AMENDMENT TASK 2 – SCOPE OF WORK: Residential Canal WQ Impacts on Near Shore Environs

A summary of the overall costs are:

TASK 2: Residential Canal WQ impacts on Near Shore Environs	YEAR 1 2019	YEAR 2 2020	YEAR 3 (Jan - May) 2021	Not to Exceed total
WQ, BENTHIC SAMPLING, and EXTREME EVENT	$211,568	$189,967	$85,323	**$486,857**

PROJECT OVERVIEW AND RATIONALE

As a separate effort and task, Monroe County has contracted the University of Miami Coastal Ecology Laboratory to carry out nearshore water quality monitoring at 65 stations throughout the Keys in a partnership with the Florida Department of Environmental Protection (FDEP). FDEP assesses available water quality data for each surface waterbody in Florida at least once every five years using the Impaired Waters Rule (IWR), Chapter 62-303, Florida Administrative Code (F.A.C.), which establishes a scientific methodology for identifying surface waters in Florida that are impaired for pollutants. Nearshore waters in the Keys were identified as impaired in 1986. The surface water bodies that comprise the Florida Keys Reasonable Assurance Document (FKRAD) are in a Group 5 basin.

Monitoring to evaluate the implementation of the FKRAD, (referred to as "Task 1" in the contract) is a 2-year study to monitor water quality stations within 500 meters from the shoreline to document changes in water quality after recent upgrades to managing land-based sources of pollution in Monroe County. These upgrades include improved storm-water management and county-wide conversion from residential septic to central wastewater treatment. This FKRAD update coincides with the assessment cycle to demonstrate reasonable assurance to the U.S. Environmental Protection Agency (EPA) that pollution control mechanisms will result in attainment of water quality standards in the future, thereby eliminating the establishment of a total maximum daily load (TMDL) for the FKRAD waterbodies. Thus, Task 1 samples 65 stations quarterly over two years and uploads water quality data into the Watershed Information Network (WIN) to demonstrate compliance with these targets.

The original FKRAD was developed by FDEP as a plan in cooperation with local governments, state agencies, and federal agencies within the Florida Keys to set forth and accelerate the actions that had been taken or were planned to be taken to specifically reduce nutrient loadings to nearshore waters so that water quality standards are met and beneficial uses are restored.

The scale of watersheds makes interrelationships between the hydrological cycle, plant diversity and natural communities easily perturbed by land-use changes on small islands. Patterns of human development in the Florida Keys have had immense impacts on ecosystem function, and have historically accelerated the amount of freshwater and nitrogen entering the hydrological cycle. Some of these trends have been reversed recently with restoration and remediation efforts

Small islands allow nutrients and sediment to enter near shore waters through groundwater seepage and surface storm run-off (Aronson et al., 2003). Tropical carbonate islands such as the Florida Keys once relied on dense broadleaf forests and mangrove wetlands to restrict nutrient input to marine environments, supporting clear turquoise waters indicative of oligotrophic conditions. The Florida Keys now has about 500 dredged canals of varying depths, lengths, and orientations. Canals can trap organic material, including seaweed and seagrass, which accumulates and contributes to poor water quality with the accumulation of nutrients. Poor design and circulation in canals have been addressed in the past through a series of demonstration projects to remediate this problem through back-filling, adding culverts, or adding seaweed curtains. Universal wastewater treatment has been implemented throughout the Florida Keys, removing cesspits and septic systems as a source of land-based sources of nutrients. However, the legacy of the past rests at the bottom of dredged canals ("Eutrophication in coastal canals," 1972).

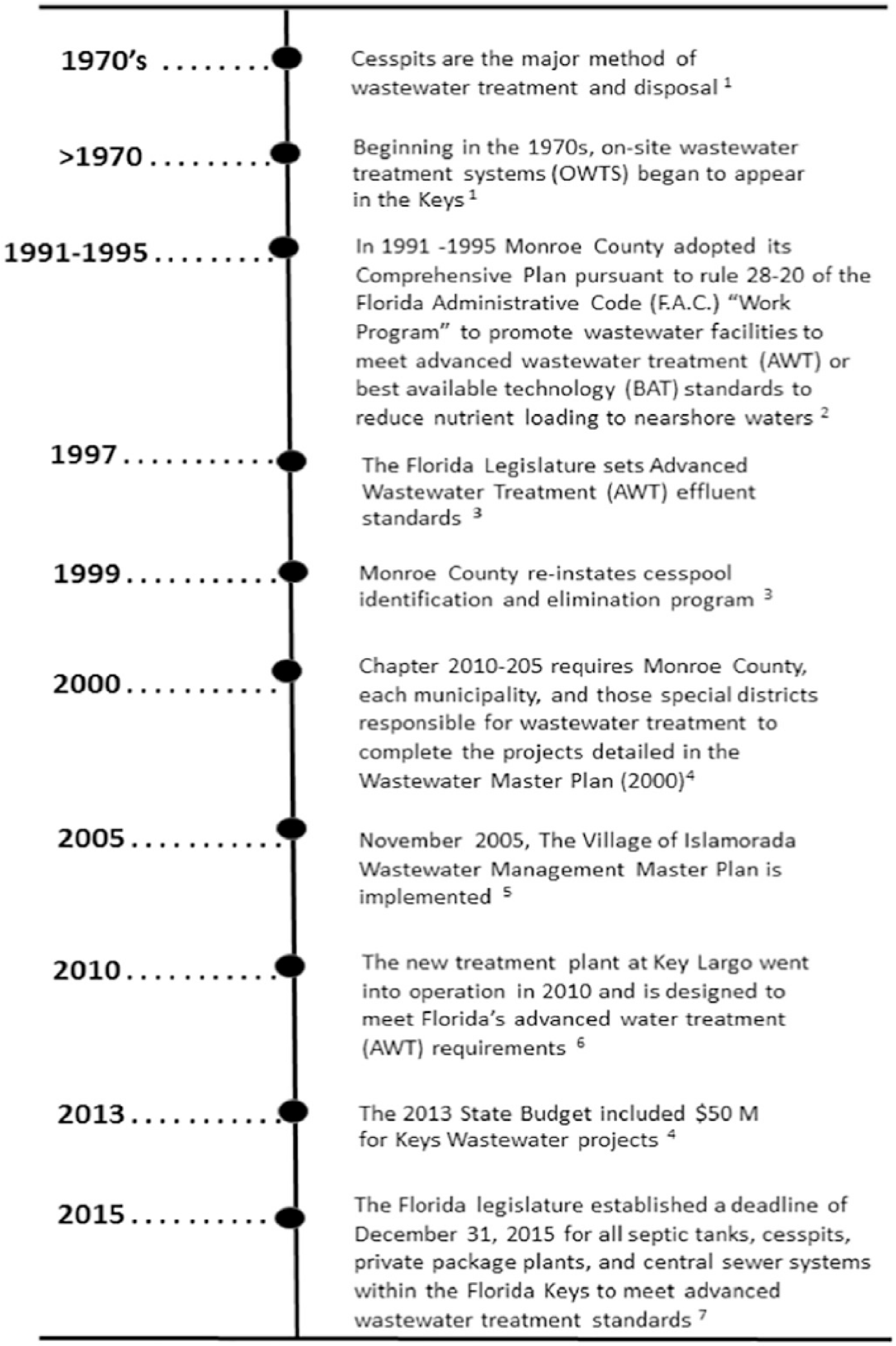
Nearshore marine communities are the downstream recipients of freshwater and nutrients from island hydrological cycles. Changes in island hydrology have potential repercussions for near shore habitats as they have been the most acutely impacted by eutrophication with the extirpation of invertebrate species and dramatic changes in the ecological community composition (De Carlo, Hoover, Hoover, Young, & Mackenzie, 2007; Lapointe & Matzie, 1996; Wagner, Mielbrecht, & van Woesik, 2008; Wolanski, Martinez, & Richmond, 2009)

The question to be addressed in this scope of work ("Task 2") is, "***Do canals in the Florida Keys contribute to nearshore water quality degradation?"*** The scope of work over two years should provide a "Yes", or "No" answer to this question with supporting data and analyses. The challenge is to design an efficient and cost-effective plan to understand any "halo" effect of nutrients from canals moving into adjacent nearshore environments.

Task 2 aims to address this question broadly by looking at 9 canals throughout the Florida Keys and comparing canal assessment to underdeveloped shorelines ("non-canals") primarily in parks and protected areas. The operation premise in FKRAD assessments is that Task 1 water quality stations located 500 meters from shore are at the limit of land-based sources of pollution (e.g. from run-off and canals), and thus represent an assessment of regional (vs. local) influences on nutrient loading. Task 2 will examine the "gap" from the canals to the 500 m Task 1 stations by sampling across a randomized block design of the shoreline to 500 m offshore gradient.

Task 2 is a "stand-alone" project designed to specifically address the question of residential canal contributions to nearshore water quality. This study will address the potential contributions of local vs. regional factors in degradation of near shore water quality after the compliance Keys-wide of advanced waste water treatment (Figure 1).

*Figure 1: Timetable of the major policies and reports that impact Florida Keys wastewater transmission and treatment (Barreras, Kelly, Kumarb, & Solo-Gabriele, 2019)***.**



TASK 2 DESCRIPTION: RESDENTIAL CANAL IMPACTS ON NEARSHORE WATER QUALITY STUDY:

The task is designed to answer specific questions relating to the impact of residential canals on the near shore water quality of the Florida Keys, regardless of canal design, size and orientation. The questions to be answered include:

1. Is there a difference in water quality between nearshore waters adjacent to canals, and nearshore waters not adjacent to canals, and does the distance from shore (zone) have an effect (up to the 500m distance from shore)?
2. Is there a difference in the number of and diversity within marine habitat types (e.g. CMECS biotopes[1]) between canal and non-canal nearshore environments, and does the distance from shore (zone) have an effect (up to the 500m distance from shore)?
3. Is there a difference in the epifauna community composition and diversity between canal and non-canal nearshore waters, does the distance from shore matter, and how does the epifauna composition and diversity compare to a reference expectation?

A STANDARD QUALITY ASSURANCE PLAN (QAPP) DOCUMENT will be submitted as per the FDEP protocols and reviews for this task. The task will include the collection of water quality and benthic data; all water quality data collected for this contract will need to be uploaded quarterly by the contractor into the Department's Watershed Information Network (WIN) database.

This task will sample surface water quality on a quarterly basis in 9 residential canals and in 4 "non-canal" sites throughout the Florida Keys, collecting up to 15 samples per site for each quarter. Biotic sampling will occur twice a year (wet season/ dry season) at all the water quality sampling stations to document biological diversity and natural community classification in and around the canal environs. In addition, surface water samples will be collected at some stations up to 48 hours after an extreme rainfall or storm event to document event impacts[2], up to 187 additional water quality samples in one year.

TASK OVERVIEW:
Start Date: 1 April 2019
End Date: 31 August 2021
Number of Sites = 13

- 9 canal sites
- 4 non-canal sites

Number of Site Water Quality Samples:

- 9 canal sites with 15 samples per canal block array
- 4 non-canal sites with 13 samples per non-canal block array (no samples taken inside canals)

TOTAL WATER QYUALITY SAMPLES per QUARTER = 15*9 = 135 (canal samples) + 4* 13 =53 (non-canal samples) = **187**

---

[1] Coastal and Marine Ecological Classification Standard (CMECS), see https://iocm.noaa.gov/cmecs/

[2] Extreme events can be defined by a specific meteorological trigger, for example, over 2" of rainfall in on 24 hour period is extremely rare, and has occurred only twice in Key West over the past 10 year (apart from direct hurricane impacts).

ONE EXTREME RAINFALL EVENT SAMPLING = up to 187 samples (optional)
Estimated total number of Canal Monitoring Water Samples per year: 748 to 935 samples (187 stations sampled 4 times each calendar year, plus an optional extreme event sampling).
Biodiversity Assessment = All 13 sites surveyed twice annually, Biological Assessments will be carried out at the same sites, with 6 stations within sites sampled twice a year (84 * 2 = 168 benthic surveys annually). Benthic stations are a subset of the water quality stations.

Task 2 will

1. Perform comprehensive water quality nutrient data monitoring of 13 sites with block design sampling to support the County's canal program to determine the connection and impact of canals on the nearshore waters with quarterly sampling,
2. Report and upload to Florida's Watershed Information Network (WIN) the water quality data collected,
3. Perform an ecological survey of benthos along the same 13 sites with bloc design sampling to determine the response of biotic communities to water quality with sampling twice a year (wet season/ dry season), and
4. Perform comprehensive nutrient data monitoring at water quality stations after an extreme rainfall event for up to 187 stations in a calendar year.

<u>Task 2a: Water Quality Block Design Description</u>

Sampling Area Design

Water samples will be collected in a "block design," using stratified random sampling of a series of stations that exist within a total sampling area that extends 500 meters out from the mouth of the canal and 100 meters parallel to the shoreline in both directions. This will result in a 500 m X 200 m area which will be divided into 50 m X 50 m blocks. The sampling area is divided into 40 blocks. The overall sampling area will be divided into three zones which will extend perpendicular from the shoreline. Zone 1 will extend from the mouth of the canal to 100 m from shore. Zone 2 will extend from the edge of Zone 1 out another 200 m from shore and Zone 3 will extend from the edge of Zone 2 out an additional 200 m (to 500 m from shore). See **Figure 2** below for an example of sample area design in Key Largo

Figure 2: Illustration of the block design to sample water quality from inshore to offshore from canal openings in the Florida Keys. A grid will be established in GIS that will extend 200 meters perpendicular to the mouth of the canal, and 500 meters offshore.

Sampling Area Design

Block sampling will be completed in two types of areas: <u>canals</u> (N=9) and <u>restored or intact coastlines</u> (N=4) to allow for comparison between the canal and "non-canal" environs. The annual monitoring will consist of an estimated 187 samples per quarter divided across 13 study sites with up to 15 samples per site per quarter; using the following distribution (See **Figure 3**):

A. 1 sample from the midpoint of the canal
B. 1 sample from the mouth of the canal
C. 2 samples from the offshore corners of the sampling area (100 m parallel to the mouth of canal, 500 meters perpendicular to the mouth of canal)
D. 2 samples from the inshore corners of the sampling area (100 m parallel to mouth of canal, as far in shore as is accessible by sampling vessel)
E. 3 samples from randomly selected blocks in Zone 1
F. 3 samples from randomly selected blocks in Zone 2
G. 3 samples from randomly selected blocks in Zone 3

Non-canal sites will have 13 stations, lacking the 2 stations at the midpoint and mouth of the canal.

Figure 3: Blocks will be selected randomly for each quarterly sampling event, with a total of three samples taken in each zone. Sample locations A-G correspond to the list above.

The sample locations will require a boat for accessibility and three staff per sampling team. The sampling guidelines are as follows:

a. Collect samples only on *outgoing* tides, while water is leaving the canal.
b. Ensure wind is not impeding water from flowing out of the canal, with collection of samples at mid-depth if wind is an issue.

Interpolation of data

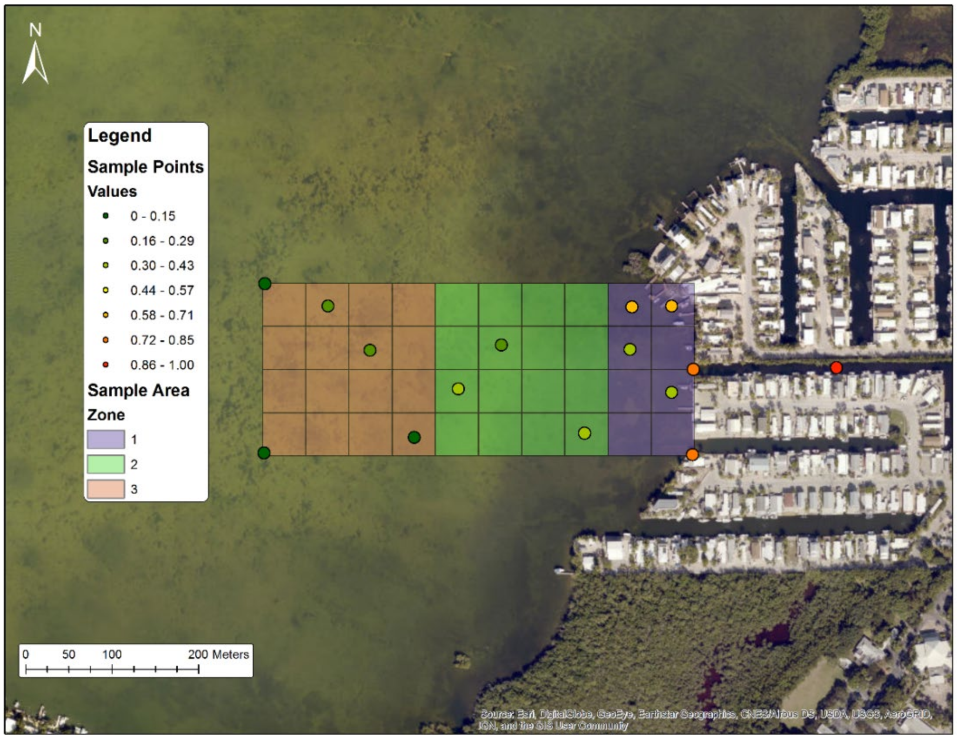
The data from the 15 samples will be interpolated to create a raster surface to estimate the water quality parameters across the entire sampling area using a spline interpolation and a grid size of 5 meters. See **Figure 4** for example of interpolated data surface. **Table 1** includes a list of water quality parameters which will be assessed at each sampling station within the sampling area.

Table 1: List of water quality parameters to be assessed at each station

Parameter	Sample Type	Description	Analytic Method	MDL
NO_x	Water Grab	Nitrite+Nitrate in aqueous matrices as mg/L as N	EPA 353.2 Rev. 2.0	0.004 mg/L
TP	Water Grab	Total Phosphorus in aqueous matrices as mg/L as P	EPA 365.1 Rev. 2.0	0.002 mg/L
TKN	Water Grab	Total Kjeldahl Nitrogen in aqueous matrices as mg/L as N	EPA 351.2 Rev. 2.0	0.08 mg/L
Chlorophyll *a*	Water Grab	Phytoplankton chlorophyll-a (corrected for phaeophytin)	SM 10200 H (mod.))	$\leq$ 1.0 ug/L

		and phaeophytin by spectrophotometry		
Dissolved Oxygen	Field Measurement	Dissolved oxygen (DO) concentration in water measured by field meter	Discrete Measurement	Not applicable
Percent DO Saturation	Field Measurement	Percent DO saturation in water measured by field meter	Discrete Measurement	Not applicable
pH	Field Measurement	pH level in water measured by field meter	Discrete Measurement	Not applicable
Specific Conductance	Field Measurement	Specific conductance of water measured by field meter	Discrete Measurement	Not applicable
Water Temperature	Field Measurement	Water temperature measured by field meter	Discrete Measurement	Not applicable

A list of the selected canal and non-canal sites is presented in **Table 2**, with a map illustrating the distribution of these sites throughout the Florida Keys in **Figure 5**



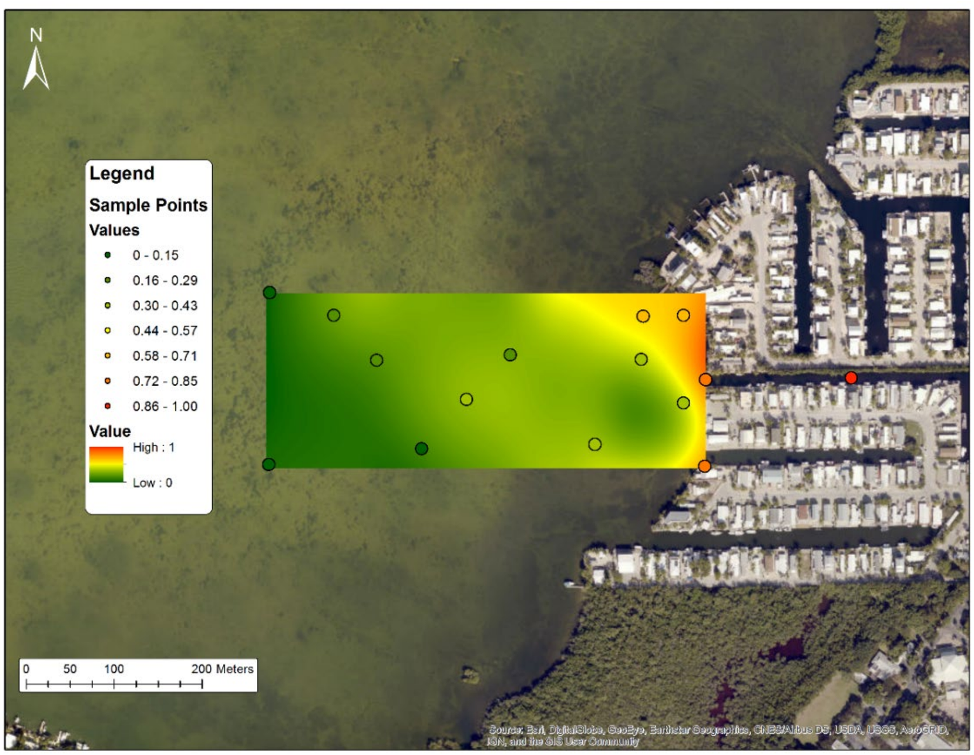


Figure 4: Examples of values for a parameter that has a maximum value of 1 and a minimum value of 0 (Top) and that dataset's corresponding interpolated surface (Bottom).

Table 2: *List of 13 block array sites for Task 2. Listed coordinates use the WGS 1984 datum*.

Site Code	Latitude	Longitude	MEU	Side	Type	Municipality	Location Name
02S-3-T2	24.5721054	-81.6531067	02S	Ocean	Task 2 - Canals		475 GEIGER KEY
04N-1-T2	24.6637173	-81.5171661	04N	Bay	Task 2 - Canals		318 SUGARLOAF KEY
04N-5-T2	24.6745453	-81.3348312	04N	Bay	Task 2 - Canals		293 BIG PINE KEY
05S-1-T2	24.6993217	-81.0716934	05S	Ocean	Task 2 - Canals	Marathon	257 MARATHON
07S-2-T2	24.8266830	-80.8037033	07S	Ocean	Task 2 - Canals	Layton	159 LONG KEY/LAYTON
08N-1-T2	24.8548145	-80.7464294	08N	Bay	Task 2 - Canals	Islamorada	155 LOWER MATECUMBE KEY
09N-3-T2	25.1644840	-80.3904724	09N	Bay	Task 2 - Canals		28 KEY LARGO
09S-1-T2	25.0405960	-80.4828796	09S	Ocean	Task 2 - Canals		84 ROCK HARBOR
10N-3-T2	25.3320408	-80.2852707	10N	Bay	Task 2 - Canals		3 OCEAN REEF CLUB
Site Code	Latitude	Longitude	MEU	Side	Type	Municipality	Location Name
04S-4-T2	24.6557407	-81.2651367	04S	Ocean	Task 2 - Intact/Restored		Bahia Honda
06S-1-T2	24.7357082	-80.9780579	06S	Ocean	Task 2 - Intact/Restored	Marathon	Curry Hammock
08N-2-T2	24.9123592	-80.7022171	08N	Bay	Task 2 - Intact/Restored		Lignumvitae Key
10S-1-T2	25.1743793	-80.3538437	10S	Ocean	Task 2 - Intact/Restored		Dagny Johnson

Task 2b: Ecological (Biotic) Sampling responding to water quality

The benthic community maps will be used to determine *a priori* what benthic substrate and biota should be throughout the block array. In the field, the blocks will be evaluated for the diversity of marine plants and invertebrates to determine patterns from inshore to offshore, associated with specific biotopes (Nero, 2005). Surveyors will conduct biodiversity assessments at the water quality sampling points throughout the block array to understand the response of benthic communities to water quality**.** Understanding the relationship between species diversity and environmental/ecological properties is crucial to evaluating and predicting ecosystem response to changes in water quality. Various studies have focused on Biodiversity Ecosystem Functions (BEF) by utilizing different measures of ecosystem function, such as biomass production and nutrient cycling (Tilman & Downing, 1994), (Naeem, Thompson, Lawler, Lawton, & Woodfin, 1994).

During the last decades, there has been increased evidence that biodiversity is strongly linked to increased stability of the ecosystem functions and enhanced Ecosystem Functions which in turn, are linked to ecosystem services (**Figure 6**) (Cardinale et al., 2012). Therefore, invertebrate and algae biodiversity can be used as an indicator of Ecosystem Function (and thus Ecosystem Services) for the Florida Keys canals and nearshore marine ecosystems.

In Task 2b, 13 sites including canals and “non-canal” sampling grids will be surveyed twice a year (wet season and dry season surveys). Within each site, a subset of the water sampling points will be surveyed, each survey point will be classified by habitat and zones. The monitoring will consist of **9** canal and 4 non-canal sites with benthic sampling carried out using the following sampling distribution, these stations are a subset of the water quality stations described in 2a:

A. 2 stations in Zone 1
B. 2 stations in Zone 2

C. 2 stations in Zone 3

The ecological surveys will focus on the conspicuous benthos and will have two components:

- Submerged Aquatic Vegetation (SAV) coverage, that will be assessed through the Braun-Blanquet method consistent with previous studies (Collado-Vides, Caccia, Boyer, & Fourqurean, 2007; Fourqurean, Durako, Hall, & Hefty, 2002; Trevathan-Tackett, Lauer, Loucks, Rossi, & Ross, 2013), and
- Invertebrate epifauna species assemblages that will be assessed through the point intercept method.

The surveys will be carried out using a 25m transect line along with 6 quadrats (per method) placed at random locations on the transect line within each block. Therefore, there will be an overall of 6 quadrats*2 blocks/zone*3 zones=36 quadrats per site and per method. Quadrats will be photographed to review species identification and field data entry. Species will be identified using a checklist of common and charismatic species (**Appendix 1** lists invertebrates and **Appendix 2** lists marine plants).

The two components are:

1. A Braun-Blanquet assessment (Kent, 2012) of substrate and algae coverage. For each of the following categories, coverage will be assessed in a .5 x.5 m quadrat (.25 m^2) as listed in Table 3. Categories include:
    a. Bare sand or mud
    b. Benthic macro algae and algal turf
    c. Seagrass
2. A point intercept method to quantify epifauna categories in a 0.5*0.5m intercept quadrat Species richness and benthic diversity will be assessed within each site. Categories will include:
    a. Sponges
    b. Hard corals
    c. Soft corals and anemones
    d. Echinoderms
    e. Mollusks
    f. Annelids

A complete list of the species that will be recorded was developed from historical records and research publications (Appendix 1). The Braun-Blanquet coverage of seagrass will allow comparison of seagrass density performed on previous surveys used to assess seagrass health in Florida Bay (Trevathan-Tackett, Lauer, Loucks, Rossi, & Ross, 2013). The focus of the surveys will be epifauna and will not include infauna surveys.

Water quality measurements will include turbidity assessments, but PAR measurements will also be made with the Hobo Pendants. Invertebrate biodiversity will be assessed in terms of evenness and species richness; species assemblages will be compared between the sites and over time as per methods in Sullivan & Chiappone, 1992.

Table 3: Scoring to be used for Braun- Blanquet surveys; r = rare species that occur along transect but not in quadrats, + = present but less than 5% of the quadrat coverage.

Braun-Blanquet scale	Range of cover
r	< 5 %; very few individuals
+	< 5 %; few individuals
1	< 5%; numerous individuals
2	5 – 25 %
3	25 – 50 %
4	50 – 75 %
5	75 – 100 %

Data will be grouped together according to the distance from the canal and analyses will be made accordingly. For the species assemblages, an MDS and cluster analysis will be conducted to visualize the similarities between blocks from the shore out to 500 m. The purpose of the Biological Assessment will be to assess the levels and composition of species diversity and link these results with Ecological Functions of the ecosystem. The biodiversity assessment should provide additional support to the conclusions drawn from the water quality sampling. Specifically, the sampling design will address the following questions,

1a "Is there a difference in water quality between canals and non-canal sites?

1b. Is there a difference in WQ between different zones/habitats within the different sites? Practically, does distance from "source" (i.e. canal) matter?

2a. Is there a difference in biodiversity between canals and non-canal sites?

2b. Is there a difference in biodiversity between different zones/habitats within the different sites? Practically, does distance from "source" matter?

3. Do biodiversity patterns align with WQ patterns?

For this purpose, several univariate and multivariate analysis will be conducted in order to investigate for statistical significance and correlation patterns correspondingly. For first questions, data will be grouped by sites (i.e. canals vs non-canals) and the mean of each measurement (TN, TP, TKN, Chla) will be calculated. The set of differences when subtracting non-canal from canal values will then be bootstrapped and the mean value and the 95% Confidence interval will be estimated. This way we could identify any statistically significant differences in WQ between canals vs non-canal sites.

The data can also be grouped by the time of the year collected and can be analyzed separately to ensure that we capture any seasonal variability (i.e. separate analysis for each quarter). In addition to this, a multivariate analysis will be conducted to visualize any temporal or spatial pattern of the WQ data. An nMDS and a Cluster analysis will be conducted using data for each measurement separately. For question 1b, data will be grouped by either zone or habitat and analyzed accordingly. The same set of analysis will be used, by utilizing the mean measurements of each zone/habitat. Therefore, the bootstrap technique will be used by estimating the differences between different zones in pairs (e.g. zone 1- zone 2 or zone 2- zone 3).

Following the same reasoning, biodiversity measurements (questions 2a and 2b) will also be analyzed using the bootstrap technique and NMDS and Cluster analysis. In this case, biodiversity measurements will be further grouped by category (hard corals, soft corals etc.).

Regarding question 3, the nMDS and Cluster plots derived from questions 1 and 2 will be compared and any overlaying patterns will be identified. In addition, the results from all the statistical tests will also be compared. For example, using the statistical outcomes form questions 1a and 2a, we could observe whether significance is present when with the same pattern (i.e. if we find significant differences in WQ between canals vs non-canal sites, we should also find significance in the corresponding biodiversity).

Extreme Event Sampling:

If there is an extreme rainfall event, the team will be ready to mobilize to sample some or all of the canal grids within 48 hours of the event to understand the role of acute water quality changes with storm events. This "extreme event" sampling would occur when a pre-determined meteorological trigger is reached in terms of defined precipitation indices (Table 4)[3]. One extreme event sampling event would be carried out once each calendar year depending on the occurrence of such events.

Precipitation indices that are used to define extreme rainfall events are likely calculated after the fact, and consultation with meteorologists can help define the specific triggers that would justify an extreme event sampling in the Upper, Middle or Lower Keys. The triggers will likely be unique to each region of the Florida Keys

Table 4: Definition of the precipitation indices used to define extreme rainfall events.

Precipitation Index with definitions and units:

PRCPTOT	Annual precipitation	Annual total precipitation	mm
SDII	Simple daily intensity index	Annual precipitation divided by number of wet days	mm/day
CDD	Consecutive dry days	Maximum number of consecutive dry days	days
CWD	Consecutive wet days	Maximum number of consecutive wet days	days
R10mm	Days above 10mm	Annual count of days when RR>10mm	days
R20mm	Days above 20mm	Annual count of days when RR>20mm	days
R50mm	Days above 50mm	Annual count of days when RR>50mm	days
RX1day	Max 1-day precipitation	Annual highest daily precipitation	mm
RX5day	Max 5-days precipitation	Annual highest 5 consecutive days precipitation	mm
R95p	Very wet days	Annual total precipitation when RR>95th percentile	mm

[3] Extreme rainfall events are defined as 5 standard deviation threshold from monthly means, and represent values that are very rare and typically only exceeded in the case of a direct impact of tropical cyclone or cold front.

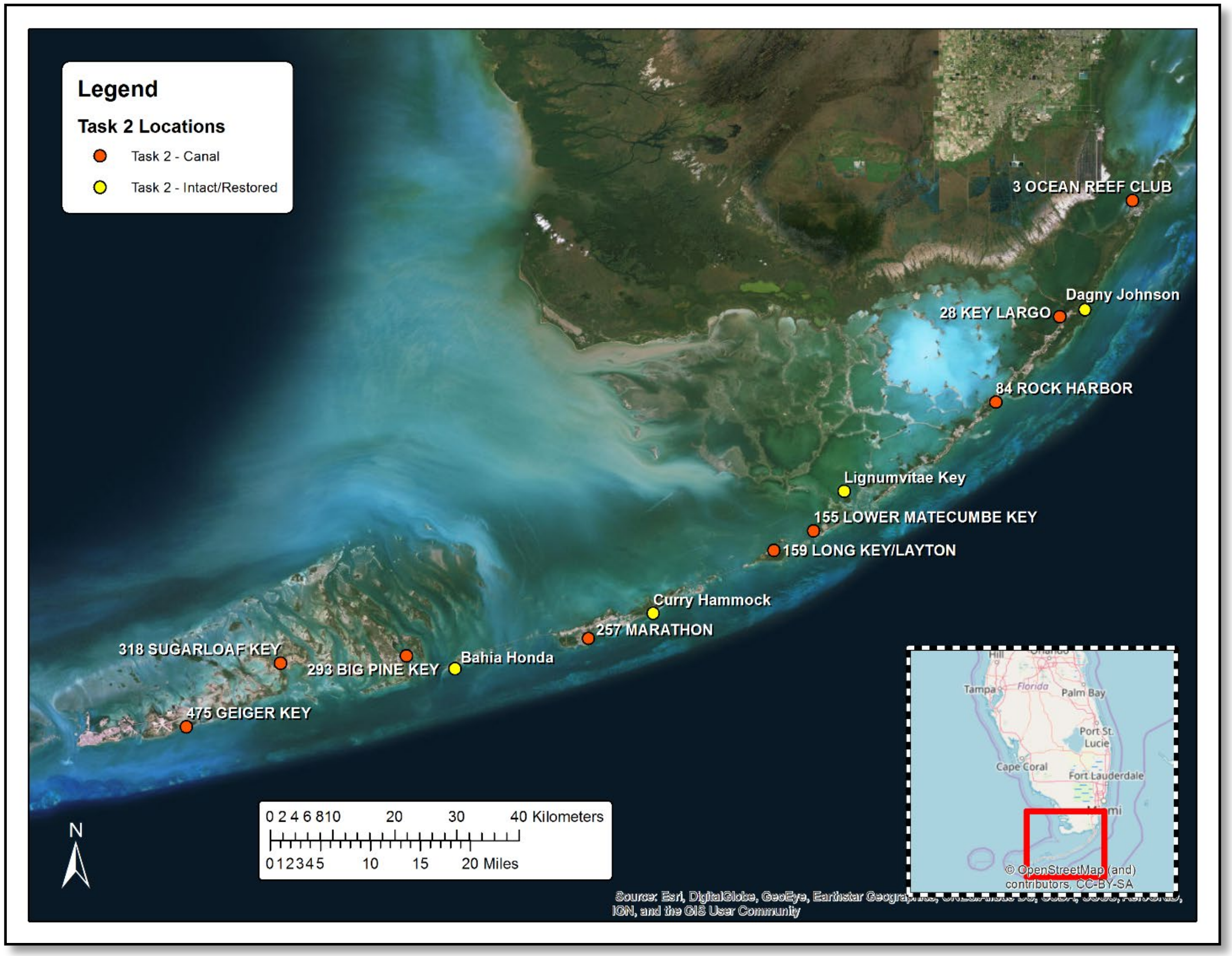


Figure 5: *Map of all 13 site locations for Task 2. Red points are canal sites (N=9); Yellow points are non-canal coastal sites (N=4).*

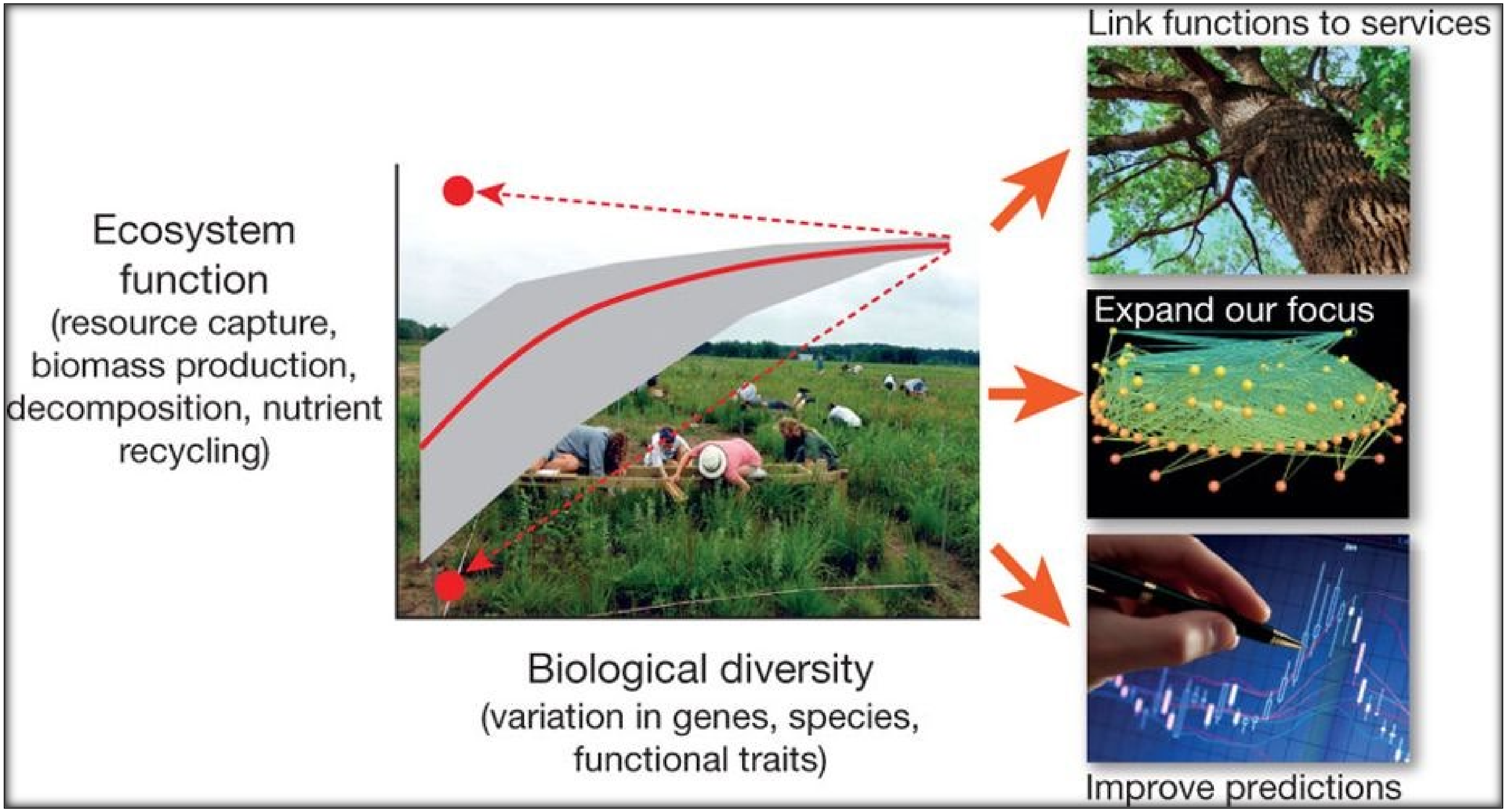


Figure 6: *Assessment of components of biological diversity, especially SAV (submerged aquatic vegetation) and benthic epifauna invertebrates can be key to understanding the history of water quality in nearshore communities. Changes in species assemblages can be modeled to better understand trends in water quality (Cardinale et al., 2012)*

APPENDIX 1: Preliminary invertebrate epifauna species list for near shore benthic communities of the Florida Keys

TAXA	Binomial	Common Name / Description
CNIDARIA	*Actinoporus elegans*	Elegant anemone
CNIDARIA	*Agalophenia latecarinata*	feather plume hydroid
CNIDARIA	*Agaricia spp*	lettuce corals
CNIDARIA	*Bartholomea annulata*	ringed anemone
CNIDARIA	*Briareum asbestinum*	corky sea finger
CNIDARIA	*Cassiopea xamachana*	mangrove upsidedown jelly
CNIDARIA	*Condylactis gigantea*	giant pink tipped anemone
CNIDARIA	*Dichocoenia stokesi*	elliptical star coral
CNIDARIA	*Diploria clivosa*	knobby brain coral
CNIDARIA	*Diploria labyrinthiformis*	grooved brain coral
CNIDARIA	*Diploria strigosa*	symmetrical brain coral
CNIDARIA	*Discosoma spp*	unknown corallimorph
CNIDARIA	*Erythropodium caribaeorum*	encrusting gorgonian
CNIDARIA	*Eunicea spp*	knobby sea rods, candelabra
CNIDARIA	*Eusmilia fastigiata*	smooth flower coral
CNIDARIA	*Favia fragum*	golf ball coral
CNIDARIA	*Halocordyle disticha*	christmas tree hydroid
CNIDARIA	*Lebrunia coralligens*	Hidden anemone
CNIDARIA	*Lebrunia danae*	branching cryptic anemone
CNIDARIA	*Manicina areolata*	rose coral
CNIDARIA	*Meandrina meandrites*	maze coral
CNIDARIA	*Millepora alcicornis*	branching/encrusting fire coral
CNIDARIA	*Millepora complanata*	Blade fire coral
CNIDARIA	*Obicella (Montastaea) spp*	All reef-building Montastraea
CNIDARIA	*Palythoa caribaeorum*	white encrusting zoanthid
CNIDARIA	*Phymanthus crucifer*	beaded or flower anemone
CNIDARIA	*Plexaura homomalla*	black sea rod
CNIDARIA	*Plexaura spp*	Unknown sea rod
CNIDARIA	*Plexaurella spp*	slip pore sea rods
CNIDARIA	*Porites asteroides*	mustard hill coral
CNIDARIA	*Porites porites*	clubtip finger coral
CNIDARIA	*Porites divaricata*	thin finger coral
CNIDARIA	*Pseudoplexuana spp*	Porous sea rods
CNIDARIA	*Pseudopterogorgia spp.*	rough sea plume
CNIDARIA	*Siderastrea radians*	lesser starlet coral
CNIDARIA	*Stephanocoenia intersepta*	blushing star coral
CNIDARIA	*Stichodactyla helianthus*	sun anemone

PORIFERA	*Amphimedon compressa*	red finger sponge (formerly H, rubens)
PORIFERA	*Aplysina sp.*	Unknown Aplysina
PORIFERA	*Callyspongia vaginallis*	branching vase sponge, grey-purple tube
PORIFERA	*Chondrilla caribensis(nucula)*	chicken liver sponge
PORIFERA	*Cinachyra sp.*	dusty orange ball sponge
PORIFERA	*Cliona (Anthosigmella) varians*	(brown) variable sponge
PORIFERA	*Cliona delitrix*	orange boring sponge
PORIFERA	*Cliona langae*	coral encrusting sponge NOW C.apria
PORIFERA	*Cliona sp.*	green velvel encrusting C. caribbaea
PORIFERA	*Dysidea etheria*	heavenly sponge
PORIFERA	*Ectyoplasia ferox*	orange volcano sponge
PORIFERA	*Haliclona sp.*	
PORIFERA	*Haliclona viridis*	small green tubes
PORIFERA	*Ircinia felix*	stinker sponge
PORIFERA	*Spheciospongia vesparium*	Florida loggerhead sponge
PORIFERA	*Tedania ignis*	fire sponge, organge color
Annelida	Anamobaea orstedii	Split-Crown Feather Duster
Annelida	Arenicola cristata	Southern Lugworm
Annelida	Bispira brunnea	Social Feather Duster
Annelida	Bispira variegata	Variegated Feather Duster
Annelida	Eupolymnia crassicornis	Spaghetti Worm
Annelida	Hermodice carunculata	Bearded Fireworm
Annelida	Notaulax nudicollis	Brown Fanworm
Annelida	Notaulax occidentalis	Yellow Fanworm
Annelida	Sabellastarte magnifica	Magnificent Feather Duster
Annelida	Spirobranchus giganteus	Christmas Tree Worm
Annelida	Spirorbis spirorbis	Seagrass epiphyte
Chordata	*Ascidia nigra*	Black Solitary Tunicate
Chordata	*Botrylloides nigrum*	Flat Tunicate
Chordata	*Botryllus sp.*	Geometric Encrusting Tunicates
Chordata	*Clavelina sp.*	Bulb Tunicates
Chordata	*Diplosoma glandulosum*	Globular Encrusting Tunicate
Chordata	*Distaplia corolla*	Button Tunicates
Chordata	*Ecteinascidia turbinata*	Mangrove Tunicate
Chordata	*Polyandrocarpa tumida*	Mottled Social Tunicate
Chordata	*Polycarpa spongiabilis*	Giant Tunicate
Chordata	*Rhopalaea abdominalis*	Reef Tunicate
Chordata	*Symplegma viride*	Encrusting Social Tunicate

Chordata	*Trididemum solidum*	Overgrowing Mat Tunicate
Arthropoda	*Callinectes sp.*	Blue Crabs
Arthropoda	*Paguristes erythrops*	Red Banded Hermit
Arthropoda	*Pagurus sp.*	Hermit Crab
Arthropoda	*Panuliris argus*	Caribbean Spiny Lobster
Arthropoda	*Petrochirus diogenes*	Giant Hermit
Echinodermata	*Astropecten spp*	Sea Stars
Echinodermata	*Clypeaster roseaceus*	inflated sea biscuit
Echinodermata	*Diadema*	antillarium
Echinodermata	*Echinaster echinoporous*	thorny starfish
Echinodermata	*Echinometra lucunter*	rock-boring urchin
Echinodermata	*Echinometra viridis*	reef urchin
Echinodermata	*Eucidaris tribuloides*	slate-pencil urchin
Echinodermata	*Holothuria spp.*	Sea Cucumber
Echinodermata	*Isostichopus badionotus*	Three-Rowed Sea Cucumber
Echinodermata	*Linckia guildingii*	common comet star
Echinodermata	*Lytechinus variegatus*	Variegated Urchin
Echinodermata	*Tripneustes ventricosus*	sea egg
Mollusca	*Atrina rigida*	Stiff Pen Shell
Mollusca	*Cyphoma spp.*	Flamingo tongue
Mollusca	*Eustrombus gigas*	Queen conch
Mollusca	*Fasciolaria tulipa*	True Tulip
Mollusca	*Lima scabra*	Rough Fileclam
Mollusca	*Octopus vulgaris*	Common Octopus
Mollusca	*Phalium granulatum*	Scotch Bonnet
Mollusca	*Pickfordiateuthis pulchella*	Grass Squid
Mollusca	*Pinna carnea*	Amber Penshell
Mollusca	*Sepioteuthis sepiodea*	Caribbean Reef Squid

APPENDIX 2: List of Marine Plants to be scored in benthic surveys. Species are grouped by Green, Brown and Red macro algae, conspicuous cyanobacteria and sea grasses. Numbers following the species are from the Caribbean Marine Plants Key (Littler & Littler, 2000).

MARINE PLANT SPECIES LIST	Littler & Littler Key
Acetabularia spp.	442
Anadyomene saldenhae	310
Anadyomene stellata	310
Avrainvillea spp.	382
Batophora oerstedii	436
Bryopsis hypnoides	342
Bryopsis pennata	342
Bryopsis plumosa	344
Bryopsis ramniosa	344
Caulerpa cupressoides	360
Caulerpa macrophysa	362
Caulerpa mexicana	364
Caulerpa paspaloides	366
Caulerpa prolifera	368
Caulerpa pusilla	368
Caulerpa racemosa	370
Caulerpa serrulata	372
Caulerpa sertularoides	374
Caulerpa taxifolia	376
Caulerpa verticillata	376
Caulerpa vickersiae	378
Caulerpa webbiana	378
Chaetomorpha gracilis	318
Chaetomorpha linum	318
Cladophora catenata	320
Cladophora sp.	320
Codium repens	354
Dasycladus vermicularis	436
Derbesia sp.	346
Dictyosphaeria cavernosa	332
Enteromorpha spp	
Halimeda discoidea	400
Halimeda incrassata	402
Halimeda lacrimosa	404
Halimeda monile	404
Halimeda opuntia	406
Halimeda scabra	406
Halimeda tuna	408

Haliphilia decipiens	480
Microdictyon marinum	312
Neomeris annulata	438
Penicillus capitatus	410
Penicillus dumetosus	410
Penicillus lamourouxii	412
Penicillus pyriformis	412
Rhipocephalus phoenix	418
Udotea spp,	422
Ulva lactuca	306
Valonia macrophysa	340
Ventricaria ventricosa	336
Cystoseira myrica	280
Dictyopteris spp	254
Dictyota spp	487
Dictyota caribaea	260
Lobophora variegata	268, 270
Padina spp	272
Sargassum spp	280
Stypopodium zonale	278
Turbinaria turbinata	290
Acanthophora spicifera	192
Amphiroa spp	20
Bostrychia spp	194
Centroceras spp.	144
Ceramium sp.	146
Chondria capillaris	198
Chondria littoralis	204
Chondria polyrhiza	204
Coelothrix irregularis	136
Dasya spp	170
Dasya ocellata	174
Digenea simplex	204
Eucheuma isiforme	94
Galaxaura comans	58
Galaxaura obtusata	60
Galaxaura sp.	58
Gelidiella acerosa	46
Gracilaria blodgetti	110
Gracilaria brevizonatum	146
Gracilaria cervicornis	112
Gracilaria cylindrica	114
Gracilaria damaecornis	114

Gracilaria mammillaris	117
Gracilaria sp.	110
Gracilaria tikvahiae	116
Heterosiphonia gibbeseii	180
Heterosiphonia crispella	180
Hydrolithon boergesenii	28
Hypnea spp	76
Jania adhaerens	30
Jania rubens	33
Kallymenia sp	78
Laurencia (Chondrophycus) iridescens	216
Laurencia chondrioides	212
Laurencia gemmifera	214
Laurencia intricata	214
Laurencia sp.	210
Liagora sp.	48
Neogoniolithon spectabile	36
Peysonellia sp.	86
Porolithon pachydermum	38
Sporolithon episporum	42
Spyridia filamentosa	164
Titanoderma spp	40
Wrangelia argus	166
Calothrix aeruginia	470
Dichothrix spp.	
Lyngbya sp.	450
Schizothrix sp.	464
Symploca hydnoides	462
Halodule beaudettei (wrightii)	484
Syringodium filiforme	484
Thalassia testudinum	482

REFERENCES

Aronson, R. B., Bruno, J. F., Precht, W. F., Glynn, P. W., Harvell, C. D., Kaufman, L., . . . Valentine, J. F. (2003). Causes of coral reef degradation. *Science (New York, N.Y.), 302*(5650), 1502-1504. doi:10.1126/science.302.5650.1502b

Barreras, H. J., Kelly, E. A., Kumarb, N., & Solo-Gabriele, H. M. (2019). Assessment of local and regional strategies to control bacteria levels at beaches with consideration of impacts from climate change. *Marine Pollution Bulletin, 138*, 11. doi:10.1016/j.marpolbul.2018.10.046

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., . . . Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature, 486*, 59. doi:10.1038/nature11148

Eutrophication in coastal canals. (1972). *Marine Pollution Bulletin, 3*(2), 23. doi:10.1016/0025-326x(72)90207-x

Group, Marine Classification Work W. (2012). *Coastal and Marine Ecological Classification Standard*. (0097-6326). DataStream Content Solutions, LLC Retrieved from http://miami.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2BQMLEwMwPWDIlJaYaJScmJlmYmiZYpRqbApj2wN2SUYoSywhepNHcTYmBKzRNlkHVzDXH20AWVkPEFkDMX4o1BU6Sg9GYoxsCbCFr8nVcC3iSWIsGgkGRmaJgIco2lqYFJWopFUjKwk2GRam6RamFkAuz7AQAW3CTT.

Kent, M. (2012). *Vegetation description and data analysis : a practical approach* (Second edition. ed.). Chichester, West Sussex, UK, West Sussex, UK: Wiley-Blackwell.

Naeem, S., Thompson, L. J., Lawler, S. P., Lawton, J. H., & Woodfin, R. M. (1994). Declining biodiversity can alter the performance of ecosystems. *Nature, 368*(6473), 734-737.

Nero, V. (2005). Benthic marine plant patterns in coastal environments of the Bahamas. *Bahamas Journal of Science, 12*(2), 14-20.

Sullivan, K. M., & Chiappone, M. (1992). A Comparison of Belt Quadrat and Species Presence/Absence Sampling of Stony Coral (Scleractinia and Milleporina) and Sponges For Evaluating Species Patterning on Patch Reefs of the Central Bahamas. *Bulletin of Marine Science, 50*(3), 464-464.

Tilman, D., & Downing, J. A. (1994). Biodiversity and stability in grasslands. *Nature, 367*(6461), 363.

Trevathan-Tackett, S. M., Lauer, N., Loucks, K., Rossi, A. M., & Ross, C. (2013). Assessing the relationship between seagrass health and habitat quality with wasting disease prevalence in the Florida Keys. *Journal of Experimental Marine Biology and Ecology, 449*(C), 221-229. doi:10.1016/j.jembe.2013.10.004

Collado-Vides, L., Caccia, V. G., Boyer, J. N., & Fourqurean, J. W. (2007). Tropical seagrass-associated macroalgae distributions and trends relative to water quality. *ESTUARINE COASTAL AND SHELF SCIENCE, 73*(3-4), 680-694. doi:10.1016/j.ecss.2007.03.009

De Carlo, E. H., Hoover, D. J., Hoover, R. S., Young, C. W., & Mackenzie, F. T. (2007). Impact of storm runoff from tropical watersheds on coastal water quality and productivity. *Applied Geochemistry, 22*(8), 1777-1797. doi:10.1016/j.apgeochem.2007.03.034

Fourqurean, J. W., Durako, M. D., Hall, M. O., & Hefty, L. N. (2002). Seagrass distribution in south Florida: a multi-agency coordinated monitoring program. In J. W. Porter & K. G. Porter (Eds.), *The Everglades, Florida Bay, and the Coral Reefs of the Florida Keys.* (pp. 497–522). Boca Raton, FL: CRC Press LLC.

Lapointe, B. E., & Matzie, W. R. (1996). Effects of Stormwater Nutrient Discharges on Eutrophication Processes in Nearshore Waters of the Florida Keys. *Estuaries, 19*(2), 422-435. doi:10.2307/1352460

Littler, D. S., & Littler, M. M. (2000). *Caribbean Reef Plants*. Washington, D.C.: OffShore Graphics.

Trevathan-Tackett, S. M., Lauer, N., Loucks, K., Rossi, A. M., & Ross, C. (2013). Assessing the relationship between seagrass health and habitat quality with wasting disease prevalence in the Florida Keys. *Journal of Experimental Marine Biology and Ecology, 449*(C), 221-229. doi:10.1016/j.jembe.2013.10.004

Wagner, D., Mielbrecht, E., & van Woesik, R. (2008). Application of Landscape Ecology to Spatial Variance of Water-Quality Parameters Along the Florida Keys Reef Tract. *Bulletin of Marine Science, 83*(3), 553-553.

Wolanski, E., Martinez, J. A., & Richmond, R. H. (2009). Quantifying the impact of watershed urbanization on a coral reef: Maunalua Bay, Hawaii. *Estuarine, Coastal and Shelf Science, 84*(2), 259-268. doi:10.1016/j.ecss.2009.06.029