The Florida Keys National Marine Sanctuary

Water Quality Protection Program

Coral Reef Evaluation and Monitoring Project

Workplan For:

FY 2021 (Oct 1 2021 – Sep 30 2022)

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FY 2022 (Oct 1 2022 – Sep 30 2023)

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April 12, 2021

INTRODUCTION

Situation, Need, and Previous Efforts

The purpose of the Coral Reef Evaluation and Monitoring Project (CREMP) is to monitor the status and trends of selected coral reefs, patch reefs, and hardbottoms in the Florida Keys National Marine Sanctuary (FKNMS) and to document change to assist the EPA Water Quality Protection Program (WQPP) in evaluating management efforts of the FKNMS and WQPP. Since 1996, sampling has been conducted annually at permanent sites from Key Largo to Key West. In 1999, CREMP was extended into the Tortugas Northern Ecological Reserve and Dry Tortugas National Park to include information from the southwestern portion of Florida's Coral Reef. Monitoring was then expanded to the northern reef tract (north of Biscayne National Park to Martin County) via SECREMP (Southeast Florida CREMP) in 2003 which utilizes the same methods as CREMP. The Fish & Wildlife Research Institute (FWRI) through support of the EPA WQPP has historically been responsible for CREMP program oversight. Financial support from the NOAA Coral Program and the Florida Department of Environmental Protection allows FWRI, in collaboration with Nova Southeastern University, to survey 22 CREMP sites in the Southeast Florida jurisdiction. A cooperative agreement between the National Park Service and FWRI supports annual surveys of 12 CREMP sties in the Dry Tortugas National Park. Collectively, the spatial effort for sampling across the three regions (Dry Tortugas, Florida Keys, Southeast Florida) includes >70 sites under the CREMP umbrella along Florida's Coral Reef.

CREMP in the Florida Keys has been extremely effective at documenting short-term (e.g. year-to-year comparisons) and long-term change in coral reef communities. The program has been successful at demonstrating how both local and global stressors have negatively impacted coral reefs in the FKNMS. For example, after the mass bleaching event associated with 1997/1998 El Niño, CREMP documented widespread coral mortality on deep and shallow forereefs (Somerfield et al. 2008, Ruzicka et al. 2013). Several years later, and on a much smaller spatial scale, the program documented how a diatom algal bloom off the southwest Florida coast destroyed much of the benthic fauna on "backcountry" patch reefs in Florida Bay and the Gulf of Mexico (Hu et al. 2003). More recently, widespread mortality was recorded on nearshore patch reefs when water temperatures plunged below the lethal threshold for many benthic organisms during the record setting winter of 2010 (Colella et al. 2012). At present, CREMP is continuing to report the ongoing mortality associated with stony coral tissue loss disease (SCTLD), the most catastrophic disease outbreak to ever occur in Florida (Walton et al. 2018, Muller et al. 2020a). The outbreak started off southeast Florida in 2014 (Precht et al. 2016), reached the Upper Florida Keys in 2016 and has slowly spread southwest through the Florida Keys over the last four years (Muller et al. 2020a, Muller et al. 2020b). SCTLD was confirmed at the western terminus of the Marquesas Islands in the fall of 2020 (DRM Quick Look Report *in prep.*). The cumulative effect of SCTLD has resulted in the mortality of millions of corals in Southeast Florida, the Florida Keys, and the Marquesas (Walton et al. 2018, CREMP unpublished data) and the leading boundary of the SCTLD outbreak sits at the doorstep of the Dry Tortugas National Park, the only portion of the reef tract unaffected by SCTLD to date.

These long-term results are essential for understanding how coral reef communities have responded to these major disturbances (e.g., cold and hot water thermal stress events, hurricanes, disease outbreaks) and how they will be structured into the future. The most worrisome concern is that following catastrophic declines in coral cover caused by major disturbances there is an irreversible proliferation of macroalgae (Hughes 1994, Rogers and Miller 2006). Abundant

macroalgal cover perpetuates the maintenance of a degraded reef because macroalgae is an aggressive spatial competitor with coral that inhibits coral settlement and thus delays recovery (Birrell 2005, Mumby et al. 2007). A spike in macroalgal cover in the Florida Keys occurred after the mass bleaching event associated with 1997/1998 El Niño (Maliao et al. 2008), but the increase in cover was ephemeral. For the last two decades, elevated levels of macroalgal cover have been reported from elsewhere in the Caribbean with estimates doubling or tripling those reported by CREMP (Schutte et al. 2010b, Schutte et al. 2010a). As a result of CREMP findings, it was perceived that the current populations of herbivores (e.g. surgeonfishes, parrotfishes) in the FKNMS were providing sufficient grazing pressure to prevent a permanent phase shift towards macroalgal-dominated reefs or that wastewater improvements (e.g. Advanced Wastewater Treatment, sewer installation) enacted in the FKNMS, with support of the WQPP, had helped reduce eutrophication in nearshore and coastal environments to stem macroalgae proliferation. However, if these management actions (e.g., protection of herbivorous fishes and improvement of water quality) can no longer counteract the more recent proliferation of macroalgal cover in the FKNMS then this has important management implications for FKNMS. The greater frequency of disturbances in recent years will promote sustained macroalgal abundance and diminish coral recovery in the FKNMS (Birrell 2005, Mumby et al. 2007).

Other important changes in the composition of the coral reef community composition have also been documented by CREMP. In the shallow forereef habitat, the predominant coral historically was elkhorn, *Acropora palmata*. Due to a multitude of stressors over the last 30 years, >90% of the *A. palmata* has disappeared from the shallow forereefs in the Florida Keys and been replaced by sea fans (*Gorgonia ventalina*) and a variety sea whips (Ruzicka et al. 2013). Although the loss of *A. palmata* resulted in a decline of reef complexity and structural integrity, the succession by octocorals at least returns some of the ecological benefits lost by the displacement of *A. palmata* and provides a more optimal environment than one principally composed of macroalgae.

Acute disturbances (e.g., the 1997/1998 and 2014/2015 mass bleaching events, SCTLD, and the 2010 cold-water thermal anomaly) have been responsible for the largest declines in coral cover in the FKNMS because they often kill entire coral colonies (Somerfield et al. 2008, Colella et al. 2012, Kemp et al. 2016, Walton et al. 2018, Rippe et al. 2019). Chronic stressors also contribute to a steady, gradual loss in coral cover even though these changes are more subtle and challenging to detect. The inclusion of the demographic surveys in CREMP methodology has illustrated this point because partial tissue loss on large framework building species like *Orbicella* spp., *Montastraea cavernosa,* and *Colpophyllia natans* is reflected by a decline in percent cover, yet not always corroborated with a concomitant decrease in the abundance (density) of corals. Often, the causes leading to partial mortality are recurring and slowly kill massive colonies over many years or decades (Bruckner and Bruckner 2006). Due to the frequency of disturbances affecting Florida's Coral Reef and the associated loss of the large "adult" colonies and the overall demise of coral populations due to acute and chronic stressors, CREMP adapted its monitoring protocols to assess if recovery can occur during periods of relative stability when major stressors are absent. To evaluate the potential for recovery, CREMP amended the demographic protocol in 2018 to include counts of juvenile corals (corals <4 cm) to determine natural coral reproductive processes are replenishing juvenile corals at a rate that can promote reef regeneration. There is a large consensus in the literature that many Caribbean coral species have undergone widespread recruitment failure (Hughes and Tanner 2000, Edmunds and Elahi 2007) and while the reasons for this are largely unknown, if coral reproduction is low or post-settlement mortality of recruits is

high, both conditions would diminish the number of juvenile corals capable of entering the adult population. Low juvenile abundance would indicate that the prospects for recovery are poor and that early life history processes are strangling recovery. The collection of juvenile data has three primary objectives: (1) determine if juvenile coral density is increasing temporally and could facilitate reef recovery, (2) compare the abundance of coral and octocoral juveniles to determine the relationship between juvenile and adult population size, and (3) compare the abundance of coral and octocoral juvenile populations across a broad spatial scale to identify reefs with large juvenile populations (reefs where presumably recruitment is high) that would be candidates for protection since they can facilitate reef recovery. The inclusion of juvenile data also takes on added importance in the aftermath of SCTLD. SCTLD is still active in the Florida Keys but preliminary analysis suggests that smaller, presumably younger corals do not incur the same rates of mortality as larger, older corals. The survivorship of small corals will be an important factor towards understanding the long-term residency of SCTLD in the marine environment, and if the juvenile coral population does not expand in upcoming years this would dim the prospects for natural reef regeneration on Florida's Coral Reef.

Objectives

In large part, CREMP's success in documenting both short- and long-term changes in benthic communities in the FKNMS is due to the program's broad spatial coverage, robust sampling design, tenure, and the program's willingness to consistently adapt its monitoring protocols to address management priorities. The initial sampling effort consisted of 40 sites in the Florida Keys and that level of spatial coverage has been maintained throughout with some modifications to the experimental design. For example, in 2009, per request of the WQPP and FKNMS, six mid-channel patch reefs were added to the effort to increase monitoring in this high-value habitat. In order to accommodate the inclusion of six new patch reefs, monitoring at six nearshore hardbottom sites was discontinued. Funding provided by the EPA WQPP has fluctuated over the last decade, but modifications to the program (e.g., elimination of subcontracts, receipt of NPS support to survey Dry Tortugas CREMP sites) have allowed for the continuous sampling at 40 sites in the Florida Keys annually. This application, with base funding set at $290,000 will continue to survey 40 sites in the Florida Keys (Appendix I); 34 which have been continuously sampled since 1996 and six patch reefs continuously sampled since 2009.

For FYs 2021 and 2022, the core activities conducted will be:

(1) Photographic Transects for Estimating Benthic Cover & Coral Demographic Surveys

At all (40) sites still camera transects and coral demographic surveys (Appendix III). Benthic cover data dates back to 1996 and coral demographic data to 2011. Historically, CREMP performed three major surveys at each station: a video survey to estimate benthic cover along three parallel transects, a bio-eroding sponge survey, and a coral species inventory survey that quantified coral species richness, the presence or absence of disease and *Diadema* abundance within the station boundaries (Appendix II). In 2011, survey methods were modified to provide a more robust assessment of the benthic community and to streamline survey efficiency in response to an external review of the monitoring programs by Battelle (2007). Specifically related to CREMP, the video survey was replaced with still photographs and reduced from the three parallel transects to a single centered transect (Appendix II). Coral species inventories were replaced by stony coral and

octocoral demographic surveys conducted on the first 10m of center transect (Appendix II). The bio-eroding sponge survey was discontinued and was replaced with a *Xestospongia muta* demographic survey. The reduction in image analyses not only reduced costs but the time saved was reallocated for conducting coral, octocoral, and *X. muta* demographic surveys. Performing these additional surveys allows for a more comprehensive assessment of changes in coral reef community composition (e.g., the inclusion of octocoral and sponge surveys) and improves the program's ability to identify processes that may lead to declines or a recovery in coral populations (e.g., changes in density or size classes, juvenile coral status and mortality, prevalence of conditions that cause mortality like SCTLD or bleaching, and the role of chronic stressors). Collectively, these surveys continue to allow CREMP to test hypotheses about how reef communities are changing over time in response to acute disturbances or chronic stressors, or corrective actions implemented by the WQPP.

(2) Octocoral Demographic Surveys

This survey is performed at a subset of 20 sites (Appendix III). Octocorals (sea fans, sea rods, and sea whips) are an integral part of many Caribbean reef communities and can rival or outnumber stony corals in certain habitats. Octocorals play vital roles in the reef ecosystem, providing food and shelter to a variety of fish and invertebrates and providing an additional layer of habitat complexity to the reef. CREMP long-term results show that octocoral cover has increased on shallow forereefs where *Acropora* corals were once dominant (Ruzicka et al. 2013). Octocorals are extremely fecund, with several species reproducing multiple times a year and can have extremely fast growth rates (up to several cm/year). Given that octocorals are a major spatial competitor with stony corals, the life history traits of octocorals could further inhibit stony coral recovery at reefs where octocorals have increasingly become the dominant component of the reef community. Octocorals also serve as another indicator for assessing overall reef condition. Like stony corals, many species are susceptible to disease (e.g., red band disease on *Gorgonia ventalina*) or thermal stress (by means of tissue sloughing). By targeting octocorals, CREMP can expand its overall understanding of how reef communities are changing and determine if periodic disturbances or chronic stressors are affecting other taxonomic groups similarly to that of stony corals. Two shallow forereef, two deep forereef, and two patch reef locations within in each region of the Florida Keys (Upper, Middle, and Lower). The survey quantifies the abundance of all octocoral species and collects demographic information (size class, prevalence of disease and bleaching) on a subset of five species - *Antillogorgia americana*, *Antillogorgia bipinnata*, *Eunicea flexuosa*, *Gorgonia ventalina*, and *Pseudoplexaura porosa*.

(3) Xestospongia muta Fate Tracking Surveys

This survey is conducted at 11 deep forereefs CREMP monitors (Appendix III) because *Xestospongia muta* is generally found at depths greater than 10m. Sponges are the most abundant sessile organisms in terms of biomass in many Caribbean reef communities and sponge species diversity can exceed that of stony corals on some reefs (Loh and Pawlik 2014). Sponges play many important roles in the reef ecosystem: filtering bacteria and nutrients from the water column, binding corals to the substrate, facilitating reef regeneration, and providing a food source for spongivores (Pawlik and McMurray 2020). Like octocorals, sponges are also major competitors with corals in terms of reef space. Sponges historically have been neglected from monitoring projects due to the myriad of challenges they pose to researchers. Field identifications can be

difficult due to their plasticity, and sponge systematics are continually in flux on all taxonomic levels. Starting in 2007, CREMP began piloting a survey to track individual colonies of *X. muta* and monitor their survival, growth, and population dynamics. This species is a major contributor to overall sponge biomass and adds to reef habitat complexity and diversity. It is an important indicator of reef health because, similar to corals and octocorals, *X. muta* is susceptible to periodic episodes of bleaching and disease. Monitoring of *X. muta* populations tests the hypotheses that this species responds to environmental regimes similarly to stony corals, and that this species' condition may be used as another proxy for reef health. The survey provides information on the density of *X. muta*, size class information, and the prevalence of malignant conditions affecting the population. The data are intended to provide information on the population dynamics, community structure, and health of these important reef organisms.

Application, Benefits, Importance

The core mission of CREMP is to repeatedly sample fixed stations with broad spatial coverage to statistically document trends of benthic communities within the FKNMS. CREMP has been very successful in detecting community change, a primary objective of the WQPP comprehensive status and trends monitoring programs. CREMP's sampling design has been effective at detecting both short-term (year to year) changes as well as determining long-term trends in benthic community composition. CREMP data has been published in numerous peer-reviewed journals, including *Science* (Gardner et al. 2003), to highlight the coral reef crisis in the Caribbean (Jackson et al. 2014). Results have been cited in numerous FKNMS reports (e.g. 2011 Florida Keys Condition Report) and assist resource managers in understanding and implementing science-based management decisions to protect coral reefs in the FKNMS (Ruzicka et al. 2013, Toth et al. 2014). CREMP data has also been used to support understanding of the spread of SCTLD in the Florida Keys (Muller et al. 2020a), understanding bio-erosional processes affecting Florida Keys reefs (Enochs et al. 2015, Toth et al. 2019), and regional coral assessments (Pandolfi et al. 2005, Maliao et al. 2008, Schutte et al. 2010b).

CREMP fulfills specific management objectives as outlined in the 2002 FKNMS Comprehensive Science Plan. The purpose of the Comprehensive Science Plan is to identify and prioritize the science needs of the FKNMS. CREMP monitoring directly addresses two key management objectives: (1) to determine the causes of coral reef decline, and (2) to identify corrective actions that are required to enhance coral recruitment and growth, and thereby prevent future causes of degradation. CREMP has documented significant losses in coral cover throughout the FKNMS at different spatial and temporal scales. Although identifying the specific agents of decline has been problematic when numerous, essentially synchronous, disturbances have occurred simultaneously, CREMP has clearly documented how coral disease outbreaks, thermal stress events, storms and hurricanes, and harmful algal blooms correlate with widespread mortality or localized mortality within specific regions or habitats. CREMP does not directly address "corrective actions"; however, long-term monitoring is necessary to assess the efficacy of current and future management actions, which in turn can lead to the development of specific studies established to support this objective.

In relation to the last objective, the FKNMS has established a network of 24 fully protected ("no-take") zones, to protect coral reefs from threats such as boat groundings, anchor damage, and

overfishing (both commercial and recreational). These zones, known as Sanctuary Preservation Areas (SPAs), cover approximately 6% of the Sanctuary, but protect 65% of the shallow bank spur and groove reef habitats. The SPAs have been a focal point of resource management strategies used in the FKNMS, and 13 CREMP sites exist within the SPAs. CREMP data from these sites have been incorporated into Sanctuary Science Reports (Keller and Donahue 2002) to evaluate the efficacy of the current zoning strategy and to determine the effectiveness of SPAs in protecting benthic organisms (Toth et al. 2014).

CREMP has documented the reduction in the spatial distribution for many species across sites confirming the vulnerability of certain species to elevated temperature stress or highly lethal stressors such as SCTLD. For example, coral species like *Millepora complanata*, *Favia fagrum*, *Acropora palmata,* and *A. cervicornis* were much more widespread during the early years of monitoring than at present but suffered major declines during the 1997/1998 El Niño that led to mass coral bleaching worldwide. More recently, the lethality of SCTLD, in particular those species within the Meandrinidae family and all brain coral species, have reduced the density of some these species by 95%. The historical declines demonstrating the loss in both abundance spatial coverage for some species in Florida was critically important for the seven corals species that were designated as Threatened under the U.S. Endangered Species Act (NOAA 2014). CREMP's documentation of the catastrophic losses associated with SCTLD have provided important information to help guide multiple response efforts to combat SCTLD. CREMP data also aids the FKNMS permit application review process by helping the FKNMS permit coordinator evaluate the suitability of using specific coral species in research projects and assists in recommending remediation strategies for development projects that may imperil less common species or species vulnerable to disturbance.

Lastly, CREMP data have been used in a variety of outreach and educational tools. Exhibits on global climate change by the Miami Science Museum have used CREMP video and images to teach students about the impacts of global climate change on coral reefs as well footage of environmental documentaries (e.g., Chasing Coral) and FWRI's annual outreach event MarineQuest.

METHODS AND APPROACH

Spatial Design

Sampling locations were initially chosen in 1994 using a stratified random sampling procedure (US EPA Environmental Mapping and Assessment Program). Forty reef sites were selected within the Florida Keys and permanent station markers (four stations per site) were installed in 1995. Annual sampling began in 1996. As mentioned under the objectives, several modifications to the sampling effort have been incorporated to account for WQPP funding reductions and reprioritization of FKNMS monitoring needs. The sampling effort planned for FY 2021 and 2022 includes 40 sites in the Florida Keys: 17 patch reefs (two in the backcountry and 15 oceanside), and 12 shallow and 11 deep forereef sites (Appendix I). Four stations will be surveyed at all sites. Each station is delineated by permanent markers on the inshore and offshore ends (Appendix II).

In addition to adjusting sampling locations, CREMP has modified its sampling design to focus more intensively on the causes of coral reef decline and to understand how reef communities are changing. Core field activities include still camera transects and stony coral demographic surveys

at all stations (N = 4) at all sites (N = 40) (Appendix III). Specialized surveys to address the condition of other associated reef taxa are performed at a subset of sites. Octocoral demographic surveys are performed at 20 sites, and *Xestospongia muta* fate tracking surveys at 11 deep forereef sites. Small *in situ* temperature loggers will continue to be deployed at all sites (Appendix III), even at hardbottom locations where in situ surveys have been discontinued.

A detailed description of diving and vessel operations is provided in the Coral/Hardbottom Monitoring Project Quality Assurance Project Plan and the Standard Operating Procedures (SOPs). All work continues to be conducted under the existing EPA-approved Quality Assurance Project Plan. Standard Field Operation Procedures have been revised annually and are provided to all CREMP team members. Updated SOPs for image acquisition with digital point and shoot cameras have been revised to incorporate use of new technology and software. SOPs have been finalized for coral, octocoral, and *Xestospongia muta* demographic surveys. Coral SOPs and training have been updated to provide an assessment for describing lesions associated with SCTLD. Staff are trained in all protocols and in situ training exercises and classroom lectures are performed annually to aid in maximizing consistency between observers during data collection.

Description of Major Tasks

Task 1 – Still Camera Transects

Comparative analyses were undertaken to ensure that images and data acquired through digital point and shoot cameras were consistent with images and datasets acquired using previous video technologies (Morrison et al. 2012). In addition, statistical appraisals confirmed that long-term trends derived from only the center transect were consistent with the trends observed from data acquired from all three parallel transects at >84% of all stations sampled for all the major benthic taxa (e.g. corals, octocorals, sponges and macroalgae) tested. This allowed a reduction from three transects to one (see Appendix II).

Images are captured using an Olympus point and shoot camera. Transects are prepared by securing a fiberglass tape between two permanent stakes and then laying a plastic chain directly underneath the tape along the substrate. The chain marks the center of the transect (Appendix II). All images are captured at a distance of 40cm above the reef to yield a ~50 cm wide image. An aluminum bar affixed to the bottom of the camera aids in maintaining a constant height above the substrate. Prior to starting each transect, the camera operator photographs a clapperboard that provides metadata on the date and location of each transect. To ensure minimal overlap between images, visual reference points are used to proceed along the transect. Each transect constitutes a sampling area of ~9 m^2; cumulatively the sampling area for an entire site is ~36m^2 (4 transects).

In the lab, images are formatted for PointCount '99 image analysis software (Dustan, 1999). Fifteen random points are placed on each image. Underneath each point, select benthic taxa are identified to species (e.g. corals, *Gorgonia ventalina*, *Xestospongia muta*), genus (e.g. *Dictyota* spp., *Halimeda* spp.), or higher taxonomic levels (e.g. encrusting or branching octocoral, crustose coralline algae, zoanthid, sponge, and macroalgae). The substrate type is identified as consolidated or unconsolidated. The software uses a "point and click" feature that enters the identification data into a spreadsheet. After all images are analyzed, the data are checked for quality assurance and entered into the Microsoft Access database.

Task 2 –Coral Demographic Survey

The demographic survey protocol is similar to that used by the Atlantic and Gulf Rapid Reef Assessment Program (AGRRA) and the Disturbance Response Program (Lang et al. 2010, Wagner and Willis 2010). At all stations divers conduct a single 1m x 10m belt transect starting at the 'offshore' side of the transect (Appendix II). Every stony coral species present is recorded and all colonies ≥4cm are measured to the nearest centimeter with a ruler affixed to a 0.5m PVC stick. The maximum diameter and height taken along the growth plane, presence of diseases and/or bleaching, and visual estimates of recent and old tissue mortality (and its cause if recent) are recorded for each colony. If a disease condition cannot be positively identified, it is recorded as unknown and a series of diagnostic records describing the condition are recorded. Mortality is considered ''recent'' only if the corallite structure can be clearly distinguished and there is minimal overgrowth by algae or other fouling organisms. Otherwise, mortality is classified as ''old'' and causality not assigned. *Millepora alcicornis* is only recorded by presence or absence, not by colony abundance. *Millepora complanata* is enumerated in the survey. Beginning in 2018 all colonies <4cm were enumerated though not measured or assessed further. Data are validated using established quality assurance/quality control protocols back at the FWRI lab.

Task 3 – Octocoral Demographic Survey

At a subset of 20 sites, divers conduct a 1m x 10m octocoral survey at each station (Appendix III). All octocoral colonies within the belt transect are counted, regardless of species. This provides a measurement of overall octocoral density. All colonies of the five target species within the belt transect are recorded and measured - *Antillogorgia americana* (formerly *Pseudopterogorgia americana*), *Antillogorgia bipinnata* (formerly *Pseudopterogorgia bipinnata*), *Eunicea flexuosa* (formerly *Plexaura flexuosa*), *Pseudoplexaura porosa*, and *Gorgonia ventalina*. These species were selected because they can be easily distinguished in the field and are relatively abundant in their preferred reef habitat. For each colony recorded, maximum height is measured. Colonies are measured to the nearest centimeter with a ruler affixed to a 0.5m PVC stick. A visual estimate of disease, syndromes, and bleaching is recorded for each species in addition to any condition leading to compromised health of the colony (e.g., predation, overgrowth). Data are validated using established quality assurance/quality control protocols back at the FWRI lab.

Task 4 – *Xestospongia muta* Survey

Xestospongia muta is predominately found on the deep forereefs and the survey is only conducted at 11 deep forereefs (Appendix III). Two stations are surveyed at each site. Three 1m x 22m belt transects are conducted at each station (Appendix II). With the aid of underwater site maps and pictures taken from the previous year, each colony is relocated. Any new colonies found within the survey area are added into the survey. The maximum diameter at the apex and base of sponge is measured along with maximum height. The presence of bleaching, disease, or predation is recorded for each *X. muta* colony and the recent mortality associated with these conditions is estimated. After all measurements are completed, a picture of the colony is taken. Data are validated using established quality assurance/quality control protocols at the FWRI lab.

Task 5 – *In Situ* Water Temperature

The collection of *in situ* water temperature data continues to be integral feature of CREMP. Data provided by the temperature loggers have been instrumental in characterizing the lethal temperatures observed during the 2010 record breaking winter (Lirman et al. 2011, Colella et al. 2012) and during recent upwelling events that may have triggered extensive macroalgal blooms in the Dry Tortugas (Ruzicka et al. 2018). Temperature loggers are deployed at all sites in the Florida

Keys (Appendix III) inclusive of most of the hardbottom sites no longer surveyed. Temperature data is also collected in the Dry Tortugas via support provided by the National Park Service and in southeast Florida as part of SECREMP. Data collected from the temperature loggers address the hypotheses that temperature varies spatially (e.g., across regions and habitats), and that anomalous or extreme temperature events may induce bleaching and disease, resulting in increased mortality at CREMP sites. Temperature loggers are programmed to record water temperatures at one hour intervals and are retrieved annually.

Statistical Analyses

All project data are entered into a Microsoft Access database, which facilitates data analyses. After entry into the database, each individual record is checked as part of the QA/QC process. Summary statistics will be calculated for coral species richness, density, and size classes. The prevalence of disease and bleaching will be calculated as the number of corals with a malignant condition divided by the total number of corals counted. Summary statistics will also be calculated for octocoral and *Xestospongia muta* density and size classes. The FWRI Coral Program works collaboratively with in-house statisticians to design univariate and multivariate models to analyze datasets collected by CREMP. Recently accepted refereed publications (Ruzicka et al. 2013) demonstrate approaches that are appropriate for CREMP long-term analyses that include analyses of both the percent cover or demographic data.

To test for single year differences (e.g., 2021 vs. 2022) in stony coral, macroalgae, octocoral, and sponge percent cover within sites, a two-way Kenward Roger mixed model ANOVA with year and site (stations nested within site) as factors are used on arcsine square-root transformed point count data pooled for each station. Significant differences between mean overall (combined for all sites) cover for coral, macroalgae, octocoral, and sponges between years were identified from F-tests. Post-hoc paired T tests with a Tukey's correction (to control for repeated testing) are used to compare differences in the mean cover of stony corals, macroalgae, octocorals, and sponges across different sites, regions, habitats or regional habitat combinations (e.g. Middle Keys patch reefs). All data will be analyzed using SAS/STAT® software using a Generalized Linear Model (GLIMMIX). The mixed model accounts for any potential interactions between years, habitats, and regions and allows for the possibility that the effect of year is different in different habitat/regions (or conversely the effect of a site, habitat, or region*habitat combination is independent of the year effect). Appropriate methods to correct for random effects and unequal variances are included in the model. All models are checked for adequacy so the assumptions for normality and homogeneous variance are satisfied.

To evaluate long-term trends in benthic cover variables (stony coral, macroalgae, octocoral, sponge) generalized mixed model regression or cubic polynomial functions (depending on the slope of the data) will be used on square-root transformed percent cover data pooled for each station. Stations are nested within sites and sites nested within regional habitat combinations (e.g. Middle Keys patch reefs) to provide long-term trend information at each level. The models provide a slope calculated from the annual mean percent cover and the slope is identified as increasing or decreasing (at $p<0.05$, or $p<0.001$) if t-tests indicate the slope as significantly different from zero.

Demographic data will be analyzed using generalized linear mixed models (PROC GLIMMIX) in SAS Enterprise Guide® v7.1. Statistical inferences will be based on parameter estimates and post-

hoc contrasts from models fit using PROC GLIMMIX. Annual or multi-year contrasts comparing coral and octocoral density will be performed for all sites or collectively for differing regions, habitats, or regional habitat combinations (e.g. Middle Keys patch reefs). To detect differences in coral and octocoral densities at any level, site and year (or multi-year time intervals) will be used as fixed effects in the generalized linear models. Tests of total coral density and total octocoral density data will be square-root transformed and use a Gaussian/normal link function. For tests of individual coral species or genera complexes (e.g. *Orbicella* complex) data will be transformed and modelled using the distribution (e.g. negative binomial) that provides the best fit of the data. Station data will be nested within sites and where needed random or residual intercepts will be applied to properly structure for autocorrelation effects due to the repeated measures sampling design. Pair-wise post-hoc comparisons will be made with a Bonferroni adjustment based upon the number of comparisons used in the post-hoc assessments.

Environmental Impact

Routine monitoring activities (e.g. photographic and demographic surveys) have no environmental impact. These activities do not require invasive sample collection and the setup of stations are temporary while monitoring is performed.

Future Efforts

CREMP team members have been actively involved in tracking the forward boundary of the SCTLD outbreak as it has progressed through the Florida Keys and Marquesas. During this application period, involvement by CREMP team members with SCTLD surveillance will continue near and around the Dry Tortugas so that response activities can be conducted in a timely manner if and when needed. Additionally, CREMP team members are involved with sample collections aimed at identifying the SCTLD pathogen and intervention attempts that are saving individual corals by placing them in land-based aquariums to preserve genetic diversity. All of these efforts are being coordinated under the Executive Committee Team for SCTLD in Florida.

PROJECT MANAGEMENT

Administration

Rob Ruzicka is the Principle Investigator and Mike Colella is the co-Principal Investigator responsible for overseeing the direction and completion of the project. Rob Ruzicka is the Research Scientist for the FWRI Coral Program and has been responsible for CREMP project management since 2008. His administrative responsibilities are dually programmatic and scientific. This responsibility includes management of coral reef grants and contracts to assure completion of project goals, preparation and management of annual budgets and planning, and coordination of all research activities of the group. Additional responsibilities include recruitment, training and supervision of coral staff (both full-time and hourly), reviewing performance, and ensuring compliance with Commission and FWRI rules, policies, and procedures, and the Coral/Hardbottom Monitoring Project Quality Assurance Project Plan and Standard Operating Procedures.

Mike Colella is an Assistant Research Scientist for the FWRI Coral Program. His primary responsibilities include oversight and management of the CREMP database. He also is responsible for developing Quality Assurance/Quality Control protocols for data entry and field monitoring protocols. Mr. Colella is responsible for coordinating and conducting descriptive and statistical

data analyses and assists in the preparation and review of reports and scientific manuscripts for peer-reviewed journals. Mr. Colella has served as the CREMP co-PI since 2007.

Roles/Assignments and Participation time

Below is a list of participants on the CREMP team. The amount of time spent supporting the project is listed in the budget.

FWC/FWRI PRINCIPAL INVESTIGATORS

Richard Robert Ruzicka III, MS, Research Scientist, Habitat/Coral Reef Research, Principal Investigator, Project Manager, Contract Manager, Team leader, Benthic Reef Ecologist, Supervises staff, and writes reports and presents project results

Mike Colella, MS, Assistant Research Scientist, Habitat/Coral Reef Research, Co-Principal Investigator, Coral Reef Ecologist, Data manager, QA/QC Coordinator, FWRI SECREMP Award Manager

FWC/FWRI CORAL REEF RESEARCH TEAM

Stephanie Schopmeyer, MS, Research Scientist, Habitat/Coral Reef Research, Coral Reef Ecologist, Acropora restoration specialist, FWRI Response Lead for SCTLD Coral Rescue and Recon and Intervention Teams

Lindsay Huebner, MS, Research Assistant, Habitat/Coral Reef Research, PI on SCTLD Investigative Study and PI on Gulf of Mexico Benthic Monitoring, Diving Safety Board Officer for Corals Team, Leads Coral Species and Disease Identification Trainings for CREMP and DRM

Ananda Ellis, MS, Research Assistant, Habitat/Coral Reef Research, Coral Reef Ecologist, PI on Acropora Monitoring & Research (Funded by NOAA Protected Species)

Jennifer Stein, MS, Biological Scientist II, Habitat/Coral Reef Research, Coral Reef Ecologist, PI on Disturbance Response Monitoring (funded by EPA)

Nate Berkebile, MS, Biological Scientist II, Habitat/Coral Reef Research, Coral Reef Ecologist, Leads *Xestospongia muta* monitoring, Field operations leader for CREMP, Vehicle & Vessel Safety Officer

Devon Pharo, MS, Biological Scientist II, Habitat/Coral Reef Research, Coral Reef Ecologist

Allan Anderson, MS, Biological Scientist II, Habitat/Coral Reef Research, Coral Reef Ecologist, Coral caretaker for SCTLD Coral Rescue Project

Katy Cummings, MS, Fish & Wildlife Technician, Habitat/Coral Reef Research, Coral Reef Ecologist, Outreach and communications liaison

Tiffany Boisvert, Fish & Wildlife Technician, Habitat/Coral Reef Research, Current Master of Science student at University of South Florida, Oversees CREMP temperature data collection and database

Christina Mallica, BS, Biological Scientist I, Habitat/Coral Reef Research, Oversees CREMP image acquisition and preparation and distribution of image files

SUPPORT REQUIREMENTS AND CONDITIONS

Cooperation from Other Organizations

FWRI & CREMP have a long history of working both in the FKNMS and Dry Tortugas National Park. CREMP is permitted to complete all activities outlined in this proposal under FKNMS permit #2013-059-A1 and the Dry Tortugas National Park permit #DRTO-2018-SCI-0011.

Data and/or Facility Access
The comprehensive data management effort is based at FWRI. All CREMP team members are qualified for data entry, summary statistics, and other data management duties. CREMP data management encompasses the following duties: track, concatenate, and oversight of QA/QC protocols, distribution of QA/QC assignments, and compilation of a master dataset of all project data; organize mathematical summaries of annual data; distribute the summaries and master dataset to the Project Manager on a timely basis; provide summary tables at the request of the Project Manager for incorporation into reports as needed and act as liaison between the Monitoring Program, the statistical consultants, and the Florida Keys National Marine Sanctuary Data Management Workgroup. These tasks will be continued under this project work period.

Data collected by the monitoring program is provided to the Information Science and Management Section (IS&M) at FWRI for inclusion into STORET and/or other databases consistent with EPA and FWC database requirements. Additional synthesized data will be provided to the IS&M Section for inclusion into a FWC GIS database. Metadata for all datasets (photographic and demographic) are compliant with Federal Geographic Data Committee (FGDC) standards. Raw data includes copies and originals of all field datasheets, video tapes (Hi-8 for 1996-1999 and digital for 2000-2009), hard drives for images collected after 2010, and copies of field logs (for image acquisition). All data files, original and copies, are secured at FWRI. Data are also stored on the FWRI server, which is backed-up on a regular basis.

RESULTS/OUTPUTS and DELIVERABLES
Biannual Progress Reports
Biannual reports will continue to be submitted as required. Biannual progress reports will follow the approved EPA format. Biannual reports will continue to update progress on Tasks 1-5 under the Description of Major Tasks, any problems encountered, actions taken to resolve problems, the financial expenditures related to completing project tasks, and discussion of upcoming/future tasks. Biannual reports are due 30 days following the preceding work period (e.g. April 30th following the October 1 – March 30 work period; October 30th following the April 1 – September 30 work period).

Executive Summaries and Final Report
Executive summaries will be provided annually and summarize the data collected in previous years and highlight the program's findings. A PowerPoint presentation and/or a written executive summary (when requested) will be provided at the WQPP Steering Committee. These meetings are generally held in the summer and winter every year. A Comprehensive Final Report consisting of analyses of all data collected throughout the funding period will be submitted as a final report. Project staff will address comments by the EPA, the Technical Advisory Committee, the Steering Committee, and NOAA Coastal Ocean Program as requested.

Plan and Schedule for Tracking Deliverable Items
The schedule of activities in this proposal can be broken down into four categories: field sampling, data entry and post processing, data analysis, and report and WQPP Steering Committee presentation preparation. These activities will be described in biannual reports. Field sampling typically occurs during May-September, data entry and post processing during September-March, and data analysis and report preparation March-April.

Environmental Results
The outputs and outcomes from the proposed monitoring are described in the methods and approach. Progress in completing the activities associated with CREMP will be summarized in biannual reports, WQPP steering committee meeting presentations, and executive summaries and final reports.

BUDGET INFORMATION

Summary, Including Co-Funding
See attached itemized budget (Excel spreadsheet) and written budget justification.

EPA Form (SF 424A)
See Attached

PAST PERFORMANCE AND PROGRAMMATIC CAPABILITY

Environmental Results Past Performance
FWC/FWRI has been conducting CREMP activities since 1996. During this time FWRI has received funding from both EPA and NOAA to complete CREMP annual monitoring. Since 2004, the National Park Service has provided funding to support CREMP in the Dry Tortugas National Park. CREMP in Southeast Florida (SECREMP) has been supported by the NOAA Coral Program and the Florida Department of Environmental Protection. Although all three programs are conducted separately, the FWRI Coral Program provides oversight and data management to ensure consistency with CREMP goals and objectives. In addition, the FWRI Coral Program administers the Disturbance Response Monitoring Program in Florida which uses a random stratified approach to sampling allocation rather than the repeated measures design of CREMP. Together, the FWRI Coral Program is responsible for the two largest benthic monitoring programs on Florida's Coral Reef. The FWRI Coral Program has also been awarded funds to assess benthic recovery in the Gulf of Mexico after a severe harmful algal bloom in 2017. A list of the awards is as follows:

1) Coral Reef Evaluation and Monitoring Project - Florida Keys National Marine Sanctuary - Award X7-00D39315-1 (Closes 9/30/2022). For this project, biannual progress reports were submitted. Executive summaries and oral presentations at the WQPP Steering Committee Meeting were provided annually. Performance measures (e.g. percent coral cover) were provided to the EPA grant administrator. Deliverables and reporting for this project are in good standing.

2) Dry Tortugas National Park (DRTO) Long Term Coral Reef Monitoring & Assessment Project – Cooperative Agreement # P16AC00991 (Ongoing). This CA supports both CREMP and DRM in the Dry Tortugas. CREMP provides biennial reports in even-year reporting years and executive summaries in odd-year reporting years. DRM provides an annual report. Tri-annual updates are submitted for two ESA listed corals (*Dendrogyra cylindrus* and *Acropora palmata*). Biannual progress reports are also submitted. Technical presentations to the NPS are prepared as needed. All data have been provided to the NPS grant administrator. Deliverables and reporting for this project are in good standing.

3) Southeast Florida Coral Reef Evaluation and Monitoring Project (SECREMP) – FDEP Purchase Order No. B54B0E (Ongoing). For this project, annual reports are submitted that

confirm all data has been received, undergone QA/QC, and stored according to the data management requirements outlined under Data and/or Facility Access. All data has been delivered the FDEP contract manager and data summaries provided to the SECREMP PI at Nova Southeastern University. Deliverables and reporting for this project are in good standing.

4) Disturbance Response Monitoring 2020 – Award X7-01D00320-0 (Ongoing). For this project, biannual reports are submitted that summarize field efforts and data collected. The annual Quick Look report is a deliverable that summarizes each program year. All biannual reporting for this project is in good standing. The Quick Look report is scheduled to be released in April of 2021.

5) Assessing Benthic Recovery Ten Years After the 2005 Harmful Algal Bloom on the West Florida Shelf – Conserve Wildlife Grant CWT 1819-12 (Closed 12/31/2019). This project has been completed. A final report was delivered on time and all deliverables approved by the granting agency.

Programmatic Capability

FWRI is the research division of the Florida Fish and Wildlife Conservation Commission. FWC/FWRI's statewide research programs focus on obtaining data and information needed by natural resource managers and stakeholders. Among other mandates, Florida Statutes charge FWRI with monitoring marine and freshwater resources, wildlife, and habitats and providing technical support for State and local government public and natural resources health concerns. FWC/FWRI has been conducting CREMP activities since 1996. Underwater sampling will be performed by FWRI Coral Program divers using SCUBA supplemented by NITROX to enhance safety when necessary. FWRI's Coral Research group maintains and operates a 22' Whaler and 26' Twin Vee research vessels specifically to support CREMP fieldwork. All FWRI staff are trained in CREMP SOPs and all work continues to be conducted under the existing approved EPA Quality Assurance Project Plan.

LEVERAGING

The State of Florida supports the salary of the FWC/FWRI Principal Investigator that manages CREMP operations. The Research Administrator (Rob Ruzicka) is matched 25% to the grant. The State of Florida also supports the salary of the FWRI's Coral Program Associate Research Scientist (Stephanie Schopmeyer) who is matched to CREMP for 12.5% of her time (see budget). Financial assistance through a cooperative agreement with the National Park Service (NPS) supports CREMP benthic resource assessments in the Dry Tortugas. Sampling of the three historical EPA CREMP sites in the Dry Tortugas are now included as part of the NPS CREMP monitoring activities. The CREMP team members supported by means of this application are also supported by other financial awards and grants that are highly complementary to CREMP objectives (e.g., DRM, SCTLD research, ESA coral research (e.g., *Acropora*), and Gulf of Mexico Benthic Monitoring assessments) and alleviate the CREMP program to have to fully sponsor full-time annual salaries for CREMP team members. FWRI oversees CREMP in all three jurisdictions (Dry Tortugas, Florida Keys and Southeast Florida) which allows for consistency with the goals, objectives, hypotheses addressed, and the protocols employed. Lastly, in addition to CREMP, FWRI oversees and administers the DRM program which makes FWRI the lead institution for the two most comprehensive benthic monitoring programs in the State of Florida.

APPENDICES

Appendix I. Map of CREMP sites supported by the EPA WQPP in the Florida Keys.
Appendix II. Past and Present monitoring methods
Appendix III. Work to be performed in FYs 2021 and 2022 at each site.

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CREMP BUDGET JUSTIFICATION FY 2021 & 2022 (10/1/2021 -9/30/2023)

See attached excel spreadsheet

APPENDIX I. CREMP SITES SUPPORTED BY EPA WQPP IN FLORIDA KEYS

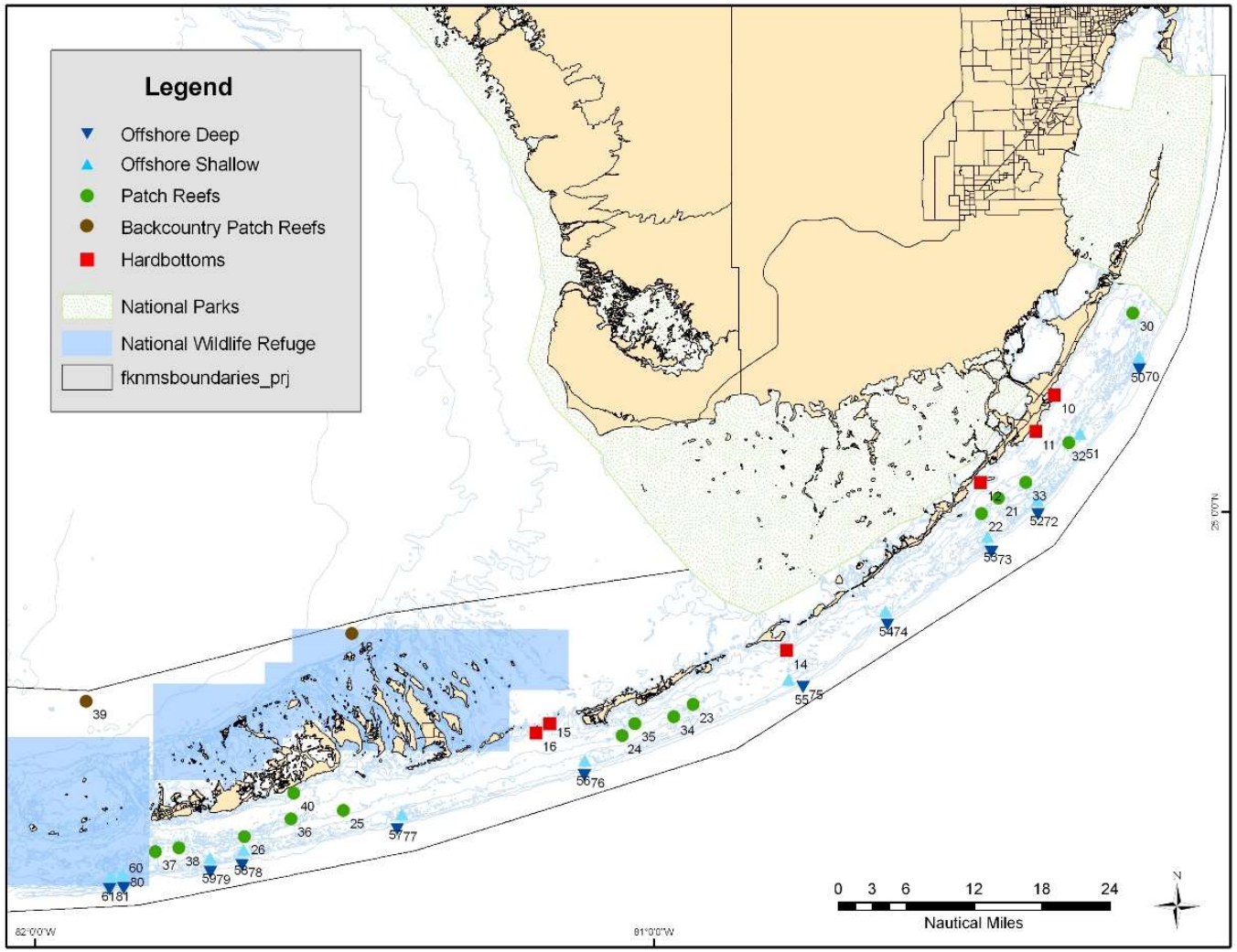

Figure 1. Location of 46 CREMP sites in the Florida Keys. Sites demarcated by red squares (nearshore hardbottom) are currently used for in situ temperature monitoring only. Annual sampling of benthic cover and demographic surveys have been discontinued at these six locations. All other 40 sites will be surveyed in FYs 2021 and 2022.

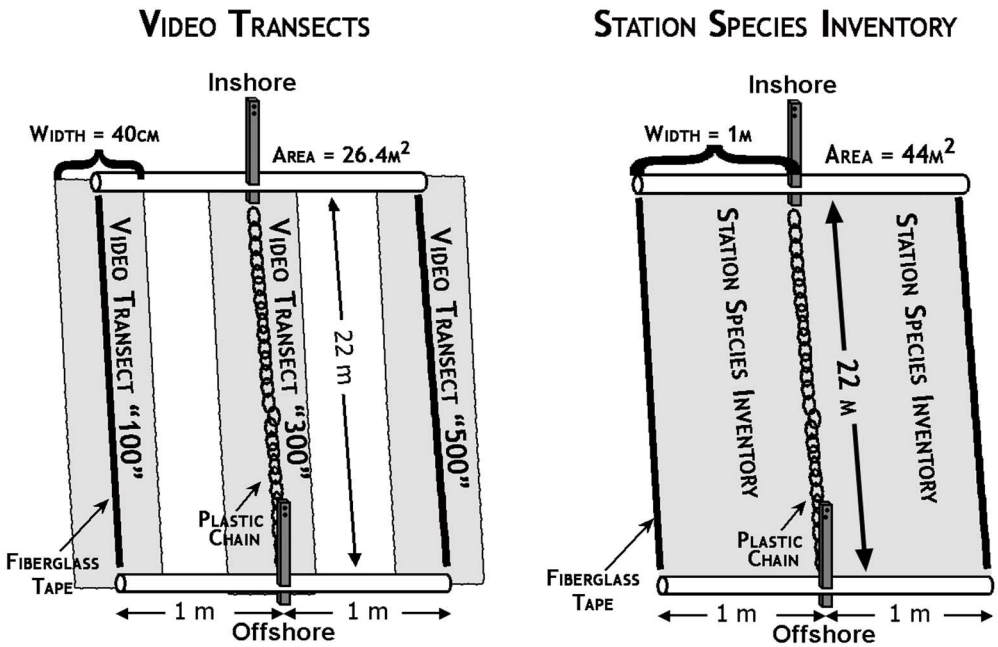

Figure 2. Previous survey design prior to 2011. Three video transects and a timed station species inventory were conducted annually at each station. Each station consisted of three parallel transects defined as the "100", "300", and "500" transects which were filmed with video. The timed station species inventory occurred within the boundaries of the "100" and "500" transects and "offshore" and "inshore" sides of the station.

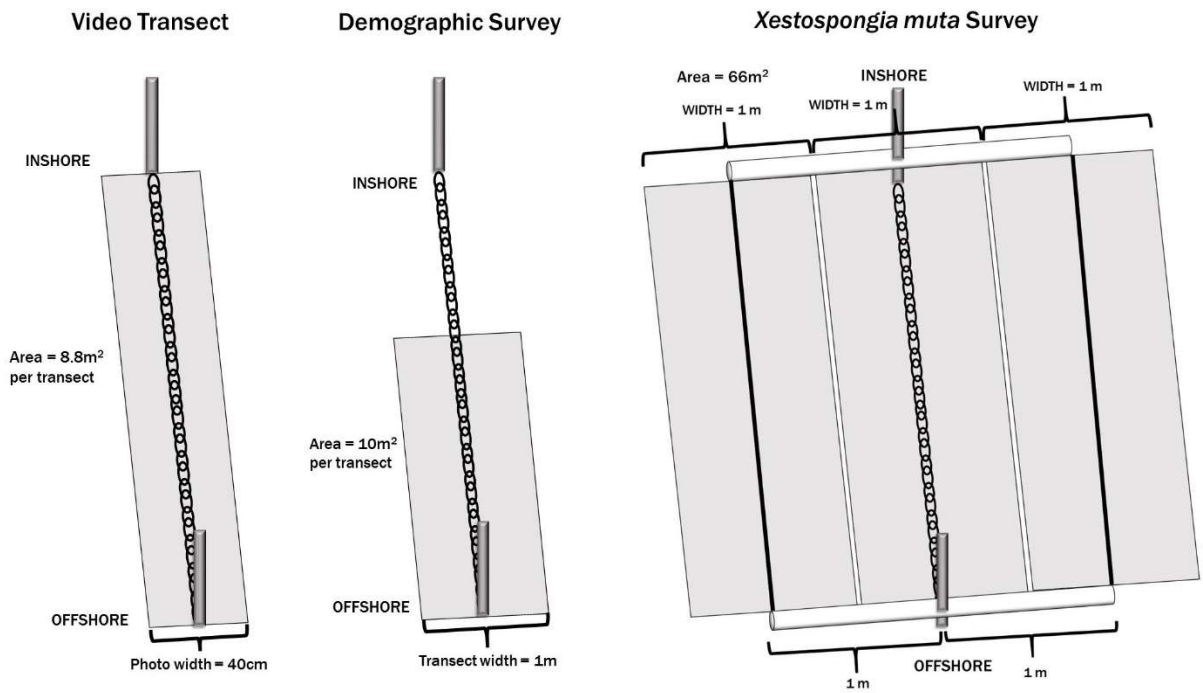

Figure 3. Current survey design. All CREMP sites consist of four monitoring stations delineated by permanent markers. Still camera transects only survey a centered transect between the permanent station markers and encompass $8.8m^2$ (22m x 0.5m) of reef per station. The octocoral and stony coral demographic surveys are performed on the first 10m of the centered transect and encompass a 1m x 10m survey area. Three parallel 1m x 22m belt transects are surveyed for *Xestospongia muta* encompassing a total survey area of $66m^2$. All surveys are conducted annually.

Appendix III. Location, reef type, number of stations sampled, and work performed at 46 CREMP sites in the Florida Keys. LK = Lower Keys, MK = Middle Keys, UK = Upper Keys. Habitat designations: BCP = Backcountry Patch Reef, D = Deep Forereef, P = Oceanside Patch Reef, S = Shallow Forereef. Work to be performed in FYs 2021 and 2022 designated with an X.

Region	Site	Habitat	Stations	Latitude	Longitude	Camera	Stony	Octocoral	Xesto	Temp
LK	Content Keys	BCP	4	24.8221	-81.4889	X	X			X
LK	Smith Shoal	BCP	4	24.7197	-81.9195	X	X			X
LK	Looe Key Deep	D	4	24.5421	-81.4153	X	X		X	X
LK	Eastern Sambo Deep	D	4	24.4884	-81.6659	X	X		X	X
LK	Western Sambo Deep	D	4	24.478	-81.7171	X	X	X	X	X
LK	Rock Key Deep	D	4	24.4532	-81.8568	X	X		X	X
LK	Sand Key Deep	D	4	24.4517	-81.8798	X	X	X	X	X
LK	Wonderland	P	4	24.5603	-81.5021	X	X			X
LK	Red Dun	P	4	24.5209	-81.6621	X	X			X
LK	West Washer Women	P	4	24.5475	-81.5866	X	X	X		X
LK	Western Head	P	4	24.4977	-81.8056	X	X			X
LK	Cliff Green	P	4	24.5036	-81.7677	X	X	X		X
LK	Jaap Reef	P	4	24.5857	-81.5826	X	X			X
LK	Looe Key Shallow	S	4	24.5453	-81.4079	X	X			X
LK	Eastern Sambo Shallow	S	4	24.4917	-81.6635	X	X			X
LK	Western Sambo Shallow	S	4	24.4796	-81.7176	X	X	X		X
LK	Rock Key Shallow	S	4	24.4545	-81.8589	X	X			X
LK	Sand Key Shallow	S	4	24.452	-81.8775	X	X	X		X
MK	Alligator Deep	D	4	24.8452	-80.6209	X	X	X	X	X
MK	Tennessee Deep	D	4	24.7527	-80.7578	X	X	X	X	X
MK	Sombrero Deep	D	4	24.6223	-81.112	X	X	X	X	X

Appendix III. Location, reef type, number of stations sampled, and work performed at 46 CREMP sites in the Florida Keys. LK = Lower Keys, MK = Middle Keys, UK = Upper Keys. Habitat designations: BCP = Backcountry Patch Reef, D = Deep Forereef, P = Oceanside Patch Reef, S = Shallow Forereef. Work to be performed in FYs 2021 and 2022 designated with an X.

Region	Site	Habitat	Stations	Latitude	Longitude	Camera	Stony	Octocoral	Xesto	Temp
MK	Long Key	H	4	24.7972	-80.784					X
MK	Moser Channel	H	4	24.6891	-81.1676					X
MK	Molasses Keys	H	4	24.6756	-81.1905					
MK	Rawa	P	4	24.7176	-80.9357	X	X			X
MK	Thor	P	4	24.6715	-81.0506	X	X			X
MK	West Turtle Shoal	P	4	24.6993	-80.9669	X	X	X		X
MK	Dustan Rocks	P	4	24.6895	-81.0302	X	X	X		X
MK	Alligator Shallow	S	4	24.8457	-80.624	X	X	X		X
MK	Tennessee Shallow	S	4	24.745	-80.7812	X	X	X		X
MK	Sombrero Shallow	S	4	24.6253	-81.1116	X	X	X		X
UK	Carysfort Deep	D	4	25.2208	-80.2099	X	X	X	X	X
UK	Molasses Deep	D	4	25.0072	-80.3756	X	X	X	X	X
UK	Conch Deep	D	4	24.9519	-80.4513	X	X		X	X
UK	Rattlesnake	H	4	25.1736	-80.3475					X
UK	El Radabob	H	4	25.1201	-80.3782					X
UK	Dove Key	H	4	25.0447	-80.4684					X
UK	Two Patches	P	4	25.0219	-80.439	X	X			X
UK	Burr Fish	P	4	24.9992	-80.4669	X	X			X
UK	Turtle	P	4	25.2947	-80.2191	X	X			X
UK	Porter Patch	P	4	25.1032	-80.3243	X	X	X		X
UK	Admiral	P	4	25.0447	-80.3948	X	X	X		X

Appendix III. Location, reef type, number of stations sampled, and work performed at 46 CREMP sites in the Florida Keys. LK = Lower Keys, MK = Middle Keys, UK = Upper Keys. Habitat designations: BCP = Backcountry Patch Reef, D = Deep Forereef, P = Oceanside Patch Reef, S = Shallow Forereef. Work to be performed in FYs 2021 and 2022 designated with an X.

Region	Site	Habitat	Stations	Latitude	Longitude	Camera	Stony	Octocoral	Xesto	Temp
UK	Carysfort Shallow	S	4	25.2201	-80.2105	X	X	X	X	X
UK	Grecian Rocks	S	4	25.1075	-80.3068	X	X			X
UK	Molasses Shallow	S	4	25.0088	-80.3765	X	X	X		X
UK	Conch Shallow	S	4	24.9553	-80.458	X	X			X