions of event types could be based on certain construction activities or their known impacts to water quality (e.g., sedimentation, specific contaminant introduction). However, regardless of the method used to define event types, these definitions would ultimately be the focus of the remaining deliverables along with the description of the spatial (or temporal) footprint for each event type, and the severity of impact to the reefs. Core deliverables also include investigating how juvenile diversity and density are impacted by these activities, but are ultimately constrained to benthic habitats in the Coral ECA and exclude fish. Desired deliverables include developing risk metrics for various benthic assemblages, mapping high risk areas, and updating construction permitting requirements to account for best management practices within this unique coastal ecosystem (Table 3).

3.3. The "Four Whats"

This section of each MURAL was designed to solicit the details that would be required for any analyst seeking to begin work on the research theme. Often, data and analytical frameworks are closely connected, since many methods have very specific data requirements and/or experimental design assumptions (Underwood 1997, Quinn & Keough 2002, Legendre & Legendre 2012). Therefore, since each theme was specific to certain aspects of the Coral ECA, and those aspects have data at varying scales of observation available to describe them, the selection of methods and frameworks to draw from was affected by these considerations. Furthermore, the goals and core deliverables for each theme were also instrumental to the conversation as, once again, these aspects profoundly affect the selection of methods or analytical frameworks employed (e.g., pattern recognition, indicator value analyses, continuous vs. categorical analysis).

3.3.1. Data On-Hand

Regardless of the particular theme being investigated, the pool of data to draw from was tempered by the overall objectives of FDOU-51 and the data discovery process used to determine which monitoring programs and data collection efforts were best suited to describing the Coral ECA and its subsystems (Kilborn 2022). Each theme was originally intended to cover all three subsystems to some degree, and doing so would draw upon those programs (or data warehouses) whose data collections spanned the full spatial extent of the Coral ECA over relatively long timescales. Thus, all themes investigating the same subsystem would necessarily draw upon some of the same datasets and monitoring programs (Table 4) to provide a foundation for analyses.

Table 9. Available and Missing Data for each Research Theme. The datasets that are currently available for each research theme discussed at CM_2. Other data that are missing, but which would be required to fully inform a comprehensive analysis under the vision statement provided for each theme, are also listed. See full text and the List of Acronyms for details of each acronym. Datasets or studies in italics were provided without citations during conversations, and follow-up information were not available for this report.

Theme	Data On-Hand	Data Missing
RT_1	**Water:** ECA-WQA, NCRMP-CCC, SECOORA, STORET/WQP, WIN **Fish:** NCRMP-RVC **Benthic:** NCRMP, SECREMP, DRM, LiDAR/Multibeam/GIS	
RT_2	**Water:** ECA-WQA, NCRMP-CCC, SECOORA, STORET/WQP, WIN **Benthic:** NCRMP, SECREMP, DRM, LiDAR/Multibeam/GIS	• Water quality data for water between sampling stations. • Finely resolved macroalgae and other benthic inhabitant census data. • Turbidity data. • Contaminants.
RT_3	**Water:** DBHYDRO **Fish:** NCRMP-RVC **Benthic:** NCRMP, SECREMP, DRM, LiDAR/Multibeam/GIS, *J. Stamates data*, *L. Toth data*, *N. Jones coral growth rate data*	• Hydrology. • Erosion vs. Accretion (*L. Toth data, USGS*). • Porosity. • Ecosystem Services. • USGS valuation data, *J. Stamates data.*
RT_{4F}	**Water:** ECA-WQA, NCRMP-CCC, SECOORA, STORET/WQP, WIN, DBHYDRO, Turbidity data **Fish:** NCRMP-RVC, MRIP, *Broward Co. biological monitoring technical report* **Benthic:** NCRMP, SECREMP, DRM **Other:** Marine planner, Permitting data, Coastal construction, MICCI-28	• Coastal project companies' sedimentation data. • Light attenuation. • MICCI-28 not immediately available. • Literature reviews for sedimentation effects.

Water Quality: Themes involving the water quality subsystem would likely be required to incorporate data from the Coral Ecosystem Conservation Area Water Quality Assessment (ECA-WQA; Whitall et al. 2019, Whitall & Bicker 2021), the National Coral Reef Monitoring Program Climate and Carbonate Chemistry survey (NCRMP-CCC; Towle et al. 2021), and various water data warehousing programs, such as Environmental Protection Agency's storage and retrieval (STORET) Water Quality Portal (WQP; EPA 2018) or Florida's Watershed Information Network (WIN; DEP 2018). Other programs such as the Southeast Coastal Ocean Observing Regional Association (SECOORA; SECOORA 2022) and DBHYDRO (SFWMD 2020b, a) also warehouse data related to hydrogeologic, hydrologic, meteorologic, and water quality parameters, and should be drawn upon for those themes which require that information (e.g., RT_3; Table 4).

Fish and Benthos: The data and information related to fishes for any of the themes discussed in this meeting will primarily be drawn from the NCRMP Reef Visual Census (NCRMP-RVC; Kilfoyle et al. 208, Towle et al. 2021) for fishes on natural habitats. In the case of RT_{4F}, additional information may be taken from the county-level Marine Recreational Information Program (MRIP; NAS 2017) or from Broward County technical reports for biological monitoring (*no citation provided*), however, these data are spatially limited. Benthic community composition and abundance data will be drawn from the three primary surveys operating within the Coral ECA (Table 4); the NCRMP benthic surveys (Roberson et al. 2014, Towle et al. 2021), the Southeast Florida Coral Reef Evaluation and Monitoring Project (SECREMP; Gilliam el al. 2021), and the Florida Reef Resilience Program's Disturbance Response Monitoring effort (DRM; FWC 2020). Additionally, various light detection and ranging (LiDAR), acoustic multibeam, and GIS resources (Kilborn 2022) should be gathered and used where possible.

3.3.2. Data Gaps

The first two themes discussed at CM_2 did not have any significant data gaps that would prevent their success, and RT_1 did not have any gaps noted for it at all. All other themes did have gaps identified, but those for RT_3 and RT_{4F} appear to be more difficult to surmount (Table 4). The gaps identified for RT_3 were mostly related to water quality considerations, and echo participant sentiments from CM_1 (Kilborn & Lizza 2022) seeking additional spatial resolution and analytes from water sampling programs, as well as very fine scale turbidity data (Table 4). While it would be better to include these data, the existing water quality data from the ECA-WQA, NCRMP-CCC, and data warehouses should still be suitable for FDOU-51's analyses (Kilborn 2022).

The data gaps associated with RT_3 and RT_{4F} were relatively substantial (Table 4), will likely take considerable effort to overcome, and may jeopardize the success of the research themes if not addressed properly. Given the focus on rugosity for RT_3, standardized data indicative of it must be collated across the entire spatial extent of the Coral ECA. These data must then be compared with numerous physical and environmental parameters while

accounting for dynamic hydrologic patterns that vary across the north-south axis of the study area. According to meeting participants, studies were previously conducted in some localized portions of the Coral ECA that would provide some limited data regarding coral erosion and accretion rates, but these may not extrapolate out to the entire region. Furthermore, other data, such as porosity levels, were absent altogether, and which would be critical to understanding how something like risk-mitigation might be affected over time. Lastly, the additional focus on ecosystem and risk-mitigation services for RT_3 highlights the fact that there are relatively few data that define these things, or their valuations, within the Coral ECA and its adjacent coastal communities.

For RT_{4F}, it was noted that data from coastal construction projects are subjected to non-uniform monitoring protocols across the study area. On the other hand, standardized background turbidity data such as those associated with SEFCRI's MICCI focus area's LAS project #28 (MICCI-28) would partially fill those needs and be instrumental to success; however, those data were unavailable at the time of this report, as MICCI-28 is still ongoing. Furthermore, additional data may exist regarding the effects of certain construction activities or sedimentation events, but which would need to be extracted from the preexisting literature on these topics. The companies that conduct construction projects in the Coral ECA may also keep their own records, and which would likely be particularly useful for these efforts, but they may be unobtainable without extensive effort or legal intervention. Lastly, light attenuation data, which may be used as a proxy variable for sedimentation or an estimation for photosynthetic depths (Morales et al. 2011), are also relatively sparse but may prove useful for this theme as well if they were able to be obtained.

3.3.3. Analytical Frameworks

As with data sources, many of the same methods or analytical frameworks identified for one theme were deemed appropriate for others (Table 5). One notable division amongst the analytical frameworks suggested here were those methods that rely on continuous data and inferential reference frames (e.g., time-series analyses, regression) versus those that employ other ecological or experimental treatments and groups (e.g., analysis of variance, cluster analysis or pattern recognition). Additionally, and as alluded to previously, many of the themes discussed by meeting participants ultimately differed from one another only with respect to their specific foci. Further, given that each theme (with the exception of RT_2) incorporated all three Coral ECA subsystems, variations in methods application often amount to the swapping of dependent and independent variables or to differential selection of specific attributes to suit particular research hypotheses. The final category of methods that were extensively discussed were explicit spatial methods such as GIS modeling or eigenvector mapping (Borcard et al. 2004, Dray et al. 2006, Dray et al. 2012).

Categorical treatments and pattern recognition underly much of the preliminary analyses that will need to be conducted for all of the themes discussed. In particular, multivariate

cluster analysis (Legendre & Legendre 2012) and similarity profiling (Clarke et al. 2008, Kilborn et al. 2017) can be useful in the detection of spatial, temporal, or ecological similarities in any of the water quality, fish, or benthic data assembled. These methods can be useful for determining which spatiotemporal bounds should be utilized when designing

Table 10. Methods, Analytical Frameworks, and Data Synthesis Considerations for each Research Theme. The different methods and analytical frameworks recommended to perform the investigations for each the research themes developed in CM_2. Likely data synthesis and organization issues are also presented to provide insight into potential data compilation challenges and the scales of inference for each theme.

Theme	Analytical Framework(s)	Data Synthesis
RT_1	**Categorical:** PERMANOVA, PERMDISP, CAP, IndVal, Random Forest, Cluster Analysis **Continuous:** Zero-inflated Regression, Linear Mixed Models, dbRDA/RDA **Other:** Decision Support Tool, Use hierarchical/stepwise analytical approach	• Combine NCRMP (2014-2020, even years, 100ft) with DRM (2005-present, all years, 60ft). • SECREMP (fixed sites) cannot be lumped with other benthic programs. Can be used for temporal change analyses. • Account for common spatial/temporal scale(s) for water quality/fish/benthic data integration. • May need to collapse biological classification levels (e.g., family/guild).
RT_2	**Categorical:** PERMANOVA, PERMDISP, CAP, IndVal, Random Forest, Cluster Analysis **Continuous:** Zero-inflated Regression, Linear Mixed Models, dbRDA/RDA **Spatial:** GIS models, Land-use models, Eigenvector Mapping	• Account for common spatial/temporal scale(s) for data aggregation. • SCTLD signal is overwhelming. May need to treat data using a before/after framework. • Lagged data to account for benthic spp. incorporation of environmental conditions. • Derived and proxy variables.
RT_3	**Categorical:** PERMANOVA, PERMDISP, CAP, Random Forest, Cluster Analysis **Continuous:** Linear Mixed Models, dbRDA/RDA **Other:** Factorial Screening Design	• Account for common spatial/temporal scale(s) for data aggregation. • Coral recruitment and juvenile data are very coarsely resolved. • Rugosity data standardization and augmentation with LiDAR/GIS. • Obtaining updated LiDAR data.
RT_{4F}	**Categorical:** PERMANOVA, PERMDISP, CAP, IndVal, Cluster Analysis **Continuous:** Zero-inflated Regression, Linear Mixed Models, dbRDA/RDA **Spatial:** GIS models, Eigenvector Mapping	• Spatiotemporal reconciliation between construction work and impact to the reefs. • Account for other disturbances that may have affected sites/data. • Much of the data are spread throughout disparate reports and technical documents. • Data accumulation and synthesis thought to be very complex.

analyses. Additional methods that can be used to test for *a priori* categorical effects include analysis of variance (ANOVA) and its multivariate equivalent (MANOVA), and the distribution-free analog called permutation-based ANOVA, or PERMANOVA (Anderson 2001, McArdle & Anderson 2001). Permutation-based multivariate dispersion estimations (PERMDISP; Anderson 2006) can also be utilized, and all ANOVA- and dispersion-based

methods can be visualized using canonical analysis of principal coordinates (CAP; Anderson & Willis 2003). Indicator value analysis (IndVal; Dufrene & Legendre 1997) also takes advantage of categorical grouping factors and seeks to identify biological species that are indicative of those groups based on the multivariate resemblance structures of the underlying data. Random forest models (Breiman 2001) represent a link between the categorical and continuous frameworks, and function as a non-parametric form of a classification and regression tree that can be used to create predictive classifiers and to understand the relationships between independent and dependent variables in a complex multivariate system.

Methods within the continuous data framework can be applied to data subdivisions based on the results of categorical and classification analyses, but can also be applied outright to any data that are structured appropriately for that purpose. Zero-inflated regression (Zuur et al. 2009) and other distance-based approaches (Legendre & Legendre 2012) can be used to account for the fact that many species are not recorded in every sample and, therefore, biological census' data distributions are often highly skewed toward zero. These methods can be used and interpreted as traditional regression would, and other more complex forms of linear analysis may also be relevant to these efforts as well (Table 5), including linear mixed models (Zuur et al. 2009). Multivariate approaches like classical redundancy analysis (RDA; Rao 1964), and its distribution-free equivalent db-RDA (Legendre & Anderson 1999, McArdle & Anderson 2001), can also be used to investigate the relationships among two (or more) multivariate datasets, and are also able to provide canonical visualizations similar to those described above for CAP.

3.3.4. Data Synthesis Considerations

Since each theme focused on different combinations of the Coral ECA's subsystems and specific problems within them, each one also presents slightly different data considerations that must be addressed prior to, or during, the course of the analysis (Table 5). One area, however, that remained consistent across all themes was the need to determine the appropriate scales at which data can be married together in order to perform constrained analyses such as those referenced above. For example, when utilizing fish data from NCRMP-RVC surveys it is important to note that they are only collected every other year (Kilfoyle et al. 2018, Towle et al. 2021), whereas the ECA-WQA monitoring performs data collections monthly. Thus, if these two were to be used in one analysis, a reconciliation of the mismatch between these two sampling frequencies must be made. Another consideration for fish census data is that there may be too many species to incorporate into one analysis and still maintain a reasonable level of interpretability of the results. The use of higher-level taxonomic groupings to aggregate species related to management guilds or ecological functional groups may be useful to focus the scope of studies related to fishes.

Likewise, among the three primary benthic subsystem monitoring programs (NCRMP, SECREMP, and DRM), SECREMP consists of surveys conducted at a fixed set of stations,

whereas the others are randomly stratified and reselected before each new sampling season (Kilborn 2022). Therefore, SECREMP data should not be used in the same manner as NCRMP and DRM data, but may prove useful in their own right for a temporal change analysis. When seeking to combine the data from NCRMP and DRM the fact that NCRMP samples to a maximum depth of 100 ft, whereas DRM samples to 60 ft, will need to be addressed prior to analysis. Additionally, there is another temporal mismatch between these two surveys due to the bi-annual sampling frequency for NCRMP versus annual sampling for DRM.

Given that RT_2 is primarily focused on condition, structure, and function of benthic communities and their relationship to water quality, there was a particular concern for signal-loss in the data due to extensive coral mortality from SCTLD in the Coral ECA (Precht et al. 2016, Walton et al. 2018, Toth et al. 2019). This is less of a consideration when investigating RT_1 since the assumption is that the drivers and pressures that precipitate a disease mortality event specific to corals may not necessarily represent the same pressures that may drive changes in fish patterns but, rather, the loss of corals itself may be. Therefore, when attempting to understand changes in coral and benthic community compositions, and ultimately relate those changes back to another subsystem within the Coral ECA, the purpose of understanding those changes must be accounted for. When benthic species composition or condition is the set of dependent variables (i.e., RT_2, RT_{4F}), then it is likely that SCTLD is going to need to be addressed. On the other hand, when the physical attributes of the benthos and/or the potential trophic contribution from the benthos is to be considered the independent datasets (i.e., RT_1), SCTLD may be less of a confounding variable.

Another data consideration discussed was investigating the timing mismatches between when certain water quality or environmental attributes change, and when the correspondent biological or ecological response is noted in fishes or benthic species. For example, fish community compositional changes may respond to dynamic water quality conditions faster than coral communities can, partially due to differences in the growth rates and turnover times between these taxa (Helfman et al. 2009, Sheppard et al. 2018). Where fish communities may respond to environmental changes at the monthly or seasonal observation scales, corals may require annualized data to detect long-term impacts to these slow growing animals. In addition to using data lags and leads, other derived variables may be important indicators of change to these systems. Specifically, percent-change with respect to the previous year in species' mean proportional coverages, sizes, or abundances may be particularly useful data when trying to describe the variability in structure and function of biological communities.

Water quality data have several synthesis considerations that must be addressed, with the most important being the selection of appropriate analytes to include for analyses (and which was not performed during CM_2). Not only is there the issue that very few parameters

are collected across all of the *in situ* monitoring programs in the Coral ECA (Kilborn 2022), there is also the fact that different questions require different water quality variables. Presumably, the fishes in the region are less affected by the aragonite saturation state (a variable observed by NCRMP-CCC) than corals are, and if the focus of a study is to determine the impacts of water quality changes on one subsystem or another, the inclusion of aragonite saturation state is theme dependent. Thus, where water quality regimes are to be described in RT_1 and RT_2, they should be derived from parameters that are specifically known or hypothesized to be important to fish or to benthos, respectively. A similar consideration should be made for benthic regimes as well, since different benthic parameters capture important information regarding the habitat features utilized by fishes as opposed to those that more generally describe the composition, structure, and function of the system.

Both RT_3 and RT_{4F} had more specialized research priorities than the other two and, therefore, included some fairly specific data synthesis considerations that should be addressed for those themes (Table 5). With respect to RT_3, rugosity data are not standardized across monitoring programs (Kilborn 2022), and while other rugosity data derived from LiDAR measurements or GIS data models are available, they too will need to be integrated with, or validated by, other *in situ* measurements first. Updated data products would also need to be obtained, and which was a general consideration with RT_3 overall, particularly given that a fair amount of data would need to be located and/or retrieved manually from the literature for this theme to be successfully completed (Table 4). Lastly, it was noted that coral recruitment and juvenile data currently are coarsely resolved, and that would reduce their capability to inform these analyses.

The specialized focus for RT_{4F} lies within the coastal construction and sedimentation aspects of the analysis, and the data considerations were reflective of that (Table 5). In particular, reconciling the timing between a construction-related disturbance event and any potential impacts to the adjacent coral reef or benthic-associated system is critical. Furthermore, since coastal construction projects do not take place one at a time, partitioning the pressures and determining which were responsible for specific outcomes would be very difficult. As with RT_3, much of the data relevant to RT_{4F} were thought to be spread throughout many disparate technical documents, and may even be embargoed.

3.4. Analytical Flows and Action Items

Due to time constraints, only RT_1 and RT_2 had completed analytical flow outlines and action items for their MURAL exercises. However, given the interpretation of "next steps" and the results of the two exercises, the action items that were created appeared to be applicable to all of the research themes. Broadly, the activity was understood as determining what to do after a specific theme's project was completed, and in both RT_1 and RT_2 the same set of three items were listed:

1. **Archive and make all data and derived products publicly available.**
2. **Create a decision support tool that highlights the results of the analyses.**
3. **Perform stakeholder outreach and engagement activities.**

These appear to be reasonable additions to the scope of work for any theme, and items #1 and #3 could be fully or partially implemented, respectively, within the scope of FDOU-51's Phase-II. Item #2, on the other hand, may require extensive effort outside the scope of this LAS project, and may be better suited for a more focused study of its own.

The analytical process outlines for RT_1 and RT_2 were specific to their core deliverables and the overall visions for those themes. While the analytical flow for RT_1 was the most well-developed of the two, they did have some overlapping components, and they were relatively similar given the themes' overlapping scopes. In both cases, the first step that must be undertaken is data compilation and organization. This step involves two parts; the determinations of, first, which subsystem-specific data are relevant to the goals of the project, and, second, the spatial or temporal scales over which those data are comparable.

For RT_1, the focus is to determine which fish assemblages may associate with various water quality or benthic habitat regimes over the spatial or temporal extent of the Coral ECA. Thus, after data aggregation, the next analysis would involve determining if any patterns exist within the water quality or benthic habitat data over either space or time (or potentially both). Once these patterns are determined, then indicator species for these various states or levels can be ascertained. Furthermore, within the relevant finer scale levels (e.g., inlet contributing areas, seasonal), constrained analyses such as random forests, dbRDA/RDA, or linear mixed models can be used to investigate the local dynamics between the fish species (dependent) and the water quality or benthic habitats (independent). In this way, the stepwise analytical process allows for the determination of the explicit spatiotemporal regions where either water quality conditions or benthic habitats are relatively similar, and then, within those individual regions, the biological associations of fishes to their unique environmental or habitat conditions can be investigated.

This process flow is similarly repeated in RT_2, but with a differing focus. One other aspect of the process that was unique to the discussion of RT_2 was the idea of developing derived or proxy variables (e.g., distance from freshwater outlet) that may be of interest to capturing the relationship between benthic habitat status and water quality conditions. After these derived indicators are added to the data compilation process, then the pattern recognition activities can begin to determine the various water quality regimes that may be influential to benthic communities and available biological habitat. These water quality regimes can then be used to constrain species indicator analyses to determine which benthic species are most indicative of various water quality states. Once again, within specific water quality regimes the relationships between coral diversity and water quality conditions can be addressed using the continuous analytical framework. Here, the benthos would represent

the dependent variables and the water, or other environmental or derived indicators, would represent the independent portion.

4. CONCLUSIONS

Overall, the collaborative meeting to determine to what extent it was feasible to perform the studies defined by the research themes proposed here was a success. The agenda called for four completed MURALs that detailed the thematic focus, definitions of success and deliverables, answers to "The 4 Whats", a general outline for an analytical flow, and an idea of the next steps that would be taken after completion, all of which was fully achieved for the first two themes discussed. The two remaining themes ultimately lacked an outline for their analyses' flows, but given the overall similarity between these themes and the fully completed ones with respect to their deliverables and the methods used to achieve them, they would likely not be too difficult to create prior to beginning the analyses.

The five research themes that were first vetted by the SEFCRI TAC, and which were subsequently presented to CM_2's participants, were all reviewed thoroughly, and proper consideration of the ultimate aims of FDOU-51 were given. After preliminary discussions regarding the fates of RT_4 and RT_5 were completed, the final slate of themes #1-4F and their respective visions captured the contemporary concerns of the Coral ECA that were not only important to stakeholders, but also analytically feasible given the data and information available at present. Thus, by pragmatically refocusing each research theme through the lens of their core deliverables and the methods and data required to achieve them, their likelihood of success should be increased.

4.1. Future Work

While the primary objectives for this collaborative meeting were ostensibly met, there remain unanswered questions related to these results that will need to be addressed prior to the start of Phase-II of FDOU-51. The first, and most important, is the determination of which of the research themes addressed here are most appropriate to move forward with. Furthermore, given that RT_2 only included two of three Coral ECA subsystems, that theme would either need to be disqualified or incorporated into another of the themes. The vision, deliverables, and methods of RT_2 are similar enough to that of RT_1 that this would be the obvious candidate for pairing, however this would add considerable time and effort to RT_1.

Another area where time constraints resulted in a loss of detail in the discussions was with respect to determining precisely which parameters would need to be included in each theme's analysis to fulfill the requirements set forth in the vision statement and to produce the core deliverables. Another way to frame this issue is that each response or predictor system (i.e., the water quality, fish, or benthos) needs to be reduced to only those variables that are best representative of the systems that are critical to the problem at hand. For example, rugosity-focused studies would likely prioritize water quality and hydrological conditions that would increase or decrease the erosion, dissolution, or deterioration rates

of the physical reef structures when assembling the set of predictors thought to affect rugosity; whereas other studies would define their respective suites of relevant water quality parameters differently. Therefore, prior to the start of Phase-II, relevant parameter lists for the selected research theme must be fully developed.

These conversations also reinforced many recommendations from CM_1 that various aspects of the monitoring programs be augmented (Kilborn 2022, Kilborn & Lizza 2022) to include more considerations related to the scientific needs and management goals required for sustainable stewardship of the Coral ECA to the satisfaction of its stakeholders. This was most noticeable with respect to the fish subsystem as NCRMP-RVC is the only fishery-independent monitoring (FIM) program currently collecting fish data throughout the entire Coral ECA, and it only surveys data bi-annually. The participants all agreed that more, and more frequent, FIM sampling throughout the region would benefit the management and understanding of the living marine resources, particularly since the fishery-dependent monitoring (FDM) data are not adequately spatially resolved, nor do they capture all fishing modes accurately and, essentially, FDM data cannot be used for this region alone.

The other subsystem that contains relatively large data and knowledge gaps that were revisited in CM_2 was the water quality subsystem. Participants once again noted that the method detection limits were problematic and may limit the scales of inference, or even the usability of certain parameters' data. They also reiterated that additional water quality analytes, such as contaminant levels, and more finely resolved turbidity and sedimentation data would be crucial to performing RT_3 and RT_{4F} adequately, along with detailed *in situ* hydrological information. Further, data collections for a subset of water quality variables that could be measured using flow-through systems while in transit between full-observation stations were also mentioned again in this meeting.

Lastly, the benthic subsystem is the most completely surveyed and monitored subsystem for the Coral ECA (Kilborn 2022) and, therefore, has the fewest monitoring gaps. However, there were still areas where participants echoed improvements called for in previous meetings. These included the addition of finer taxonomic resolution with respect to non-coral community members of the benthic subsystem, particularly macroalgae and sponges, as well as some reef structural parameters, including measures of erosion and accretion rates, and porosity estimations for the underlying substrate.

4.1. Final Thoughts

Collaborative Meeting #2 for FDOU-51 was a success, and it produced four detailed analytical plans for describing the connections between the three subsystems of the Coral ECA. These themes can offer greater insight into the contemporary issues that are known to affect the system and its resources, and a selection of one or more of them will adequately complete the goals of this LAS project. Thus, to close out Phase-I of this project, the questions stated above in the Future Work section must be answered and, using these

results as an outline, the final proposal will be developed for work to be completed in Phase-II of FDOU-51.

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6. APPENDICES

6.1. Appendix 1 – Definitions of Success Voting Results

Each table list all of the ideas brainstormed for the definitions of success for each of the four final research themes examined at CM_2. Each participant was given two votes for each voting session so that they could identify their top-two choices.

Research Theme #1 - Definitions of Success	Votes
Statistically significant relationship between fish and benthic and/or water quality metrics	4
Determine which species serve as indicator species on a regional/spatial scale	4
Identify ecological correlates of the diversity, abundance, size-composition (of selected species) of the fishes in the Coral ECA	3
Produce a list of indicator fish species relevant to specific management concerns in the Coral ECA	3
A stratification of areas based on the relationships	2
Identification of species indicative of water quality of benthic conditions	1
Strong recruitment class in size composition data	1

Research Theme #2 - Definitions of Success	Votes
To identify key traits of quality benthic habitat to determine benchmarks for other areas	3
Identify which fish and benthic species survive what WQ parameter levels	2
Identification of key environmental drivers of heath of benthic organisms (corals, sponges, gorgonians etc.)	2
Evaluate models that include both direct measures of WQ and proxy variables (e.g., distance to outfalls, ICA flows) on corals & other members of the benthic assemblage	2
Use empirical observations to develop metrics of condition, e.g. turf algae, attached macroalgae	2
Identifying meaningful biological indicators	2
Produce correlation of fish and benthic species by site condition	1
Keystone WQ attributes defined	1
Suggest ways to decrease the unexplained variation (i.e., how to improve sampling programs, including by co-locating sampling in space & time)	0
Identify spatial variability in water quality regimes across the ECA	0
Quantify temporal and spatial variability in water quality to determine if variability is even sufficient to relate to benthic health	0

Research Theme #3 - Definitions of Success	Votes
Development of a model that relates rugosity and other aspects of 3-dimensional reef structure on ecosystem services provided by reefs, especially regulating (e.g., risk-reduction) and supporting (e.g., larval recruitment, fish assemblages) services	4
Determine whether the presence of the nearshore/inner reef habitats provide added shoreline protection from wave action	3
Determine if additional targeted rugosity and structure can increase risk-mitigation services	2
Dollar amount value per rugosity increase/decrease (or something similar people can understand)	1
Identifying a relationship between rugosity and coral recruitment	1
Identifying a relationship between rugosity and octocoral and *Xestospongia muta* recruitment	0
Identifying rugosity/geomorphology relationship with fish assemblages	0
Determine if sand retention is related to reef development offshore	0
Identify if equal rugosities really equal? (can explain, having trouble putting into words)	0

Research Theme #4F - Definitions of Success	Votes
Clearly defining resilience/resistance for the coral ECA	4
Apply risk level for different benthic communities depending on proximity to and types of coastal construction	3
Identify spatiotemporal patterns in coral condition to sedimentation and coastal construction	3
Improve understanding of impact area (e.g., distance from source) to benthic communities from construction activities	2
Spatially identifying areas that may be more resilient or resistant	2
Improved understanding of how stressors from coastal construction projects add to or interact with (i.e., synergistic effects) other stressors on the reef community	2
Identify spatiotemporal relationships between the distribution of benthic and fish to construction and sedimentation data	1
Identify locations less impacted by coastal construction (specifically lower partial and whole coral colony mortality)	1
Improve engineering models to more realistically calculate the "toe of the reef", including adding an element of uncertainty in its position on the seaward side	0
Improved permitting requirements for coastal construction projects	0
Ability to identify reefs that are resilient/resistant	0