FIELD OPERATIONS
WATER QUALITY AND REEF MONITORING
ALONG THE SOUTHEAST FLORIDA COAST

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The Southeast Florida coast includes the counties of Miami-Dade, Broward, and Palm Beach (~25.6 to ~26.9°N latitude), containing about 142 km of coastline extending approximately parallel to the flow of the Florida Current to the east. The region contains three non-continuous reef tracts[1] containing ecosystems of significant economic[2], ecological[3], and aesthetic value to the 5.5 million residents therein (2010)[4]. This area also contains significant point sources of pollution, i.e., five important ocean inlets and six treated-wastewater outfalls[5], and two ocean dredged materials disposal sites (ODMDS)[6] (Figure 1). The task of conserving and managing this important ecosystem is performed by Florida's Department of Environmental Protection, including developing a consistent and effective regulatory process. In the past, standards for inland and coastal water quality were written as narrative standards, viz., *in no case shall nutrient concentrations of body of water be altered so as to cause an imbalance in natural populations of flora or fauna*.[7] The primary "nutrients" referred to are nitrogen and phosphorous. The impetus for the work described herein is the surface water quality monitoring plan requirement associated with the permitting of wastewater ocean outfalls by the Miami-Dade Water and Sewer Department.[8]

Recently, a decision was made (in conjunction with the U. S. Environmental Protection Agency) to replace the narrative standards with numeric nutrient criteria (NNC) for these variables.[9] Three different approaches to developing NNC have been promulgated:[10] 1) the reference condition approach, which employs observations in minimally disturbed conditions within a region; 2) the mechanistic modeling approach, that develops relationships between stressors and ecological effects; and 3) empirical stressor-response modeling, in which sufficient data is available to accurately relate stress (e.g., N and P concentrations) to a measured ecosystem response. Each of these procedures requires

1 Banks, K.W., B. M. Riegl, V. P.. Richards, B. K. Walker, K. P. Helmle, L. K. B. Jordan, J. Phipps, M. S. Shivji, R. E. Sp[ieler, and R. E. Dodge, in B. M. Riegl and r. E. Dodge (eds.), *Coral Reefs of the USA*, Springer Science + Business Media B. V., 2008.
2 Johns, G. M., V. R. Leeworthy, F. W. Bell, M. A. Bonn, 2001. *Socioeconomic study of reefs in Southeast Florida, Final Report*, Hazen and Sawyer, 348 pp.
3 Gregg, K., 2013. *Literature review and synthesis of land-based sources of pollution affecting essential fish habitats in southeast Florida.* Report for NOAA Fisheries Southeast Region , Habitat Conservation Division, West Palm Beach, FL, January 2013, 55 pp.
4 U.S.Census (http://quickfacts.census.gov/qfd/states/12000.html)
5 B. Koopman, J. P. Heaney, F. Cakir, M. Rembold, P. Indeglia, and G. Kini, 2006. *Ocean Outfall Study Final Report*. Prepared for the Florida Department of Environmental Protection, Tallahassee, Florida, april 18, 2006.
6 http://epa.gov/region4//water/oceans/sites.html#portevergladesharbor
7 FDEP, *State of Florida Numeric Nutrient Criteria Development Plan*, March 2009
8 Miami-Dade Water and Sewer Department, North District Wastewater Treatment Facility, Administrative Order AO-06-0060-DW-SED. *Annual Status of Compliance Report.* July, 2013.
9 Sloan, M., and J. Hulbert (undated). *Florida's Numeric Nutrient Criteria Development Plan*. Downloaded from http://www.dep.state.fl.us/water/wqssp/nutrients.
10 EPA, *Using stressor-response relationships to derive numeric nutrient criteria,* EPA-820-S-10-001, 2010

a sufficient data set of relevant chemical, oceanographic, and biological data from the region; in particular, nutrient concentrations and ecosystem response measurements. FDEP has determined that the nutrients will be TN and TP, with chlorophyll-a and *in situ* coral reef assessments providing the ecosystem response measurements.[11]

This three-year project is designed to assist in providing those data that would be used in the development of the NNCs as indicated by FDEP as described above. Field work will be conducted during the first two years, followed by time for the development of various deliverables including the final report, as delineated in the signed Memorandum of Agreement (MOU).[12] This includes three separate efforts: 1) Water Quality Cruises; 2) Coral Assessments, and 3) Ocean Current Measurements. Each component will be described in detail. The cruise track is outlined in Figure 1 and the sampling sites listed in Appendix 1.

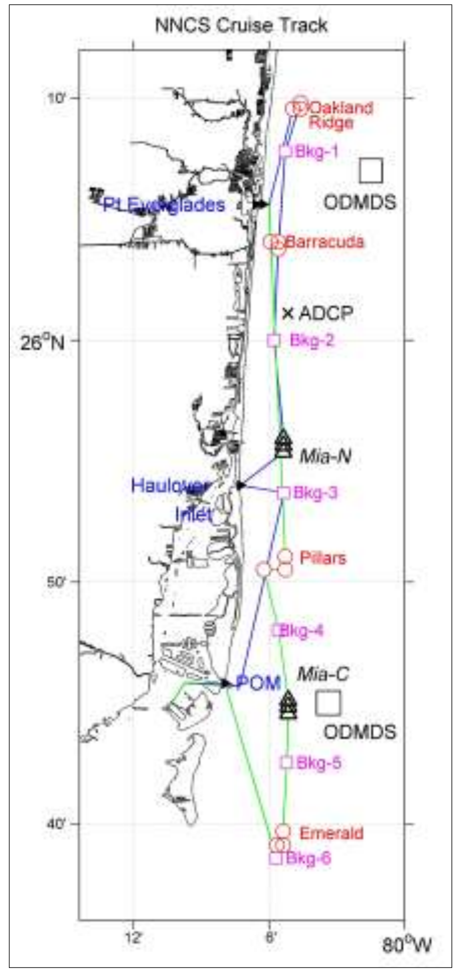

Figure 1. Map of Florida's SE coast, showing track lines for day 1 (blue line) and day 2 (green line), outfalls (black Δ), inlets (black ►), reef sites (red o), background sites (magenta □), and the boundaries of the Ocean Dredged Material Disposal Site (ODMDS) for Pt. Everglades and Miami-Dade (black □). The ADCP location is given by the "X".

Chemistry

Nutrients are chemical species that are essential requirements for the maintenance of life. Generally, "nutrients" refer to biologically available species of nitrogen, phosphorous, and silicon.[13] While these elements are found in many chemical forms (e.g., dissolved or particulate, organic or inorganic), the forms most readily available to living organisms are the simple ions in solution (dissolved), viz., nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+), phosphate (PO_4^{-3}), and silicate ($Si(OH)_4^{-4}$).[14] These are commonly denoted in nutrient literature without charge designations and subscripts (e.g., nitrite is NO2); this nomenclature will be employed in this document. Other forms of these compounds exist; for example as a component of a particle (e.g., particulate nitrogen); these are much less readily used by living organisms. Also, these elements may be included in organic molecules (e.g., nitrogen in urea, amino acids, proteins, and

11 Frydenborg, R., FDEP Division of Resource Assessment and Management, personal communication.

12 *Memorandum of Understanding between Brown and Caldwell and the Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, for Water Quality and Reef Monitoring Along the Southeast Florida Coast.* Agreement No. 1. September 2013. Available from thomas.p.carsey@noaa.gov.

13 EPA (United States Environmental Protection Agency), 2001. *Nutrient Criteria Technical Guidance Manual Estuarine and Coastal Marine Waters*. EPA-822-B-01-003.

14 Murasko, S. M., 2009. *Particulate carbon, nitrogen and phosphorus stoichiometry of south west Florida waters.* Dissertation, USF Graduate School, University of South Florida, Tampa, Fl, 33620.

humic substances), either dissolved or in particles, again not as readily available. A major concern in recent decades for both nitrogen and phosphorus in the coastal environment is the increased use of fertilizers.[15]

Nitrogen species undergo a complex set of reactions in the coastal environment. Nitrogen (N_2) is the major atmospheric gas (~78%), but is not readily biologically available in this form (or in the other nitrogen gasses in the atmosphere, viz., NO, N_2O, NO_2). Atmospheric N_2 can be converted to ammonium (NH_4^+) by certain plants (e.g., legumes), and by nitrogen-fixing bacteria and macroalgal species in the ocean. Nitrogen species In seawater are commonly designated as either organic or inorganic; the major inorganic molecules are nitrate (NO_3^{-1}), nitrite (NO_2^{-1}) and ammonium (NH_4^{+1}) (these are commonly denoted without superscripts or subscripts, i.e., NO3, NO2, and NH4). For geochemical reasons (these species interconvert rapidly) and for analytical reasons (how they are analytically determined), it is convenient to denote groupings of these species. The num of nitrate and nitrite concentrations is denoted "N+N"; N+N plus ammonium is denoted DIN ("dissolved inorganic nitrogen"). Dissolved organic nitrogen species are denoted "DON". In the waters off of Broward County, DON is the predominant form of nitrogen[16]. Total nitrogen (TN), the quantity requested by FDEP, is the sum concentration of all the various nitrogen species. It is commonly determined as the sum of [N+N] + [TKN], where the latter term ("total Kjeldahl nitrogen") refers to a particular analytical method that measures a subset of the N species (organic N + ammonium)[17].

Phosphorus is an essential element for life, playing a critical role in the storage and transfer of energy in the cell. Major natural sources include bird droppings (guano) and the weathering or leaching of rocks. A major anthropogenic source is fertilizer application in agriculture. Phosphorus occurs in the environment in several forms. 1) Orthophosphate (denoted PO4), also called soluble reactive phosphorus (SRP), includes the species $H_2PO_4^{-1}$, HPO_4^{-2}, and PO_4^{-3}; 2) particulate organic phosphorus (POP), including living or decaying plants, animals and bacteria; 3) particulate inorganic phosphorus (PIP), derived from minerals; and 5) dissolved organic phosphorus (DOP), generally derived from organisms but also from anthropogenic sources such as detergents. Total phosphorus (TP) is the sum of all of the above. In surface waters of much of the world's oceans, most of the TP is in the form of dissolved organic phosphorous (DOP).[18] This was also found in the waters off of Broward County.

Chlorophyll-a measurements provide a metric of phytoplankton photosynthesis and biomass production.[19] Excess nutrients due to human activities may generate a condition of accelerated growth known as eutrophication[20], which results in high levels of chlorophyll-a and other undesirable effects including overgrowth of seaweed, anoxia, algal blooms, and loss of submerged aquatic vegetation.[21]

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[15] National Research Council, 2000. *Clean Coastal Waters, Understanding and Reducing the Effects of Nutrient Pollution*. National Academy Press, Washington DC, 428 pp.

16 Carsey, T., J. Stamates, J. Bishop, C. Brown, A. Campbell, H. Casanova, C. Featherstone, M. Gidley, M. Kosenko, R. Kotkowski, J. Lopez, C. Sinigalliano, L. Visser , J.-Z. Zhang. 2013. Broward County Coastal Ocean Water Quality Study, 2010-2012, NOAA Technical Report, OAR AOML-44. Atlantic Oceanographic and Meteorological Laboratory Miami, Florida, September, 2013. 261 pp.

[17] EPA. Nutrient Criteria Technical Guidance Manual. Estuarine and Coastal Marine Waters. U.S.Environmental Protection Agency, Office of Water. EPA-882-B-01-003. October 2001, p 4-13 to 4-14.

[18] Karl, D.M., and K. Bjorkman, 2002. *Dynamics of DOP.* In *Biochemistry of Marine Dissolved Organic Matter.* Elsevier Science, USA, pp 249-366.

[19] U. S. Environmental Protection Agency, 2001. *Nutrient Criteria Technical Guidance Manual, Estuarine and Coastal Waters*. EPA Office of Water, EPA-822-B-01-003, 362 p 2-13.

20 Howarth, R., 2008. *Coastal nitrogen pollution: A review of sources and trends globally and regionally.* Harmful Algae 8, 14-20.

21 Bricker, S., *et al.*, 2003. *National Estuarine Eutrophication Assessment Update: Workshop summary and recommendations for development of a long-term monitoring and assessment program.* Proceedings of a workshop September 4-5, 2002, Patuxent Wildlife Research Refuge, Laurel, Maryland. NOAA, National Ocean Service, National Centers for Coastal Ocean Science. Silver Spring, MD: 19 pp.

This work will involve the measurement of chlorophyll-a from water samples by FDEP (initially by both fluorescence and by visible spectrophotometry[22]) as well as chlorophyll-a profiles from the CTD (using fluorescence) down the water column as described below.

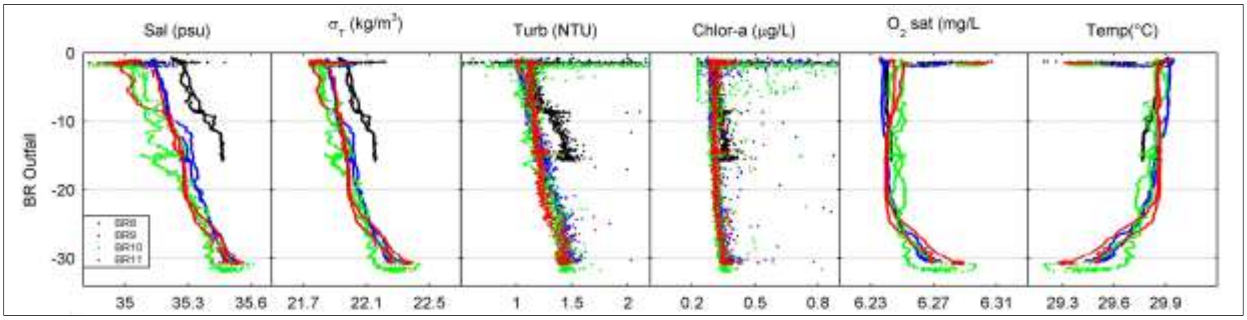

Figure 2. CTD measurements near the Broward treated-wastewater outfall sampled on 15-Sep-2011. The colors refer to four samples near the outfall; BR10 was on the outfall, BR 8 and 9 were south and BR11 north of the outfall. The six plots present (left to right): salinity, density, turbidity, chlorophyll-a, dissolved oxygen saturation, and temperature. The vertical axis is depth in meters. From Carsey *et al*. 2013.

Some typical results from the CTD apparatus from a similar region off of Broward County in 2011 are shown in Figure 2. One can see that salinity increases with depth (because the surface waters are freshened by terrestrial waters). Temperature decreases by less than a degree. Density (reported as σ_T), a function of salinity and temperature, increases with depth as expected.[23] Turbidities were low, indicating clear waters (which promote health in corals[24]). Chlorophyll-a concentrations were consistent low away from inlets, indicating non-bloom conditions.

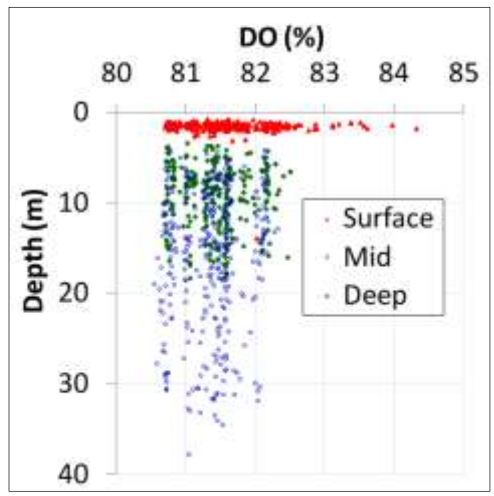

Figure 3 Dissolved oxygen (as per cent saturation) data from three depths versus depth. From Carsey *et al*. 2013.

Oxygen saturations as measured during the Broward-Hollywood cruise are shown in Figure 3. Saturations were consistently >80% (FDEP recently set a minimum of 42% for coastal waters[25]). Consequently, we will measure dissolved oxygen (on the CTD) for the initial cruises then determine if additional measurements are necessary.

1. WATER QUALITY CRUISES

Overview

[22] Phone conversation with K. Weaver and R. Frydenborg, FDEP, 5-Nov-2013.
[23] Picard, G. L., and W. J. Emery. *Descriptive Physical Oceanography.* 4th Ed. Pergamon Press, 1982, p. 17.
[24] Waddell, J.E. (ed), 2005. *The State of Coral Reef Ecosystems in the United States and Pacific Freely Associated States: 2005.* NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 522 pp.
[25] FDEP Division of Environmental Assessment and Restoration, 2013. *Technical Support Document: Derivation of Dissolved Oxygen Criteria to Protect Aquatic Life in Florida's Fresh and Marine Waters.* March, 2013.

The Water Quality (WQ) field program will involve twelve bimonthly 2-day water quality cruises from Port Everglades to Miami (day 1) and return (day 2) (Figure 2). Water quality samples will be obtained (for analysis by FDEP) in the vicinity of four specific coral groups, two off of Broward County and two off of Miami-Dade County. Two of these sites are near sites monitored by SECREMP (Southeast Florida Coral Reef Evaluation and Monitoring Project[26]). Water samples will also be obtained from the Miami Central and Miami North outfalls, three inlets (Port of Miami, Baker's Haulover, and Port Everglades), as well as six control sites distant from those point sources (Table 1 and Appendix 1). This effort will expand on a series of coastal monitoring efforts organized by NOAA-AOML[27] and the Southeast Florida Coral Reef Initiative (SEFCRI).[28] A detailed listing of cruise activities is given in Appendix 1.

Figure 4. Left: R/V Hildebrand forward view. Middle: aft view showing A-frame. Right: Seabird rosette and CTD being deployed from the Hildebrand by NOAA scientists C. Featherstone and LT. R. Kotkowski.

The WQ cruises are scheduled to begin in November of 2013, on board the NOAA research ship Hildebrand. The Hildebrand is a 41' former USCG UTB[29] outfitted with an A-frame (1000 lbs capacity), a winch with 180 ft. of ⅛" wire rope, and a Seabird ECO 55 rosette sampler holding six 4-L seawater sampling bottles and a SBE 19V2 CTD (conductivity-temperature-density) instrument package[30]. The ship and CTD unit are shown in Figure 4. Typical CTD results are described below.

Table 2: Analytes to be measured in the Water Quality cruises

Analyte	Laboratory	Matrix	DL, Accuracy
Total Phosphorous	FDEP	Water sample	DL=4 µg/L
Total Nitrogen	FDEP	Water sample	DL=11 µg/L
Chlorophyll-a	FDEP	Water sample	
Depth	NOAA AOML	CTD profile measurement	
Temperature	NOAA AOML	CTD profile (SBE 3)	Acc ±0.001°C
Conductivity	NOAA AOML	CTD profile (SBE 4)	Acc 0.00003 S/m
Density	NOAA AOML	CTD profile measurement	
Dissolved Oxygen	NOAA AOML	CTD profile measurement	
CDOM	NOAA AOML	CTD (Turner Designs Cyclops 7)	
Chlorophyll-a	NOAA AOML	CTD profile (Seapoint)	DL 0.02 µg/L
Turbidity	NOAA AOML	CTD profile (Seapoint)	2% of sat

26 Gilliam, D.S., *Southeast Florida Coral Reef Evaluation and Monitoring Project 2011 Year 9 Final Report*, Florida DEP report #RM085, Miami Beach, FL. Pp. 49, 2012.
[27] http://www.aoml.noaa.gov/themes/CoastalRegional/projects/FACE/faceweb.htm
[28] http://www.dep.state.fl.us/coastal/programs/coral/documents/2011/LBSP/05-06/TAC_Spring_2011_Minutes.pdf
[29] For a description see http://www.uscg.mil/datasheet/41utb.asp
[30] http://www.seabird.com/products/spec_sheets/55data.htm

Each bi-monthly WQ cruise will obtain 78 water samples from 27 cast locations (see Appendix 1). Due to the time required for collecting samples, each bi-monthly cruise will be divided into two one-day legs as noted above. At each site, water will be sampled at up to three depths using the CTD on board the R/V Hildebrand (Figure 7), to be analyzed by FDEP for nutrients (TP, TKN, NO2+NO3), and chlorophyll-a. To maintain high quality analytical standards, four duplicate and four blanks (8 total) will be analyzed on each bi-monthly cruise (as per FDEP requirements), for a total of 86 samples (78+8) per cruise, or 1032 (86*12=1032) total samples. These analytes are listed in Table 2.

For TKN, NO2+NO3, and TP, a single 500-ml (acid stabilized) sample is required; for chlorophyll-a, a single 1-L bottle is required; both are to be transported to FDEP for analysis using standard FDEP procedures within 48 hours.[31] With the 6-bottle CTD rosette, we may sample 2 bottles (total of 8 liters) at three depths with each cast. In addition, the CTD will generate depth profiles of turbidity, chromophoric dissolved organic material (CDOM), salinity, temperature, density and depth. The complete list of parameters to be analyzed is given in Table 2

Figure 5. Day 1 sampling locations. Left: NSU Dock in Lake Mable, PEI location in Pt. Everglades Inlet, Oakland Ridge reef sites (OR1-3), BKG1 site, Barracuda Reef sites (B1-3). Right: BKG 2ites, Miami-North WWP outfall sites, and Bakers Haulover inlet site, and Bkg3. Ship docks at Rickenbacker Marina at the end of Day 1.

The data from these field programs will be evaluated by FDEP to develop numeric nutrient criteria that are protective of the reef ecosystems.[32]

Ship Tracks and Sampling Sites

The overall track lines for the two legs (one day each) of a typical WQ cruise are shown in Figure 1. The two-day requirement is due to the number of samples that can be obtained during a day on the ship, taking into account logistics. Two days is required (see Appendix 1) and a dockage at a Miami marina (e.g., Rickenbacker Marina) is appropriate. A listing of the sample names, locations, and estimated times of each CTD cast is given in Appendix 1. A narrative of a cruise is given below.

Pre-Cruise: A two-day sampling time is chosen that is expected to have acceptable weather (e.g., seas 1-3 feet). The sampling equipment (coolers with ice, sample bottles, shipping containers) will be loaded onto the R/V Hildebrand and the ship fueled.

[31] *Information on DEP Laboratory Sampling Kits*, undated pdf, supplied by Dr. T. Fitzpatrick on 6-March-2013.
[32] Frydenborg, R. Proposed coastal chlorophyll criteria. NNC Estuary Workshops, West Palm Beach, Florida, April 15, 2013.

Day 1 (Figure 5). The crew arrives and the ship leaves at ~7am and proceeds to site 1 within the Lake Mabel / Pt. Everglades system (Figure 7). With care for boat traffic, the CTD is prepared and lowered into the water column. Due to the shallow depth, only two depths are sampled in an inlet. After the cast, the ship proceeds north to the Oakland Ridge reef sites while the CTD water bottles are sampled with the appropriate pre-labeled sample bottles and stored under ice in the proper sample cooler. Following sampling (at 3 depths; denoted as bottom=C, mid=B, surface=A) at Oakland Ridge (OR1-3), the ship proceeds to Bkg1, to the Barracuda Reef sites (B1-3), to Bkg2, then to the three Miami-N outfall sites (MN1-3), down to Bakers Haulover Inlet (BHI), to Bkg3, then to dockage at a Miami marina (e.g., Rickenbacker Marina) at about 2 pm for equipment offloading and ship shutdown procedures.

Table 3: Sample parameters for the Water Quality cruises

	Day1	Day2	Both Days	Bottle Size
Sampling (cast) locations	14	13	27	
# of Samples (sites * depths)	40	38	78	
blanks & duplicates	4	4	8	
Nuts (TKN,DIN, TP)	44	42	86	500 mL
Chlor-a (fluorescence)	44	42	86	1L
Chlor-a (spectrophotometric)	44	42	86	1L
Total # Bottles	132	126	258	

The sequence is estimated to take about seven hours. The fourteen sites generate 40 samples of each analyte. FDEP has required that there be one duplicate for each 20 samples and one field blank for each 20 samples; this adds 4 (2+2) making the total sample bottles 44. Filled sample bottles are placed in the mailer boxes and FEDEXed express overnight to FDEP. Table 3 outlines the sampling requirements for the two cruises.

Day 2 (Figure 6). The crew arrives at the R/V Hildebrand at the Rickenbacker Marina for a ~7 am departure, samples the Port of Miami (POM) site, then proceeds south to Bkg6 site south of the Pillars reef site. The ship then turns north, samples the Emerald Reef sites (ER1-3), then Bkg5, then three sites near the Miami-Central outfall, then Bkg4, the Pillars sites (P1-3), Miami-North outfall sites (MN1-3), and then deadheads to the dock at NSU. The ship is docked at NSU and washed down. For this leg, there are 13 sites generating 38 samples. With two blanks and two duplicates there are 42 sample bottles for each analyte (Table 3). The sample bottles are FEDEXed express overnight to FDEP for analysis.

An additional consideration is the tide. Three inlets are to be sampled during the two days (Pt. Everglades, Haulover, and the Port of Miami). Each should be sampled during an outgoing (ebb) tide, otherwise only coastal seawater would be sampled. Note that each can be sampled during either Day 1 or Day 2. The choice of which day each inlet will be sampled will depend on which day better accommodates the ebb tide requirement at that inlet; the sampling sequence would then be modified from that listed in Appendix 1.

Following the cruise, a cruise report will be submitted to Brown and Caldwell with preliminary data (e.g., cruise track, sample CTD profiles, weather) and commentary on how the cruise proceeded, as a part of that month's monthly report.

The WQ cruises should be understood within the context of the entire project. A timeline is shown in Appendix 2. The twelve bimonthly cruises, beginning in November 2013, are thus scheduled to be completed in September 2015. FDEP, which will be using the data for coastal water numeric nutrient calculations, will have access to data as the experiment proceeds because they are performing the analysis and because they have access to the monthly reports.

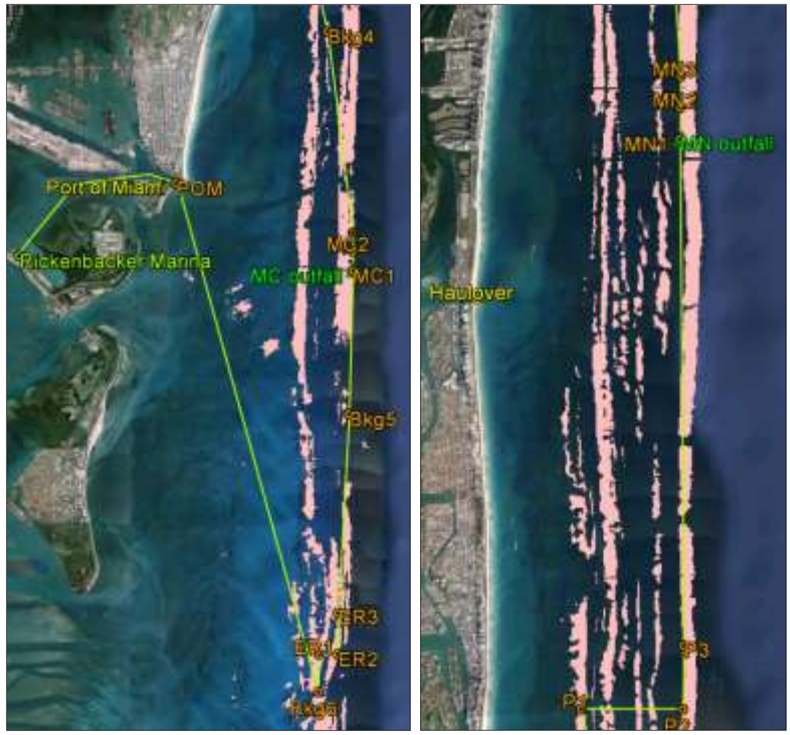

Figure 6. Day 2 sampling locations. Left: Ship proceeds from Rickenbacker Marina to the Port of Miami site, then south to Bkg6 and then the Emerald Reef sites (ER1-3), followed by the Miami-Central outfall sites (MC1-3) and Bkg4. Right: ship proceeds to the Pillars Reef sites (P1-3) followed by the Miami-North outfall sites (MN1-3) before dead-heading back to the NSU dock in Pt. Everglades.

2. OCEAN CURRENT MEASUREMENTS

Overview

We wish to assess the general characteristics of the ocean currents in the region of the water sampling (not designed to provide data representative of the conditions at each cast site). This is accomplished by use of an acoustic Doppler current profiler (ADCP) instrument. The ADCP is mounted in an adequate structure at the sea floor so that it may direct three acoustic beams upward; the return signal from the beams is interpreted to provide current velocity and direction in a number of 'bins' of vertical height above the instrument. Such a mount near the Hollywood outfall (26°1.1075'N, 80°5.1716'W, Figure 1), has been made available to AOML (Figure 7). The ADCP instrument (ADD: JACK), owned by NOAA-AOML, will be deployed at in ~25 meters of water depth. The instrument will internally record a measurement of the 3 dimensional ocean current

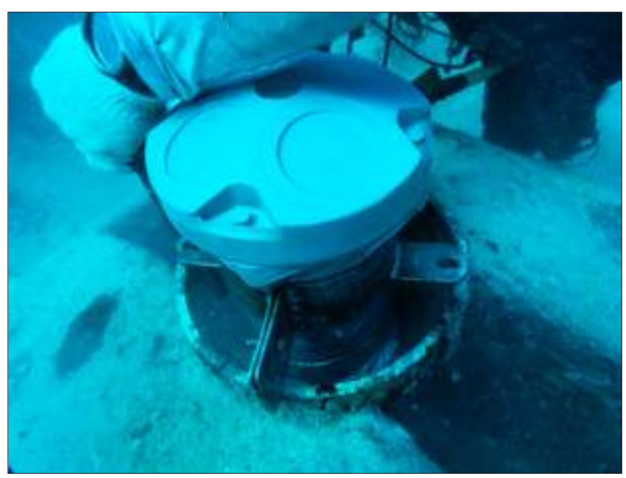

Figure 7. Mount with ADCP instrument.

velocities every 20 minutes. This instrument will be configured to profile the water column in 1-m cells starting at a distance of 3.2 m from the instrument , through the water column and up to within 2 m of the ocean surface.

The instrument is also equipped with a temperature sensor. This sensor will provide a time series of near bottom temperature data at the same rate as the current velocity measurements (i.e., every 20 min). This temperature date is particularly valuable and relevant to this study as significant drops in bottom temperature may be indicative of upwelling events (cold, nutrient-rich water being brought up from deeper depths).[33] These upwelling events are of considerable interest to fishermen, who have found the frontal zone at the western edge of the Gulf Stream to be a good fishing area.[34] The western edge of the Gulf Stream is available from NOAA's marine forecast website.[35]

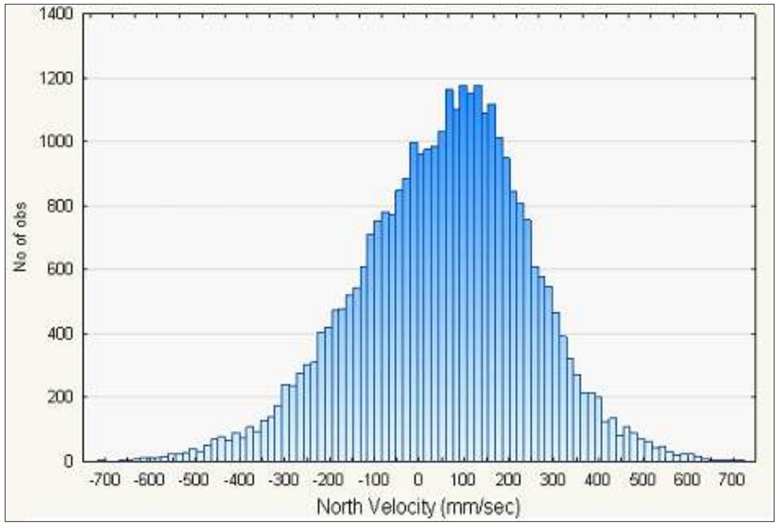

Figure 8. Water column averaged currents from an ADCP deployed near the Hollywood outfall. Although the average and the mode are both >0 (northward), the frequent occurrence of south-flowing current is evident.

As configured, the instrument has an endurance of 6 months. After this time the instrument will be recovered by divers and replaced with an identical system so that the measurement time series will be essentially continuous. The ADCP swap-out schedule is shown in Appendix 2. Deployment and maintenance of the ADCP units will be performed by NOAA divers (led by LT Rachel Kotkowski) from the R/V Hildebrand or the R/V Cable.

Data from this location has been previously analyzed by our laboratory (Carsey *et al.* 2013). With that experience, we are expecting to obtain data to elucidate these features:

- The values of the current velocity in a vertical profile from near the bottom to near the surface.
- The frequency and magnitude of current reversal events.
- The frequency and magnitude of sudden temperature drops (likely related to upwelling)
- The seasonal and temporal variability of the above mentioned phenomena.

Of particular interest are the magnitude and duration of current reversals or southern flow events. At this location, southern flow has the potential to transport water from the Port Everglades inlet to the south into the region of the wastewater outfall. Likewise, these events may transport

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[33] Lee, T., 1975. *Florida Current spin-off eddies*. Deep-Sea Res. 22, 753-765.
[34] Conway, D. Finding Offshore Currents adn Eddies. Florida Sportsman, 3-October 2012. Downloaded from http://www.floridasportsman.com/2013/09/24/features_050730/
[35] For example, http://forecast.weather.gov/MapClick.php?zoneid=AMZ651

effluent from the Hollywood outfall to the south. These events have the ability to intermingle waters from the inlets and outfalls and then redistribute these waters across the region.

Figure 8 shows a histogram of the north component of the water column averaged currents taken at this location. From this it can be seen that current reversals (velocities less than zero) were present for a significant portion of the time and are occasionally of a magnitude exceeding 500 mm/sec.

3. CORAL REEF BIOMETRIC MONITORING

Rationale

Coral reefs are ecologically and economically important ecosystems, consisting of a wealth of biodiversity[36] and productivity[37], as well as providing valuable services through tourism, fishing, and breakwater protection.[38] South Florida reefs are no exception, providing important economic services to the surrounding counties through diving, snorkeling and fishing. In a year-long period spanning 2000 to 2001, reefs in Miami-Dade County alone were responsible for 9.18 million person-days of use, resulting in 1.297 billion dollars in sales, 614 million dollars in income, and roughly 19,000 jobs.[39] Given their strong link to the South Florida economy, it is imperative that managers have a solid understanding of the potential impacts associated with anthropogenic stressors such as nutrients.

There is strong evidence that nutrient enrichment can affect the benthic composition of a reef ecosystem. From the 1950's into the 1970's high sewage inputs and siltation caused a large-scale die-off of the coral community in Kaneohe Bay, Hawaii and switch to an algal dominated (*Dictyosphaerin cavernosa*) state.[40] When raw sewage inputs were stopped in the late 70's macroalgae abundance gradually decreased along with an increase in coral cover.[41]

Mechanisms behind nutrient-associated reef degradation are numerous. Some macroalgae species are nutrient limited and increases in nutrient concentrations could potentially lead to their proliferation.[42, 43] Additionally, algae have been observed to out-compete corals[44] and some species are known to overgrow and detrimentally shade coral colonies.[45] With respect to nutrients directly influencing coral health, high nutrient levels can decrease the reproductive success of certain coral

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[37] Odum, H., Odum, E. 1955. *Trophic structure and productivity of a windward coral reef community on Eniwetok Atoll*. Ecol. Monogr. 25, 291–320
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species[46] which may allow algae to gain a competitive advantage. Increased nutrients may also increase coral mortality[47] which would allow algae to establish on a subsequently dead and barren coral substrate. Certain nutrients such as phosphate may decrease coral growth[48] which may give macroalgae a competitive advantage. Additionally, elevated nutrients are known to influence calcification, resulting in lower density skeletons[49] and corals that are subsequently more susceptible to physical stress and fragmentation[50].

These studies underscore the need to understand the nutrient dynamics in South Florida and to determine how natural gradients and fluctuations influence the health of these important reef ecosystems. Accordingly, the following methodologies will be employed to quantify coral and algal communities at the same sites where accurate nutrient measurements will be taken.

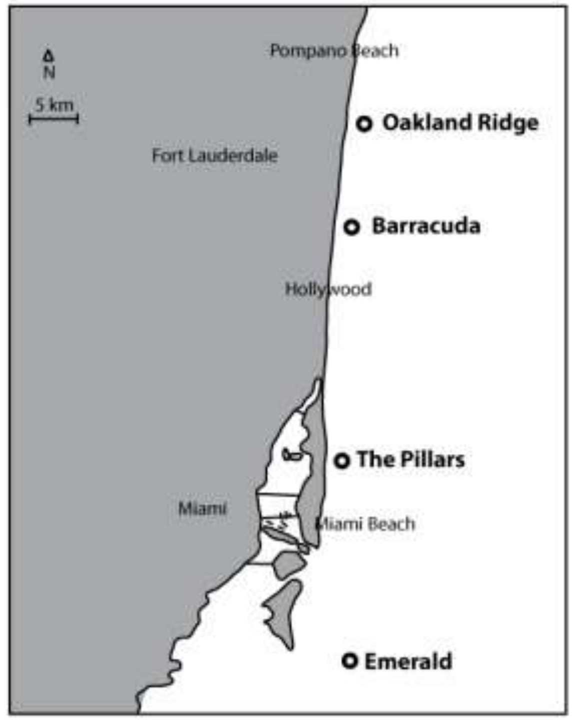

Figure 9. Location of the four study reef sites

Study sites

Coral reef ecosystems will be assessed to document nutrient dynamics in relation to benthic community structure and health. Four reef sites (Oakland Ridge, Barracuda, Pillars, Emerald) were chosen based on their location in the SEFCRI region, proximity to nutrient sources, as well as similar benthic composition and depth (Figure 9). Three permanent monitoring stations will be established at each site for a total of 12 sampling sites. Sites will be marked with GPS at the surface to assist in precise location on subsequent monitoring trips.

Assessment methodology

Corals surveys will be conducted using the guidelines and suggestions of the EPA Stony Coral Rapid Bioassessment Method.[51] At each of the 12 sampling sites, a three by five meter radial belt transect will be employed to survey a roughly 50 m^2 planar area of the benthos. One diver will attach a transect tape to a central axis at the study site, with the three and five meter distances clearly delineated. The line will be held taught above the surface of the reef so as to avoid contact with the underlying community. As the first diver slowly rotates the transect tape around the central axis, a

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second diver will conduct an assessment of the underlying benthic community. Each coral within the belt transect will be identified to the species level and counted. Scleractinian corals located on transect margins where an excess of 50% of the colony is within the belt transect will be included in the analysis. All corals greater than 10 cm maximum diameter will be measured in order to approximate total volume and surface area. Maximum length, width, and height will be recorded. General colony morphology (e.g., planar, spheroidal, branching) will be noted to aid in geometric approximation.

A survey of reef algae will be conducted concurrently with the aforementioned coral census. Algae survey methodologies will follow a modified version of the EPA Periphyton Protocol (method II).[52] Whereas the aforementioned protocol was originally developed for freshwater systems, methodologies herein are specifically tailored to capture the composition and temporal dynamics of the reef algal communities. Coral reefs are heterogeneous environments and as such often necessitate greater sampling effort in order to adequately quantify the benthic community. Accordingly, photo quadrats will be taken over the extent of the radial belt transect to quantify the percent algal composition at each sample site. Photo quadrats will be analyzed using Coral Point Count (CPCe) software.[53] Random points will be overlaid on each quadrat and the underlying species will be noted. Analysis will be conducted at the species level as well as at the functional group level (e.g., crustose coralline algae, calcifying macroalgae, turf algae, green macroalgae, red macroalgae) in order to identify community shifts impacting groups with similar life history characteristics. Additionally, the photo quadrat approach will allow for the direct enumeration of various non-scleractinian invertebrate communities which are known to respond to changes in nutrient concentration (e.g., bioeroding sponges[54]).

Community analysis

Analysis of reef corals and algae will include the calculation of univariate community parameters such as abundance, density, species richness, and diversity. Coral condition will be quantified including percent live tissue and presence of bleaching. These types of data may be regressed against gradients in nutrient concentration in order to identify significance and develop models of community response to stress. Additionally, size-frequency distributions of common coral species will be analyzed to assess the relative longevity and recruitment success of coral populations at each study site.[55] Populations skewed towards larger size-classes of corals reflect low recruitment yet long-lived colonies, whereas those populations with higher than expected frequencies of small size class colonies are expected to have higher recruitment and higher than expected mortality of older corals. With this type of analysis we can use existing population structure to make inferences on present and past stressors influencing benthic cover. Finally, multispecies abundance data will be analyzed using various multivariate techniques included in the PRIMER-E statistical package.[56] Species assemblages will be plotted in Euclidian space using non-metric multidimensional scaling (nMDS) of Bray-Curtis similarity matrices in order to visualize and identify perturbations which influence community composition.

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Sampling logistics

Surveys will be conducted four times per year so as to capture seasonal fluctuations in benthic community composition. Transportation to reef sites will be achieved using NOAA-AOML's R/V Cable, a 21-foot Parker powered by a 200 hp Yamaha 2-stroke. The two southern reef sites (Pillars, Emerald) will be accessed by launching the boat from Virginia Key, while the northern sites (Oakland Ridge, Barracuda) will be reached by trailering the boat and launching from a more northerly location. At least three and likely four researchers will be involved with each sampling mission, so that there will always be a dedicated boat tender and a two to three diver team. All diving operations will conform to the safety guidelines and procedures of the American Academy of Underwater Sciences (AAUS). Because of the logistics and safety requirements inherent in diving operations, the duration of each coral survey will be dependent on the weather. Each sampling operation is expected to last roughly four days.

APPENDIX 1. WQ CRUISE PLAN

						D to next	Cum D	Cum D	Trv	Cum T	Time of Day	#	#
DAY	**NOTES**	**Name**	**Type**	**Lon**	**Lat**	**km**	**km**	**nm**	**T[Hr]**	**[hr]**	**EDT**	**casts**	**Samples**
1	Dock at Pt. Everglades			-80.11192	26.09082	0.0	0.0	0.0	0.00	0.00	11/13/13 7:00 AM	0	0
1	Port Everglades Inlet / PEI	PEI	In	-80.10972	26.09345	0.4	0.4	0.2	0.02	0.27	11/13/13 7:15 AM	1	2
1	turn 1			-80.10000	26.09305	1.0	1.3	0.7	0.04	0.31	11/13/13 7:18 AM	0	0
1	Oakland Ridge 1	OR1	CR	-80.08250	26.15929	7.6	8.9	4.8	0.34	0.90	11/13/13 7:54 AM	1	3
1	Oakland Ridge 2	OR2	CR	-80.07698	26.15929	0.6	9.5	5.1	0.02	1.18	11/13/13 8:10 AM	1	3
1	Oakland Ridge 3	OR3	CR	-80.07698	26.16357	0.5	9.9	5.4	0.02	1.45	11/13/13 8:26 AM	1	3
1	Bkg betw'n BC2 and Hilsb In	Bkg1	BKG	-80.08816	26.13000	3.9	13.8	7.5	0.18	1.87	11/13/13 8:52 AM	1	3
1	Barracuda 1	B1	CR	-80.09333	26.06304	7.5	21.3	11.5	0.34	2.46	11/13/13 9:27 AM	1	3
1	Barracuda 2	B2	CR	-80.09900	26.06767	0.8	22.1	11.9	0.03	2.74	11/13/13 9:44 AM	1	3
1	Barracuda 3	B3	CR	-80.09333	26.06767	0.6	22.6	12.2	0.03	3.02	11/13/13 10:01 AM	1	3
1	mid MNout and Hwout	Bkg2	BKG	-80.09642	26.00000	7.5	30.2	16.3	0.34	3.61	11/13/13 10:36 AM	1	3
1	1 km N of Mia-N	MN3	OF	-80.08937	25.93216	7.6	37.7	20.4	0.34	4.20	11/13/13 11:11 AM	1	3
1	½ km N of Mia-N	MN2	OF	-80.08937	25.92765	0.5	38.2	20.6	0.02	4.47	11/13/13 11:28 AM	1	3
1	Miami-N outfall	MN1	OF	-80.08937	25.92306	0.5	38.7	20.9	0.02	4.74	11/13/13 11:44 AM	1	3
1	Bakers Haulover Inlet	BHI	In	-80.12139	25.90000	4.1	42.8	23.1	0.18	5.18	11/13/13 12:10 PM	1	2
1	mid DC123 & MNout	Bkg3	BKG	-80.08937	25.89500	3.3	46.1	24.9	0.15	5.57	11/13/13 12:34 PM	1	3
1	Mia turn 1			-80.12162	25.76175	15.2	61.3	33.1	0.68	6.26	11/13/13 1:15 PM	0	0
1	Mia turn 2			-80.16248	25.76392	4.1	65.4	35.3	0.18	6.44	11/13/13 1:26 PM	0	0
1	Dock (Rickenbacker Marina)			-80.17432	25.74624	2.3	67.7	36.5	0.10	6.54	11/13/13 1:32 PM	0	0
2	Dock (Rickenbacker Marina)			-80.17432	25.74624	0.0	0.0	0.0	0.00	0.00	10/14/13 7:00 AM	0	0
2	Mia turn 2			-80.16248	25.76392	2.3	2.3	1.2	0.10	0.10	11/13/13 7:06 AM	0	0
2	Port of Miami Inlet	PMI	In	-80.13278	25.76361	3.0	5.3	2.8	0.13	0.49	11/13/13 7:29 AM	1	2
2	1km S of DC5	Bkg6	BKG	-80.09468	25.64296	13.9	19.2	10.4	0.63	1.36	11/13/13 8:21 AM	1	3
2	Emerald Reef 1	ER1	CR	-80.09460	25.65187	1.0	20.2	10.9	0.04	1.66	11/13/13 8:39 AM	1	3
2	Emerald Reef 2	ER2	CR	-80.08965	25.65187	0.5	20.7	11.2	0.02	1.93	11/13/13 8:55 AM	1	3
2	Emerald Reef 3	ER3	CR	-80.08965	25.66158	1.1	21.8	11.8	0.05	2.23	11/13/13 9:13 AM	1	3
2	between DC5 and MC	Bkg5	BKG	-80.08693	25.70871	5.2	27.0	14.6	0.24	2.72	11/13/13 9:42 AM	1	3
2	Miami-C outfall	MC1	OF	-80.08597	25.74282	3.8	30.8	16.6	0.17	3.14	11/13/13 10:08 AM	1	3
2	½ km N of Mia-C	MC2	OF	-80.08597	25.74746	0.5	31.3	16.9	0.02	3.41	11/13/13 10:24 AM	1	3
2	1 km N of Mia-C	MC3	OF	-80.08597	25.75184	0.5	31.8	17.2	0.02	3.68	11/13/13 10:40 AM	1	3
2	between MCof and DC123	Bkg4	BKG	-80.09296	25.80000	5.4	37.2	20.1	0.24	4.18	11/13/13 11:10 AM	1	3
2	Pillars 1	P1	CR	-80.10403	25.84210	4.8	42.0	22.7	0.22	4.64	11/13/13 11:38 AM	1	3
2	Pillars 2	P2	CR	-80.08810	25.84210	1.6	43.6	23.6	0.07	4.96	11/13/13 11:57 AM	1	3
2	Pillars 3	P3	CR	-80.08810	25.85098	1.0	44.6	24.1	0.04	5.26	11/13/13 12:15 PM	1	3
2	turn 1			-80.10000	26.09305	26.9	71.6	38.6	1.21	6.47	11/13/13 1:28 PM	0	0
2	Dock at Pt. Everglades			-80.11192	26.09345	1.2	72.8	39.3	0.05	6.52	11/13/13 1:31 PM	0	0
	Totals Leg 1					leg 1	67.7	36.5		6.54		14	40
	Totals Leg 2					leg 2	72.8	39.3		6.52		13	38
	Total both legs				TOTAL	Both Legs	140.4	75.8		13.1		27	78

APPENDIX 2. Schedule of Events.

	SCHEDULE	MTP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
			Oct 13	Nov 13	Dec13	Jan 14	JFeb14	Mar 14	Apr 14	May 14	Ju 14	Jul 14	Aug 14	Sep14	Oct 14	Nov 14	Dec 14	Jan 15	JFeb15	Mar 15	Apr 15	May 15	Ju 15	Jul 15	Aug 15	Sep15	Oct 15	Nov 15	Dec 15	Jan 16	JFeb16	Mar 16	Apr 16	May 16	Ju 16	Jul 16	Aug 16	Sep16
	Task 1: ***Project Planning and Manag.***																																					
1	Project Management Plan																																					
2	Projec Schedule																																					
3	Project Kickoff																																					
4	Monthly Progr Reports & Review Calls																																					
	Task 2: ***Lit Review & Test Plan***																																					
1	Literature Review																																					
2	Draft Plan of Study																																					
3	Final Plan of Study																																					
	Task 3a: ***WQ Cruises***																																					
1	Pre-cruise call																																					
2	WQ cruise			c1		c2		c3		c4		c5		c6		c7		c8		c9		c10		c11		c12												
3	Post-cruise call																																					
4	Monthly report																																					
	Task 3b: ***Coral Surveys***																																					
1	Coral survey cruises				cs1			cs2			cs3			cs4			cs5			cs6			cs7			cs8												
	Task 3c: ***ADCP Measurements***																																					
1	Deploy ADCP units																																					
2	Service trip									svc1						svc2						svc3																
3	Retriev ADCP units																																					
	Task 4: ***Exec Sum. & Final Report***																																					
1	Draft Project Report & review meeting																																					
2	Revised Draft Project Report																																					
3	Final Project Report																																					
4	Presentation of Results																																					

c=WQ Cruise
svc=ADCP service
cs=Coral survey