National Park Service
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A Cooperative Multi-agency Reef Fish Monitoring Protocol for the Florida Keys Coral Reef Ecosystem

Natural Resource Report NPS/SFCN/NRR—2009/150

ON THE COVER
Clockwise from top left: face of a French angelfish (*Pomacanthus paru*), school of Creole wrasse (*Clepticus parrae*) swimming over a *Montastraea franksi* coral, a rock beauty (*Holacanthus tricolor*), a red grouper (*Epinephelus morio*), a school of permit (*Trachinotus falcatus*). All photos taken in the Dry Tortugas by J. Luo.

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Natural Resource Report NPS/SFCN/NRR—2009/150

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Executive Summary

Reef fish populations are conspicuous and essential components of coral reef ecosystems in the south Florida region. Recent precipitous declines in these populations are believed to be due to severe habitat degradation as well as significant increases in recreational and commercial fishing. The monitoring methodologies described in this document are necessary for understanding how natural and man-made stressors are changing reef fish populations and communities. These stressors will continue to increase, and understanding the responses of populations and communities will be critical for their sustainable management.

This document provides the background behind and descriptions of the protocols developed for a collaborative, multi-agency effort to monitor reef fish populations in the Florida Keys and Dry Tortugas. Agencies involved include the National Oceanic and Atmospheric Administration Southeast Fisheries Science Center (NOAA Fisheries), Florida Fish and Wildlife Conservation Commission's Florida Fish and Wildlife Research Institute (FWRI), the University of Miami's Rosenstiel School of Marine and Atmospheric Science (UM-RSMAS), and the National Park Service (NPS). This collaborative effort is the culmination of nearly three decades of independent Florida Keys monitoring programs aimed at fish populations in the region.

The Florida Keys reef tract extends some 370 km from Miami to the Dry Tortugas and encompasses a variety of benthic habitat types and management areas. In order to more efficiently sample within such a heterogeneous region, the sampling effort is optimized using a two-stage stratified random sampling design. Before sampling occurs, the Florida Keys and Dry Tortugas sampling domains are partitioned into 200 x 200 m grid cells, or primary units, which are each assigned to a strata designation based on habitat type, geographic sub-region, management type (open vs. closed to extraction), and depth. The number of primary units to be sampled in each stratum type is based on a Neyman allocation scheme, which accounts for the stratum's size and the strata standard deviations for eight focal fish species densities. Once the optimal number of primary units per stratum is chosen based on a target precision and the capabilities of the agencies, primary units to be sampled are randomly selected from a list of all possible primary units for each stratum. Within each selected primary unit, two smaller second-stage units are haphazardly selected. Each second-stage unit consists of a buddy pair of divers who each perform a Reef Visual Census (RVC) which is a 15 m diameter stationary point count. A stationary point count method was chosen as the *in situ* visual sampling method of choice because the complexity and spatial extent of Florida Keys habitats often precludes the use of linear transects and it has also been found to be a better estimator of exploited fish densities in the Florida Keys. The RVC method allows divers to simultaneously collect data on the density and size distributions of the entire fish community, as well

as information on benthic habitat features. Sampling occurs annually in the summer months throughout the Florida Keys reef tract and every even year in the Dry Tortugas. Qualified and trained personnel are represented from all participating agencies.

This document first gives an overview of the objectives of the monitoring program, which are focused on tracking changes in the abundances, spatial distributions and size structures of exploited reef fish species and the reef fish community as a whole. These changes are evaluated each year with respect to the habitat features, the physical environment and potential management actions that may have affected the dynamics of the populations.

The specifics of the methods used to accomplish monitoring objectives are detailed in five Standard Operating Procedures (SOPs). The SOPs are meant to be stand-alone documents that can be used at different stages of program implementation. These SOPs include A) Statistical Sampling Design, B) Participant Training, C) Field Data Collection Methods, D) Data Entry and Proofing, and E) Data Analyses and Reporting. This document also includes an appendix that is a glossary of statistical symbols and computational formulae used in the sample size calculations, an appendix of guides to habitat component identification that can be printed and used in the field for reference, an appendix of printable data sheets, and an appendix of the benthic habitats of the Florida Keys as defined by the Florida Department of Environmental Protection.

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Development and application of these mapping and assessment methods over the last several years would not have been possible without the technical assistance of John Brock at USGS who provided LIDAR data for the Dry Tortugas. A thematic layer classification scheme modified by us was originally created by the Florida Marine Research Institute (FMRI 1998) from photogrammetric interpretation of aerial surveys performed between December 1991 and April 1992 (see Franklin et al. 2004 for more information). The following funding sources in previous years contributed greatly to program development and/or application of these methodologies (in no particular order): U.S. Man and the Biosphere Program, National Undersea Research Program, Southeast Fisheries Science Center (SEFSC, NMFS), Department of the Interior and the National Park Service, Biscayne National Park, Everglades/Dry Tortugas National Park, Florida Keys National Marine Sanctuary, U.S. Army Corp of Engineers, NOAA Coastal Ocean Program, U.S. Environmental Protection Agency, National Fish and Wildlife Foundation, Florida Fish and Wildlife Conservation Commission, National Sea Grant College Program, NOAA Biogeography Program, Florida Fish and Wildlife Research Institute, the U.S. Fish and Wildlife Service, Federal Aid for Sportfish Restoration fisheries independent monitoring (F-43) and reef fish (F-7) projects, proceeds from the sale of Florida recreational fishing licenses, and NOAA's Coral Reef Conservation Program.

Introduction

Rationale behind this Document and Reef Fish Monitoring

This document is meant as a reference and provides guidelines for survey design, training, sampling, data entry, data management, analysis and reporting for the annual fishery-independent monitoring of reef fish populations within the Florida Keys and Dry Tortugas reef ecosystems. This document conforms to the Oakley et al. (2003) formatting guidelines for NPS long-term monitoring protocols and is a more detailed and updated follow-up to a previously published guide for reef fish monitoring (Menza et al. 2006). A collaborative effort among government and university groups characterized the first instance of monitoring following these specific protocols in 2008, marking the culmination of nearly 30 years of fishery-independent reef fish monitoring by multiple independent groups in the South Florida region.

Reef fish communities are a vital component of coral reef ecosystems, and have major economic and ecological importance throughout the world. Reef fish communities are the #2 vital sign ("vital sign", as defined by NPS, being a subset of physical, chemical and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources or elements that have important human values) as ranked out of 69 considered by the seven National Parks within the South Florida / Caribbean Network of the National Park Service's Inventory and Monitoring program. Their high ranking is due their significance to the functioning of coral reef ecosystems and because of their economic importance. These factors make coral reef fish communities a sensitive indicator of both ecosystem degradation and/or overexploitation, and they are therefore readily affected by management actions.

Yet despite their significance, the abundance and diversity of reef fish communities throughout the Caribbean have seen unprecedented declines due to a combination of direct and indirect anthropogenic stressors, including overfishing (Hughes 1994, Ault et al. 1998, 2002, Mora 2008). Although the dynamics of reef communities have likely been altered for much longer (Jackson et al. 2001), recent increases in recreational and commercial fishing in the Florida Keys region have resulted in an overfished status for several economically important fish species (Ault et al. 2005a). Loss of spawning aggregations, declines in densities, and changes in size structures of exploitable fish populations have been documented and are indicators of overexploitation (Bohnsack et al. 1994, Ault et al. 1998). Once historically productive reef fisheries, such as groupers and snappers, have experienced major declines in catch estimates in recent times (Allen and Tashiro 1976, Bohnsack et al. 1994, Ault et al. 2005b). Extraction of key species has led to the alteration and/or shortening of marine food webs, which can result in a loss of ecosystem functioning and fishery resilience (Pauly et al. 2002).

Changes in habitat structure and quality are also known to have quantifiable repercussions to associated reef fish abundances and diversity (McClanahan 1994, McClanahan et al. 1999, Wilson et al. 2006). Coastal development has increased sedimentation and has led to a degradation of water quality, with negative consequences to fish habitat. At regional-levels, events such as mass coral bleaching and disease epizootics have altered the structure and function of reefs by removing reef framework-building live coral (Gardner et al. 2003, Miller and Williams 2007) or causing coral community shifts such that topographic complexity is lost (Aronson and Precht 2001, Graham et al. 2007). Also, the complex life history strategies of many reef fish species can span multiple habitats and can include a large-scale dispersal phase. Fish assemblages can therefore be characteristic of specific habitats and the transport mechanisms among habitats and regions (Kimmel 1985, Chittaro et al. 2005). While changes in reef fish abundances and structure may indicate direct effects from overfishing, they can also be indicators of the status and trends of the system as a whole, and may be a reflection of one or a combination of changes in habitat quality, connectivity, fishing pressure and long-term ecosystem resilience.

If coral reef ecosystems including reef fish abundance and diversity continue to decline, the many and diverse benefits provided by reef fish communities will be lost, with severe ecological and economic consequences. Monitoring programs, such as that described in this document, assess the temporal and spatial patterns of change in reef fish communities. Information from these monitoring programs can document and provide insight into ecosystem decline and its potential for recovery.

Fishing and Other Pressures on the Reef

Florida has been dubbed the "fishing capital of the world" by the Florida state legislature (FWC 2007) because its coral reefs support, in large part, the vital fisheries and tourism-based economy that generates an estimated $6 billion in economic activity per year (Johns et al. 2001). Fishing activities occurring in the waters of the Florida Keys are both commercial and recreational, though, in recent decades, recreational vessel registrations in South Florida have more than doubled and represent a significant portion of the overall fishing impact. Fishing has contributed significantly to the depletion of multiple reef fish stocks. Ault et al. (1998) found that 13 of 16 groupers, 7 of 13 snappers, 1 wrasse (hogfish), and 2 of 5 grunts were overfished according to federal (NMFS) standards. In addition, fishing can negatively impact reef habitats by the direct removal of key species and non-target species as bycatch and by fishing-related habitat damage (Davis 1977, Clark 2006). Other impacts that have resulted in the degradation of Florida's reef habitats and fish populations include hurricanes, coral bleaching events, and coastal development due to the exponential growth of Florida's human population and a high volume of tourism. Additionally, over the past century activities managing water movement through the Everglades has lead to the massive alteration of land drainage patterns in the South Florida region. Although intensively managed, the Florida reef ecosystem is also considered one of the most stressed ecosystems in the nation (Porter et al.

1999). Clearly, reef fish populations represent one of the most valuable but also most threatened resources of the Florida Keys.

Fishing Management

Numerous protected areas have been established within the South Florida region (Figure 1.1) for various purposes and with various levels of protection against resource use and extraction. As with all coastal regions in the state, the Florida Fish and Wildlife Conservation Commission and the Federal South Atlantic Fishery Management Council are responsible for specific fishery management regulations inside and outside of 3 miles of the coast, respectively. The largest designated area is the Florida Keys National Marine Sanctuary (FKNMS) which covers a total area of 9,515 km^2 (3,673 mi^2) extending from Miami to beyond the Dry Tortugas. Moving from east to west, other protected areas in the "Upper Keys" include Biscayne National Park (BNP), Key Largo National Marine Sanctuary, John Pennekamp Coral Reef State Park, Biscayne Bay and Card Sound Aquatic Preserve, and Lignumvitae Aquatic Preserve. In the Middle and Lower Keys, there are the National Key Deer Refuge, Coupon Bight Aquatic Preserve, Looe Key National Marine Sanctuary, the Great White Heron National Refuge, and the Key West Wildlife Refuge. To the west is the Dry Tortugas National Park (DTNP). In 1997, a network of 23 no take marine reserves (NTMRs) were implemented by FKNMS in various areas throughout the Keys. These are small areas, comprising a total area of 46 km^2, and they vary in level of protection, ranging from accessible only by special permit to the allowance of catch-and-release surface trolling. This network was expanded in 2001 in the Dry Tortugas with the addition of two NTMRs prohibiting anchoring and extraction: the Tortugas Ecological Reserve North and South, which cover approximately 566 km^2. Most recently, in 2007, the National Park Service designated a 46 square mile area within Dry Tortugas National Park as a Research Natural Area, which also prohibits anchoring and extraction.

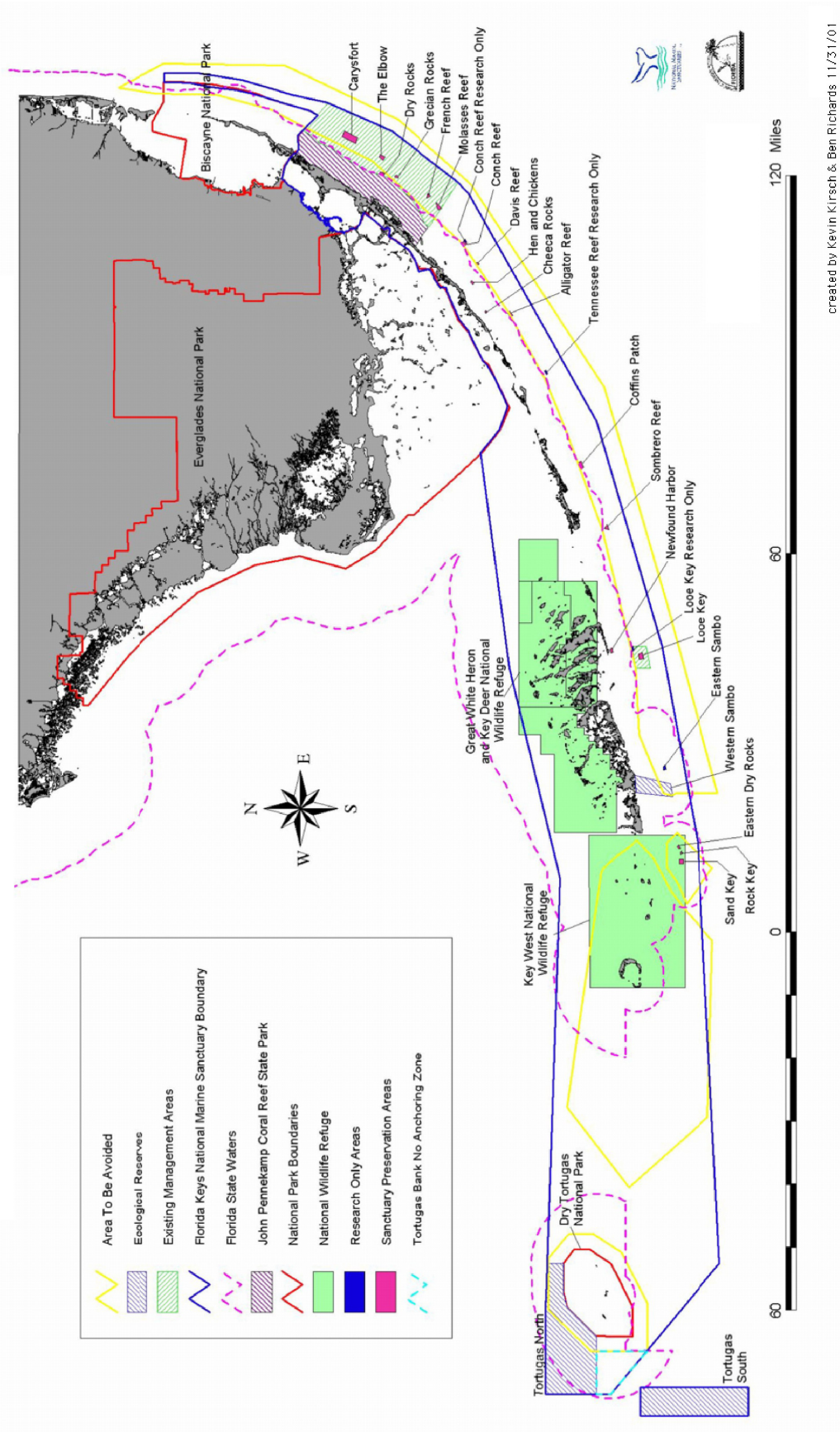

Figure 1.1. Designated management zoning of the Florida Keys coastal marine ecosystem, including the Florida Keys National Marine Sanctuary, Biscayne National Park and Dry Tortugas National Park.

Background and Objectives

History

In 1979, the National Oceanic and Atmospheric Administration Southeast Fisheries Science Center (NOAA Fisheries) began monitoring reef fish populations at fixed sites along the Keys using a scuba-based Reef Fish Visual Census (RVC) approach (Bohnsack and Bannerot 1986). Through time the number and spatial distribution of these sites expanded. In 1997, the University of Miami's Rosenstiel School of Marine and Atmospheric Science (UM-RSMAS) joined NOAA Fisheries as a partner and helped to design and implement a habitat-based stratified random survey design to locate RVC sample locations (Ault et al. 2001, 2002). In 1999, the first multi-agency high-intensity survey of the Dry Tortugas took place, and approximately 941 RVCs were completed using the habitat-based stratified random sampling design. Sampling has since continued as a collaborative effort between UM-RSMAS and NOAA Fisheries on an annual basis in the Florida Keys and every even year in the Dry Tortugas. Publications that documented or have resulted from these efforts are numerous and span multiple decades (Table 1.1).

Meanwhile, in 1998, the Florida Fish and Wildlife Conservation Commission's (FWC) Fisheries Independent Monitoring (FIM) program began a long-term monitoring effort of key reef fish populations in the Florida Keys National Marine Sanctuary. This effort was aimed at evaluating the relative abundance, size structure, and habitat utilization of specific reef fish species that are targeted by commercial and recreational fisheries. In 1999 and 2000, FWC did a formal comparison of the two most commonly used visual sampling techniques, the stationary point count method used by the NOAA/UM-RSMAS group (Bohnsack and Bannerot 1986) and the strip transect method (as reviewed in Sale 1997). This comparison determined that the stationary point count method was most successful at estimating fish densities, and was employed annually within FKNMS in the Florida Keys regions (Colvocoresses and Acosta 2007).

In April 2007, FWC's Fish and Wildlife Research Institute (FWRI) and the Florida Wildlife Legacy Initiative conducted a two day joint workshop to examine Reef Fish Visual Census techniques (RVC) for the assessment of population structure and biodiversity in waters of South Florida, U.S. The proposed outcome of the workshop was to establish a consensus on the most appropriate methodologies to use, and to standardize methodologies across the South Florida Region. The workshop goals included examining RVC techniques currently in use in South Florida, exploring alternative techniques and determining the types and magnitude of biotic change we want to detect. The final outcome from this workshop was an agreement between FWC-FWRI, NOAA Fisheries, and UM-RSMAS to collaborate on the design and conduct of annual coral reef fish monitoring and assessment efforts in the Florida Keys coral reef ecosystem. Early in 2008, the National Park Service Inventory and

Monitoring Program South Florida and Caribbean Network Office (NPS) added their cooperative support.

The protocols have been developed with the goal of determining trends in reef fish populations through time and across space, including determining the effect of various management zones on these trends. The protocols have been agreed upon by the representatives of the NOAA Fisheries, FWC-FWRI, UM-RSMAS, and NPS. These protocols are meant to guide cooperative monitoring efforts that began in 2008.

Table 1.1. Publications documenting the development or results of the multi-agency reef fish sampling in the Florida Keys and Dry Tortugas.

Year	Publication
1986	Bohnsack, J. A. and S. P. Bannerot. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. **NOAA Tech. Report** NMFS 41. 15 p.
1998	Ault, J. S., J. A. Bohnsack, and G. A. Meester. A retrospective (1979-1996) multispecies assessment of coral reef fish stocks in the Florida Keys. **Fishery Bulletin** 96:395-414.
1999	Ault, J.S., Diaz, G.A., Smith, S.G., Luo, J. and J.E. Serafy. An efficient sampling survey design to estimate pink shrimp population abundance in Biscayne Bay, Florida. **North American Journal of Fisheries Management** 19:696-712.
1999	Bohnsack, J.A., McClellan, D.B., Harper, D.E., Davenport, G.S., Konoval, G.J., Eklund, A., Contillo, J.P., Bolden, S.K., Fischel, P.C., Sandorf, G.S., Javech, J.C., White, M.W., Pickett, M.H., Hulsbeck, M.W., Tobias, J.L., Ault, J.S., Meester, G.A., Smith, S.G., and J. Luo. Baseline data for evaluating reef fish populations in the Florida Keys, 1979-1998. **NOAA Technical Memorandum** NMFS-SEFSC-427. 61p.
2001	Ault, J. S., S. G. Smith, G. A. Meester, J. Luo, and J. A. Bohnsack. Site characterization for Biscayne National Park: assessment of fisheries resources and habitats. **NOAA Technical Memorandum** NMFS-SEFSC-468. 185 p.
2002	Ault, J. S., S. G. Smith, J. Luo, G. A. Meester, J. A. Bohnsack, and S. L. Miller. Baseline multispecies coral reef fish stock assessment for the Dry Tortugas. **NOAA Technical Memorandum** NMFS-SEFSC-487. 117 p.
2002	Bohnsack, J. A., D. E. Harper, D. B. McClellan, D. L. Sutherland and M. White. Resource survey of fishes within Looe Key National Marine Sanctuary, 1983. **NOAA Technical Memorandum** NOS-NCCOS-CCMA-160 and NMFS-SERSC-478. 327 p.
2003	Ault, J. S., D. B. Smith, E. C. Franklin, J. Luo, and J. A. Bohnsack. Sampling design analysis for coral reef fish stock assessment in Dry Tortugas National Park. **Final Report, National Park Service** Contract No. H5000000494-0012. 87 p.
2003	Franklin, E. C., J. S. Ault, S. G. Smith, J. Luo, G. A. Meester, G. A. Diaz, M. Chiappone, D. W. Swanson, S. L. Miller, and J. A. Bohnsack. Benthic habitat mapping in the Tortugas region, Florida. **Marine Geodesy** 26:19-34.
2004	Bohnsack, J. A., J. S. Ault, and B. Causey. Why have no-take marine protected areas? **Aquatic Protected Areas as Fisheries Management Tools** 42:185-193.
2005	Ault, J. S., J. A. Bohnsack, S. G. Smith, and J. G. Luo. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. **Bulletin of Marine Science** 76:595-622.
cont'd	

2005	Ault, J. S., S. G. Smith, and J. A. Bohnsack. Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. **Ices Journal of Marine Science** 62:417-423.
2006	Ault, J. S., S. G. Smith, J. A. Bohnsack, J. G. Luo, D. E. Harper, and D. B. McClellan. Building sustainable fisheries in Florida's coral reef ecosystem: Positive signs in the Dry Tortugas. **Bulletin of Marine Science** 78:633-654.
2007	McClellan, D. B. and D. E. Harper (eds.). Compilation of selected unpublished RVC studies conducted by the Reef Resources Team, 1985-2002. **NOAA Technical Memorandum** NMFS-SEFSC-561. 104 p.
2008	Ault, J.S., Smith, S.G., Luo, J., Monaco, M.E., and R.S. Appeldoorn. Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. **Environmental Conservation** 35(3):221-231.
2008	Bartholomew, A., J. A. Bohnsack, S. G. Smith, J. S. Ault, D. E. Harper, and D. B. McClellan. Influence of marine reserve size and boundary length on the initial response of exploited reef fishes in the Florida Keys National Marine Sanctuary, USA. **Land. Ecology** 23:55-65.

Measurable Objectives of Monitoring

The objective of the monitoring effort is to document reef fish community composition, abundance, and size structure and determine changes in these parameters over time within the Florida Keys region, specific sub-regions, and inside vs. outside different management zones. Special attention is also paid to specific exploited reef fish species. While each agency may have their own specific objectives that can vary by sampling year, this overall objective is agreed upon by all agencies and guides the monitoring effort.

The sampling design is optimized with respect to eight focal species which are all important commercial and recreational fisheries in the South Florida region: white grunt (*Haemulon plumieri*), bluestriped grunt (*H. sciurus*), hogfish (*Lachnolaimus maximus*), mutton snapper (*Lutjanus analis*), gray snapper (*L. griseus*), yellowtail snapper (*Ocyurus chrysurus*), red grouper (*Epinephelus morio*), and black grouper (*Mycteroperca bonaci*). These species are the most prominent examples of overfished high-level predators in the Florida Keys (Ault et al. 1998). The sample design is optimized with respect to these species, but because all fish species are recorded, monitoring efforts also obtain important information about many other non-targeted species, the overall trophic structure, and form the scientific basis for effective management actions.

Sampling Design

Rationale for Selecting This Sampling Design over Others

There are many ways to select a sample from a population, but if information is known about a population, a selection method can be devised that provides more accurate and precise survey estimates. A simple random sampling design is appropriate for situations where there is no spatial structure in the variance of the investigated species or when little information is available upon which to logically stratify the sampling effort. But reef fish are typically heterogeneous with respect to

geographic distribution and vary in space according to certain environmental covariates, such as depth and vertical relief. Knowing this, maps of environmental covariates can be used to effectively divide the sampled area into strata. Random samples can then be allocated into these strata based on each stratum's proportional area and the variance structure of the population within that stratum. This type of stratified random sampling design is capable of more effectively and efficiently sampling a reef fish population than a simple random sampling design (Cochran 1977).

As documented in detail in **SOP A**, existing benthic habitat maps and data collected from previous reef fish sampling are used to optimize sampling according to this protocol. Site selection is based on a two-stage stratified random sampling design which uses the variance structure of collected data to select sites more efficiently from the sampling domain. Certain benthic habitat measures are strongly associated with principal reef fish population and community metrics. These measures include, depth, the degree of vertical relief (e.g., rugosity, complexity), and the degree of patchiness (e.g., amount of soft bottom substrate interspersed among reef structures) of the hardbottom substrate (Ault et al. 1999; Ault et al. 2002; Franklin et al. 2003; Ault et al. 2005a). The survey domain (i.e., the Florida Keys reef tract and the Dry Tortugas reef shelf) is partitioned into 200 x 200m grid cells called primary units, and each primary unit is defined by different strata including region, habitat, depth, and management level. The number of samples (primary units) allocated to these strata is based on the variance structure of fish species densities developed from previous sampling. Applying a stratified random method such as this instead of a simple random design has been shown to dramatically improve sampling efficiency (Ault et al. 1999; Ault et al. 2005a). A benefit of this sample design used here is that there is a clearly defined sample frame, with non-overlapping sample units that have a known chance of selection. This is essential for data analysis under sampling theory (Cochran 1977). These sample units are also updateable if the original designation is inaccurate, or as habitats change or better information becomes available.

A stationary point count methodology was chosen as the fisheries-independent *in situ* visual sampling method versus other fishery-independent methods for several logistical reasons. Other methods include image-based methods (Risk and Risk 1997), aerial surveys (Sale and Sharp 1983), and *in situ* methods such as belt transects (Brock 1954) and roving diver surveys (Pattengill-Semmens and Semmens 2003). For the purposes of this survey, stationary point counts are less costly than image-based analysis (Risk and Risk 1997) and provide more detailed and quantitative information than aerial or roving diver surveys. In comparison with belt transects, stationary point counts allow divers to simultaneously collect data on the density and size distributions of the entire fish community, with the exception of rare cryptic species (Bohnsack and Bannerot 1986). Most transect methods only target one or a limited number of specific fish groups and were found to be biased in their estimates of fish density and frequency of occurrence (Demartini and Roberts 1982; Sale and Sharp 1983). Also, the Florida Keys reef tract encompasses a variety of habitat types,

including some that are restricted in size, such as patch reefs, artificial reef structures, and areas that have been impacted by ship groundings. These habitats preclude the use of linear transects. Most recently, work in the Florida Keys by Colvocoresses and Acosta (2007) found higher, more accurate density estimates for the targeted fish groups using the point count versus belt transect method.

Sampling Domain

The Florida Keys reef tract consists of a system of reef habitats that extend approximately 370 km from Key Biscayne near Miami to the Dry Tortugas. The reef tract lies parallel to the Straits of Florida with the Florida current to the south and Florida Bay to the north. The reef tract encompasses a variety of habitats in addition to coral reefs, including mangrove stands, sea grass beds, lagoons, and freshwater marshes and estuaries. These diverse habitats are known to support more than 500 species of fish (Stark 1968), many of which, including important commercial and recreational fisheries species such as snappers and groupers, utilize a range of habitats throughout their life history (Lindeman et al. 2000). However, 389 of the fish species are primarily associated with coral reef habitat (Stark 1968). Therefore, in order to increase efficiency and because the RVC methodology is optimized for reef habitat (Bohnsack and Bannerot 1986) the sampling domain for this protocol does not include the seagrass, mangrove, or other, non-reef habitats that lie within the region. Instead, the monitoring program for which this protocol was developed specifically targets reef fish populations and their primary associated coral reef habitats. Therefore, the sampling domain for reef fish monitoring in the Florida Keys and Dry Tortugas consists of all coral reef habitat stretching from Biscayne National Park to the lower Florida Keys as well as the shallow banks of the Dry Tortugas.

Sampling Frequency and Replication

Based on current funding allocation, sampling in the FKNMS and BNP will occur once annually and once in DTNP every other year. Optimally, sampling should occur in DTNP annually when funding permits. Available resources from each agency may vary extensively through time but the methodology does not require a fixed sample size. Therefore, the target sample size can be adjusted based on resources, goals, and participation, with the understanding that this will affect the precision of the sampling results.

Number and Location of Sampling Sites

Site locations are determined before each sampling season using a stratified random sampling design (rationale and details in **SOP A**). Stratification is based on geographic sub-region (e.g., upper Keys, middle Keys, lower Keys), management zone, depth, and habitat class. Digital layers for each of these components are contained within a geographic information system (GIS) and are used to delineate the survey domain, strata, and sample units. In order to control for spatial variation in population metrics, a two-stage sampling design following Cochran (1977) is used where 200 m by 200 m (40,000 m^2) grid cells serve as primary sample units, and two second-stage samples are randomly distributed within each primary unit. Each

second-stage sample consists of a diver buddy team (typically two divers, sometimes more), with each diver executing a stationary point count. Therefore, at least four scientific dives are completed within each primary unit, but the average is taken of data for each buddy team, resulting in two samples per primary unit. The number of sites to be sampled in each stratum follows a Neyman allocation scheme, in which allocation is based on the proportional area of the stratum and the variance structure of the population metric (i.e., fish density) among strata. This analysis is performed using previous years' data and under different levels of precision for the eight focal species (listed in Section 1.3). The final target number of primary sample units represents a balance between achieving an acceptable precision level in estimating abundances for each of the eight species as well as the capacities of the agencies to sample.

The actual primary units and second-stage units are then selected for sampling based on a two-stage process (details in **SOP A**). The first stage of the sample selection process consists of randomly selecting primary units from the total possible primary units for each stratum. Then, two second-stage units are randomly selected from the list of total possible second-stage sample units within the selected primary unit.

Frequency and Timing of Sampling

After the list of sample sites is generated each year, representatives from the participating agencies will meet and assign responsibility for each specific sampling site to an agency. Thereafter, it is the responsibility of the agency to determine when each site will be surveyed. A list of alternate sites will also be generated and distributed in case sites are not accessible (e.g., outside safe diving limits). Surveying should occur sometime between May and September each sampling season. All sites should be surveyed during these summer months where minimum winds will not interfere with diving logistics and so that possible seasonal effects do not impact assessments of the status of the fish populations through time.

Level of Change That Can Be Detected for Sampling Being Instituted

The sampling design is targeted to allow statistically valid comparisons of population metrics through time and in space for selected economically and ecologically important reef fish species and their life stages (listed in Section 1.3). A second major goal is to be able to determine the efficacy of management zones in protecting and enhancing stocks of these species, therefore optimal sampling allocation distributes sites in protected and unprotected areas to allow for direct comparisons between them. Focal species include those targeted heavily by recreational and commercial fisheries. These species have seen significant declines in recent years and are currently considered overfished in South Florida (Ault et al. 2005a). The major population metric used for sampling optimization is mean stratum fish density (D_{st}), and the coefficient of variation (CV) of this metric for each species is used as a dominant performance measure (**SOP A**). Each year, the precision of sampling will change depending on the capacity of the agencies to perform the surveys, but typically a CV of <30% is achievable for the dominant species investigated.

Field Methods

Field Season Preparations and Equipment Setup

In preparation for each field season, agency groups will meet and determine the abilities and needs of each group for participation in field sampling. At this time, a schedule will be determined for all training activities (details in **SOP B**) that must take place prior to the start of sampling. All participants are personally responsible for ensuring their compliance with diving authorization requirements. Each agency will be responsible for verifying that their participants conform to the requirements and that they are equipped with all necessary sampling gear for that season. Equipment details can be found under the section "Equipment" in **SOP C**. Sample numbers, locations, and the agency/group responsible for each sample will be determined prior to the start of the field season (**SOP A**).

Sequence of Events during Field Season

At the start of the field season, each agency will be provided a list of sites which they will be responsible for sampling to the best of their abilities. Sampling schedules will likely vary by agency and due to considerations of weather and equipment. A list of alternate sites will also be provided that can be used in cases where sites are not accessible or if an agency has met their goal and is capable of additional sampling. As many sites as possible should be surveyed during a day: this goal should determine the assembly of sampling teams and location of sites that are in the same vicinity. Data that are collected are the responsibility of the participants and their respective agencies and should be entered and catalogued by the end of the field season following the methods detailed in **SOP D**. Preferably, data should be entered immediately upon return from the field (or within 1 day), as this tends to reduce error in data entry. However, all data must be entered at least by the end of the field season. Once all data are catalogued, each agency will follow proofing steps before submitting the data for final verification and entry into central database (**SOP D**).

Details of Making Observations

The RVC method used in these surveys is based on the stationary point count method of Bohnsack and Bannerot (1986), with some modifications and additions. The rationale and details of making observations in the field is covered in **SOP C**. In general, however, two sets of paired surveys take place per site, optimally separated by 20-60 m distance but within the same primary unit (200 x 200 m grid cell). Diver deployment can occur either by live boating or by anchoring. Live boating is preferred when 4-6 divers are aboard, while anchoring is best when the team consists of 3-4 members. Each buddy team will carry a reel with line attached to a surface buoy and surface GPS unit to record the location of the actual sample. For each site, three types of data are taken, including: 1) Field/Boat Log form data, which records where, when and by whom sites were sampled, 2) Water Quality/Environmental Log data, which are records of the water quality and environmental data associated with

each set of paired surveys, and 3) fish/habitat data, which are the RVC-specific data recorded by each diver.

Post-collection Data Sheet and Logs Processing

Once data collection is completed and all divers are aboard, initial QA/QC should include discussions between buddy teams to ensure agreement on main variables (e.g., habitat characteristics, visibility, current). Data sheets should be maintained securely while on board, and once on land, copies of data sheets should be made and then distributed to data collectors for data entry. Data should then be entered according to the protocols detailed in **SOP D**.

End-of-Season Procedures

At the end of the season, each agency should follow their respective methods for cataloging and backing up data. All data should be proofed following methods in **SOP D** and then submitted to UM-RSMAS for final verification and use in future sample allocation (as described in **SOP A**).

Data Handling, Analysis and Reporting

Data Entry, Verification and Editing

Data collected for each stationary point count should be entered via the RVC Data Entry Program following the methods outlined in **SOP D**. Data for the Field/Boat log and Water Quality/Environmental log should be kept on an agency-specific Excel spreadsheet. Initial data entry and proofing is the responsibility of the participants who collected the data in field. At the end of the field season, designated agency-specific data managers will be responsible for assuring that all data collected have been entered and proofed (as described in **SOP D**). Each diver must maintain a minimum level of accuracy as described and defined in **SOP D**. Data managers will then distribute their agency's data to the NOAA and UM-RSMAS data managers, who will be responsible for data verification, storage, and distribution following steps in **SOP D**.

Recommendations for Routine Data Summaries and Statistical Analyses

The range and types of statistical analyses that should be performed to assess the status and dynamics of reef fish populations and communities depends on the specific management questions and resource goals to be addressed. These questions and goals may change through time or vary by agency, but there are some fundamental metrics that should be generated after each sampling season which are outlined in **SOP E**. These analyses utilize a range of survey data types (abundance, size, taxonomic identification), and allow for the assessment of the status and trends of reef fish communities and populations over time and in relation to specific sustainability metrics. First, a basic descriptive ecological analysis, including species inventories and calculations of biodiversity indices, is recommended. For the eight focal species (*Haemulon plumier*, *H. sciurus*, *Lachnolaimus maximus*, *Lutjanus analis*,

L. griseus, *Ocyurus chrysurus*, *Epinephelus morio*, and *Mycteroperca bonaci*) calculations of the fish stock status indices outlined in SOP E are also recommended, and details describing how to assess change in the these metrics provided in SOP E.

Personnel Requirements and Training

Roles and Responsibilities

At the start of each field season, responsibilities for sampling will be delegated among the participating agencies. Each agency will provide participants, equipment, and facilities to the best of their ability depending on their budgeting constraints and responsibilities to other projects for that year. All agencies will designate a data manager, a chain of command, and points of contact for dealing with scheduling and logistical considerations, as well as for questions regarding procedures and policies. Points of contact should be clarified so that all participants, regardless of agency, are aware of who should be contacted in the event of a question or issue.

Qualifications

All participants must be trained in reef fish identification as well as in the ability to make the necessary observations (training requirements are covered in the subsequent section). All participants must also be certified to SCUBA dive in open water by a recognized and licensed organization (e.g., NAUI, PADI) and for work in the Dry Tortugas must also possess a certification to use enriched-oxygen (NITROX). Participants must be in compliance with their agency's dive safety regulations. Depending on the agency in charge of the diving operations, reciprocity may need to be exchanged. In the Dry Tortugas, it is the responsibility of the agency in charge to confirm prior to operations that participating divers are cleared to dive.

Training

Training is a critical component of the RVC monitoring program, and should incorporate both initial and annual refresher training components. Participants should be capable of accurately identifying and estimating sizes of reef fish that are encountered on the Florida Keys reef tract. Participants should also be familiar with the habitat assessment techniques and benthic categories that are included in the method and detailed in **SOP C**. Annual out-of-water training meetings and in-water training activities will be held each year before sampling commences as detailed in **SOP B**. Out-of-water meetings will be held either jointly or independently depending on the needs of each agency and will consist of overviews of sampling design, logistics, RVC methods, habitat characteristics, and data entry and proofing. In-water training will be organized and executed by each agency independently, although exchange of personnel among agencies is encouraged.

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Standard Operating Procedure A: Statistical Sampling Design

(Version 1.0)

Revision History Log

Previous Revision No.	Revision Date	Author	Change Made	Reason for change	New Version No.

A.1 Introduction

This SOP outlines a two-stage stratified random sampling allocation scheme that was been developed over the last decade and has been successfully applied in order to estimate important metrics for reef fish populations in the Florida Keys and Dry Tortugas (e.g., Ault et al. 1999, Ault et al. 2002, but see also Table 1.1). These methods are also useful for estimating population abundances in other regions (Ault et al. 2008) and for other types of marine populations (Smith et al. in prep a).

This sampling scheme includes stratifying the sample domain based on habitat, sub-region, management zone, and depth and then follows a Neyman (or optimal) allocation in which sample units are allocated according to both stratum size and the strata standard deviations of specific fish species densities. This scheme increases the efficiency of sampling by allocating greater sampling effort to those strata that are larger and more variable while smaller, less variable strata receive less effort.

A.2 Stratification

The Florida Keys survey domain includes all mapped area of live coral habitat less than 33m depth between Miami and Key West. Similarly, the Dry Tortugas survey domain contains all mapped coral habitats shallower than 33 m but which are located on three distinct bank or atoll-like formations, including Dry Tortugas National Park, Tortugas Bank and Little Bank, and Riley's Hump. To control for spatial variation in population abundance metrics, the survey domain is divided into strata based upon: (1) habitat characteristics and depth; (2) geographic sub-region; (3) management zone (see Figure 1.1 for management areas). The reef habitat classification scheme accounts for features that correlate with reef fish distributions, including topographic complexity (low-relief, mid-relief, high-relief), and the proportion of sand interspersed among hard-bottom structure (e.g., isolated reef, spur and groove, continuous reef). In the Florida Keys sampling, depth (shallow: 0-6 m, mid-depth: 6-18 m, deep: 18-33 m) is also used to distinguish strata. The geographic sub-regional stratification variable (upper, middle, and lower Keys, and Dry Tortugas) and cross-shelf position in the Florida Keys (e.g., Hawk's Channel inshore, Hawk's Channel mid-channel; as described by FMRI 1998, included as Appendix 4) are used to account for oceanographic and geological features that influence the distribution, community dynamics, and biotic composition of reefs (Marszalek et al. 1977; Shinn et al. 1977). Management zones (i.e., no-take marine

reserves) are incorporated as a third stratification variable and delineate areas open or closed to consumptive activities. Strata defined for the Florida Keys and Dry Tortugas are listed in Tables A.1 and A.2.

A geographic information system (GIS) containing digital layers for benthic habitat (FMRI 1998, included as Appendix 4), bathymetry (NGDC 1998), and no-take marine reserve boundaries (FKNMS, Marathon, Florida) is used to facilitate delineation of the sampling survey domain into strata. Map resolution is such that the survey domain (i.e., the entire Florida Keys reef tract and the three bank formations of the Dry Tortugas) is divided into a grid with individual cells of size 200 m by 200 m (40,000 m^2), each cell designated as belonging to a specific stratum (e.g., Figure A.1). These grid cells are designated as ***primary sample units***. Primary sample units are further subdivided into 15 m diameter visual census circular plots that can be sampled by divers which are the ***second-stage sample units***.

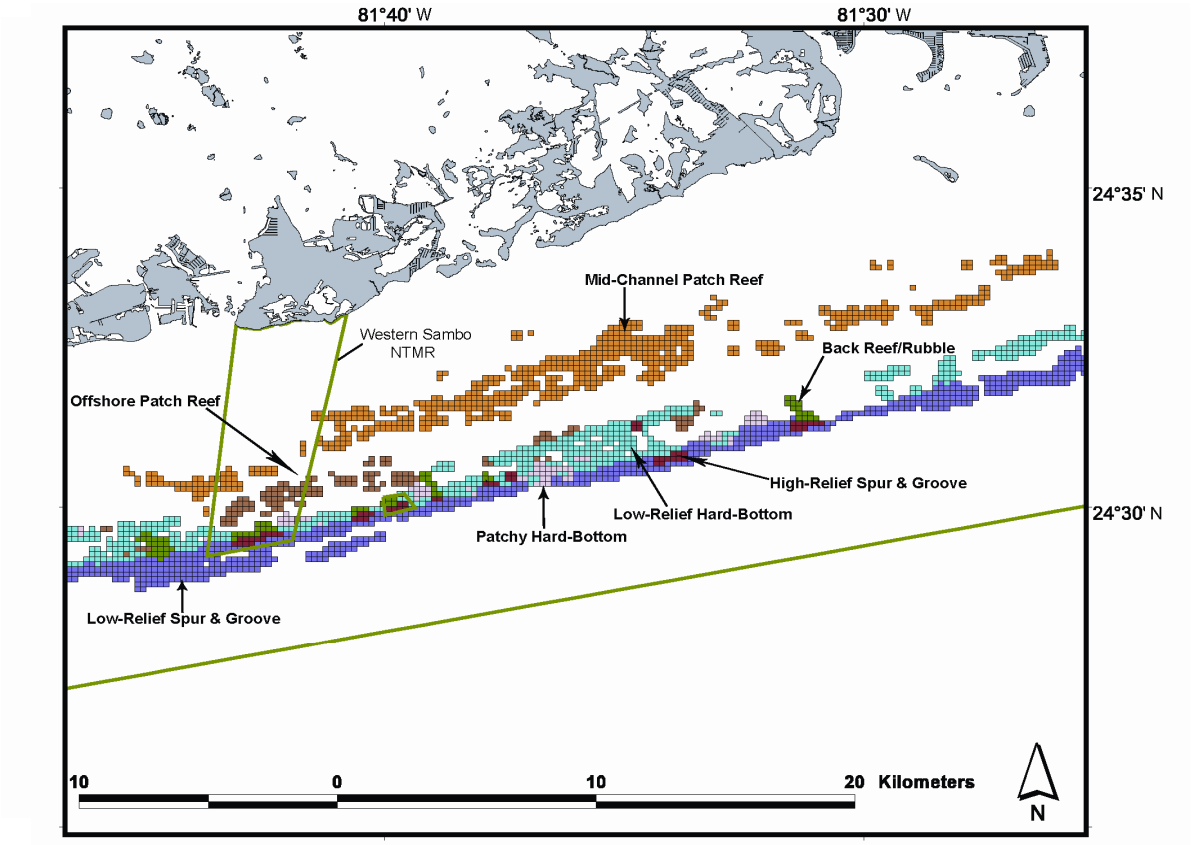


Figure A.1. Cross-shelf distribution of coral reef and hard-bottom habitat classes in the vicinity of Western Sambo NTMR overlain with the 200 m by 200 m primary unit sampling grid.

The conceptual layout of this two-stage stratified random sampling (StRS) design is shown (Figure A.2), and survey design symbols and definitions are provided in Appendix 1. The survey domain A is divided into h strata. Each stratum is further subdivided into primary sample units i, and each primary unit is again subdivided

into second-stage sample units *j*. Note that each primary and second-stage sample unit contains a fixed amount of area; thus, the sum of second-stage sample units within primary units of all strata approximately equals the total area of the survey domain. The number of possible primary sample units (N_h) calculated for each stratum for the Florida Keys and Dry Tortugas survey domains are given in Tables A.1 and A.2.

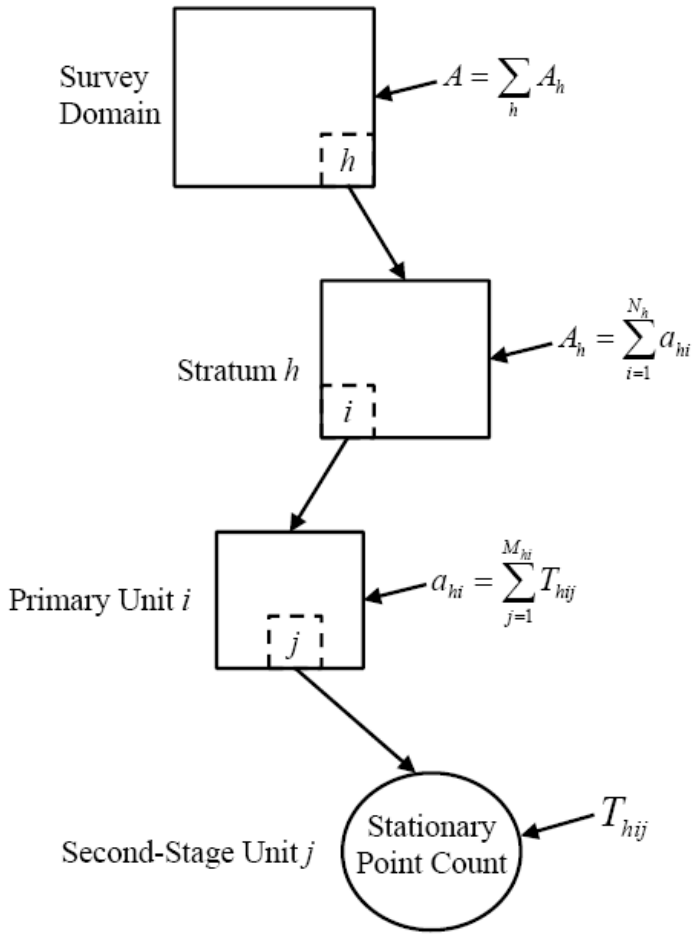


Figure A.2. Conceptual diagram of the sampling domain and sample units for a two-stage stratified random survey design. Symbols are defined in Appendix 1.

Table A.1. Total possible primary units (N_h) in statistical strata defined by sub-region (e.g., Lower Keys, Middle Keys), cross-shelf zone, habitat class and depth, and management zone ("prot" = protected, "unprot" = unprotected) in the sampling surveys of the Florida Keys.

			Lower Keys		Middle Keys		Upper Keys		Biscayne
Stratum	**Cross-Shelf Zone**	**Habitat Class (depth)**	**prot**	**unprot**	**prot**	**unprot**	**prot**	**unprot**	**unprot**
1	Hawk's Channel, Inshore	Mid-relief isolated reef (0-6 m)	30	114	0	31	0	76	166
2	Hawk's Channel, Mid Channel	Mid-relief isolated reef (0-6 m)	38	840	0	165	21	706	1366
3	Hawk's Channel, Offshore	Mid-relief isolated reef (0-6 m)	74	458	0	94	11	1025	144
4	Hawk's Channel, Offshore	High-relief spur and groove (0-6 m)	0	0	0	0	20	78	0
5	Forereef	Low-relief continuous reef (0-6 m)	0	71	27	176	46	775	276
6	Forereef	Low-relief continuous reef (6-18 m)	26	576	0	311	56	662	219
7	Forereef	High-relief spur and groove (0-6 m)	57	49	7	3	89	34	33
8	Forereef	Low-relief spur and groove (6-18 m)	32	684	25	807	95	709	317
9	Forereef	High-relief spur and groove (18-33 m)	53	535	0	74	27	468	315
10	Forereef	Low-relief isolated reef (0-6 m)	7	26	7	128	10	217	220
11	Forereef	Low-relief rubble (0-6 m)	36	67	0	62	26	95	80

Table A.2. Total possible primary units (N_h) in statistical strata defined by sub-region (Tortugas Bank and Dry Tortugas National Park), habitat class, and management zone ("prot" = protected, "unprot" = unprotected) in the sampling surveys of the Dry Tortugas.

		Tortugas Bank		Dry Tortugas National Park	
Stratum	**Habitat Class**	**prot**	**unprot**	**prot**	**unprot**
1	Low-relief continuous reef	1269	1111	1087	1301
2	Mid-relief continuous reef	23	12	56	164
3	High-relief continuous reef	255	26	31	15
4	Low-relief isolated reef	18	28	419	418
5	Mid-relief isolated reef	275	126	360	401
6	High-relief isolated reef	20	0	20	3
7	Low-relief spur and groove	0	0	17	261
8	High-relief spur and groove	0	0	22	86

A.3 Sample Allocation

The two-stage stratified random design increases the efficiency of sampling by effectively stratifying the entire domain based on variables (e.g., habitat characteristics, depth, and management) that influence the variability of fish population densities. With this stratification scheme in place, the sample size necessary to achieve a specified level of precision can be calculated based on existing data. This type of allocation scheme is termed a Neyman (or optimum) allocation scheme (Cochran 1977) and it is used to determine the number of ***primary units*** to be sampled within each stratum.

First the total number of primary units that would be required to achieve a specified variance under an optimal allocation scheme, n^*, is calculated for each species. Derived from Cochran (1977), this optimal allocation of primary units for a given target variance, V, of fish density, $\overline{\overline{D}}_{st}$ (individuals m^{-2}), is calculated as:

$$n^* = \frac{\sum_h w_h s_{uh}\left(\sum_h w_h s_{uh} + \sum_h \frac{w_h^2 s_{2h}^2}{m^*_h \; w_h s_{uh}}\right)}{V\left[\overline{\overline{D}}_{st}\right] + \sum_h \frac{w_h^2 s_{1h}^2}{N_h}} \qquad \text{(Eq. A-1)}$$

In Equation A-1:
s_{1h}^2 is the sample variance among ***primary units*** i in stratum h and s_{2h}^2 is the sample variance among ***second-stage units*** j in stratum h:

$$s_{1h}^2 = \frac{\sum_i (\overline{D}_{hi} - \overline{\overline{D}}_h)^2}{n_h - 1} \qquad \text{(Eq. A-2)}$$

$$s_{2h}^2 = \frac{1}{n_h}\sum_i \left[\frac{\sum_i (D_{hij} - \overline{D}_{hi})^2}{m_{hi} - 1}\right] \qquad \text{(Eq. A-3)}$$

where $\overline{D}_{hi}$ is the mean density in primary unit i in stratum h, $\overline{\overline{D}}_h$ is mean density in stratum h, D_{hij} is density in second-stage unit j in primary unit i in stratum h, and n_h is the number of primary units sampled in stratum h.

Also in Equation A-1, s_{uh} is the sample standard deviation in stratum h:

$$s_{uh} = \sqrt{s_{1h}^2 - \frac{s_{2h}^2}{M_h}} \qquad \text{(Eq. A-4)}$$

and w_h is the weighting factor for each stratum, calculated as its proportion of the overall survey domain (or sampling frame) where N_h is the total possible number of primary units in stratum h based on its total area, and M_h is the total possible number of second-stage units in a primary unit:

$$w_h = \frac{N_h M_h}{\sum_h N_h M_h} \qquad \text{(Eq. A-5)}$$

Finally, in Equation A-1, m^*_h is the optimal number of ***second-stage units*** within a primary unit calculated as:

$$m^*_h = \frac{\sqrt{s_{2h}^2}}{s_{uh}} \qquad \text{(Eq. A-6)}$$

The value of m^*_h has consistently been estimated as 2 by these monitoring efforts (Ault et al. 2002), and therefore this value is used in all calculations of n^*.

The target variance for a given species ($V[\overline{\overline{D}}_{st}]$ in Eq. A-1) is calculated based on a target coefficient of variation (CV), which is an easily expressed standard measure of performance (Cochran 1977). The CV of a sample is actually the standard error expressed as a proportion (or percentage) of the mean:

$$CV[\overline{y}_{st}] = \frac{SE[\overline{y}_{st}]}{\overline{y}_{st}} \qquad \text{(Eq. A-7)}$$

Since the 95% confidence interval for a population metric is approximately two standard errors above and below the mean, the ability to statistically detect a difference translates to approximately ±2 times the CV. Therefore, if mean fish density in a sub-region has a CV of 50%, then a 100% change in the population, or a doubling of the population, can be detected.

In calculations of the target variance for fish density under this design, $\overline{\overline{D}}_{st}$ is used as $\overline{y}_{st}$ in Eq. A-7, which is mean fish density under a stratified design. Using a target CV, the target variance in Eq. A-1 is:

$$V = \left(CV\left[\overline{\overline{D}}_{st}\right] \cdot \overline{\overline{D}}_{st} \right)^2 \qquad \text{(Eq. A-8)}$$

The optimal number of primary units to sample in *each stratum* is then calculated as:

$$n^*_h = n^* \cdot \left(\frac{w_h s_{uh}}{\sum_h w_h s_{uh}} \right) \qquad \text{(Eq. A-9)}$$

These calculations are made for multiple levels of desired variance for each species. They are then compared among species and also with the total capacity of the cooperative sampling group. A final target n^* is chosen that will accomplish the best possible balance between achievable precision for the most number of exploited species and the capabilities of the agencies.

All variable names and equations are also listed in Appendix 1.

A.4 Sample Unit (Location) Selection

Once the total number of primary units is determined, the actual selection of sites is carried out in two stages. First, the primary units i to be sampled per stratum are randomly selected from the complete list of N_h units within a stratum using a discrete uniform probability distribution, which assigns equal selection probability to each primary unit (Law 2007). Second, when in the field, two second-stage units j are haphazardly chosen from the total possible M_h units within a primary unit based on the distribution of target habitat within the primary unit and diving safety considerations.

In concern for dive safety and because of possible spatial autocorrelation, each diver station (i.e., second-stage unit) consists of the ***average of combined stationary point count (RVC) estimates from the buddy pair*** for each metric recorded. Therefore, each diver station (i.e., second-stage unit) is sampled by two individual divers (i.e., a buddy pair), for a total of 4 scientific dives within each primary unit (2 scientific dives per second-stage unit, two second-stage units sampled) under normal operations. The size of an individual primary sampling unit allows divers to swim to the location of any given second-stage sampling unit from a moored vessel.

In theory, the selection of second-stage units within each primary unit should be random and not haphazard, but this is not practical in a field sampling situation. The authors have examined the distribution of secondary units within primary units using past field data and the distribution of second-stage units was biased towards the center point (Figure A.3). Therefore, the probability that a second-stage unit would be selected within a primary unit was not uniform across all second-stage units, and there was an increased probability of sampling secondary units near the center of the primary unit. This is likely due to a combination of the resolution of the grid and the distribution of habitat within primary units, and there is a possibility that spatial autocorrelation could affect the results. However, it is unlikely that this affects the overall results of sampling, but efforts are underway to evaluate its impact.

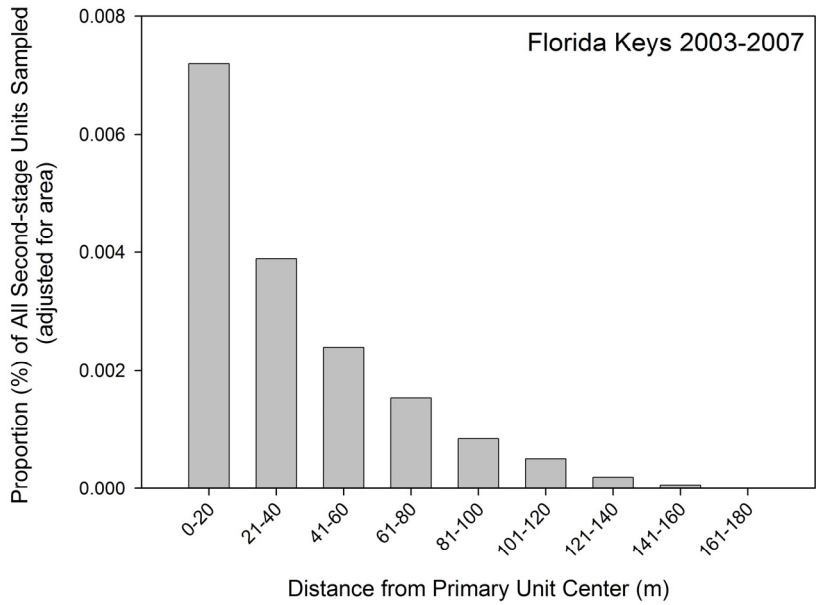


Figure A.3. Percent of all second-stage units (adjusted for area) sampled in the Florida Keys (2003-2007) which fell within different distances (m) from the primary unit center.

A.5 Example

Reef fish populations are highly variable among species and within species among life history stages. Therefore, calculations should be made independently by species and life stage, and by taking into account the historical sampling design used to collect the data as well as the established and possible future goals of each targeted area in question. The n^* calculated in this example is a baseline, but **by no means should it be treated as a constant to be used for all future surveys**. Optimal sampling allocation should be recalculated iteratively, and take into account acquired knowledge of the system, future data, and/or improved stratification methods.

The suggested analyses focus on eight species of reef fish commonly targeted by commercial and recreational fisheries on Florida Keys reefs: white grunt (*Haemulon plumieri*), bluestriped grunt (*H. sciurus*), hogfish (*Lachnolaimus maximus*), mutton snapper (*Lutjanus analis*), gray snapper (*Lutjanus griseus*), yellowtail snapper (*Ocyurus chrysurus*), red grouper (*Epinephelus morio*), and black grouper (*Mycteroperca bonaci*). Because these species are known to exhibit habitat-specificity based on life stage which may influence their abundances across spatial gradients, each analysis is done separately by life stage (juveniles and adults). The current sampling allocation strategy is targeted towards these species because of their economic importance. However, these species are found in relatively low abundance throughout the Keys region and are considered overfished (Ault et al. 2005a). Therefore, if a sampling strategy is doing an adequate job of sampling for these low-abundance species, it is also likely doing an adequate job of sampling for other, more abundant, species such as the major herbivorous fish groups (e.g., parrotfishes, surgeonfishes) that may be important ecologically but not necessarily economically.

To show this, the example has also calculated optimal sample numbers for an additional selection of non-targeted species.

Below are the results of a performance analysis of reef fish sample data taken in Biscayne National Park (BISC), which is then used to calculate n^*. The analysis focused on calculating n^* for BISC with the **goal of detecting differences in fish density for targeted species/life stages among years within BISC**. To do this, sample data from Keys-wide annual sampling between 2005 and 2007 were analyzed using equations A-1 and A-9 with region as the stratum in calculations. Results are presented as tables with n^* values for specified CV values, and CV versus n^* graphs with actual sample sizes and CVs calculated from sampling in specific years. These calculations were compared with the number of primary units actually sampled in previous surveys (Table A.3). Also, a comparison was made of the CV achieved with current sampling and that which could be achieved with additional sampling. In 2008, 68 primary units were sampled in BISC and approximately 6 samples were made per day. If an additional 10-11 days of sampling were assumed, this would approximately double the number of primary units sampled. Therefore the comparison of current CV achieved with potential CV attainable is based on a doubling of sampling effort to $n = 136$.

Table A.3. Primary units (n) sampled by sub-region and year.

Sub-region	2003	2004	2005	2006	2007	2008
Biscayne National Park	70	40	41	55	59	68
Upper Keys	96	70	88	110	84	103
Middle Keys	23	ND	49	62	72	86
Lower Keys	54	22	78	106	113	130
Total	243	132	256	335	328	387

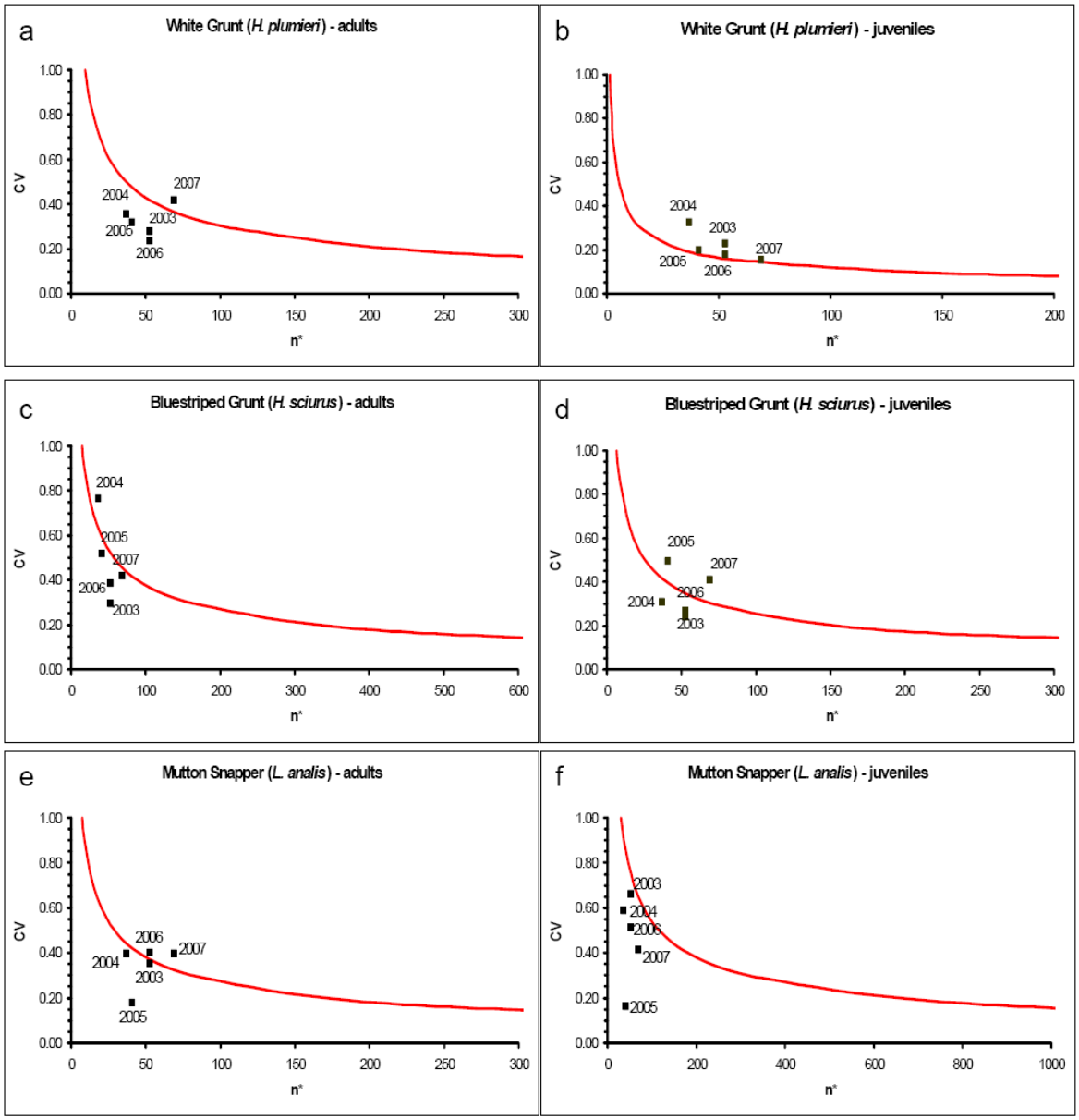
CV versus n^* graphs were created for an additional ten non-targeted fish species that tended to be numerically more abundant. These species are important ecologically but not necessarily economically like the eight focal species. They included: ocean surgeonfish (*Acanthurus bahianus*), blue tang (*A. coeruleus*), foureye butterflyfish (*Chaetodon capistratus*), bluehead wrasse (*Thalassia bifasciatum*), spotted goatfish (*Pseudopeneus maculatus*), queen angelfish (*Holocanthus ciliaris*), gray angelfish (*Pomacanthus arcuatus*), bicolor damselfish (*Stegastes partitus*), striped parrotfish (*Scarus iseri*), and redband parrotfish (*Sparisoma aurofrenatum*).

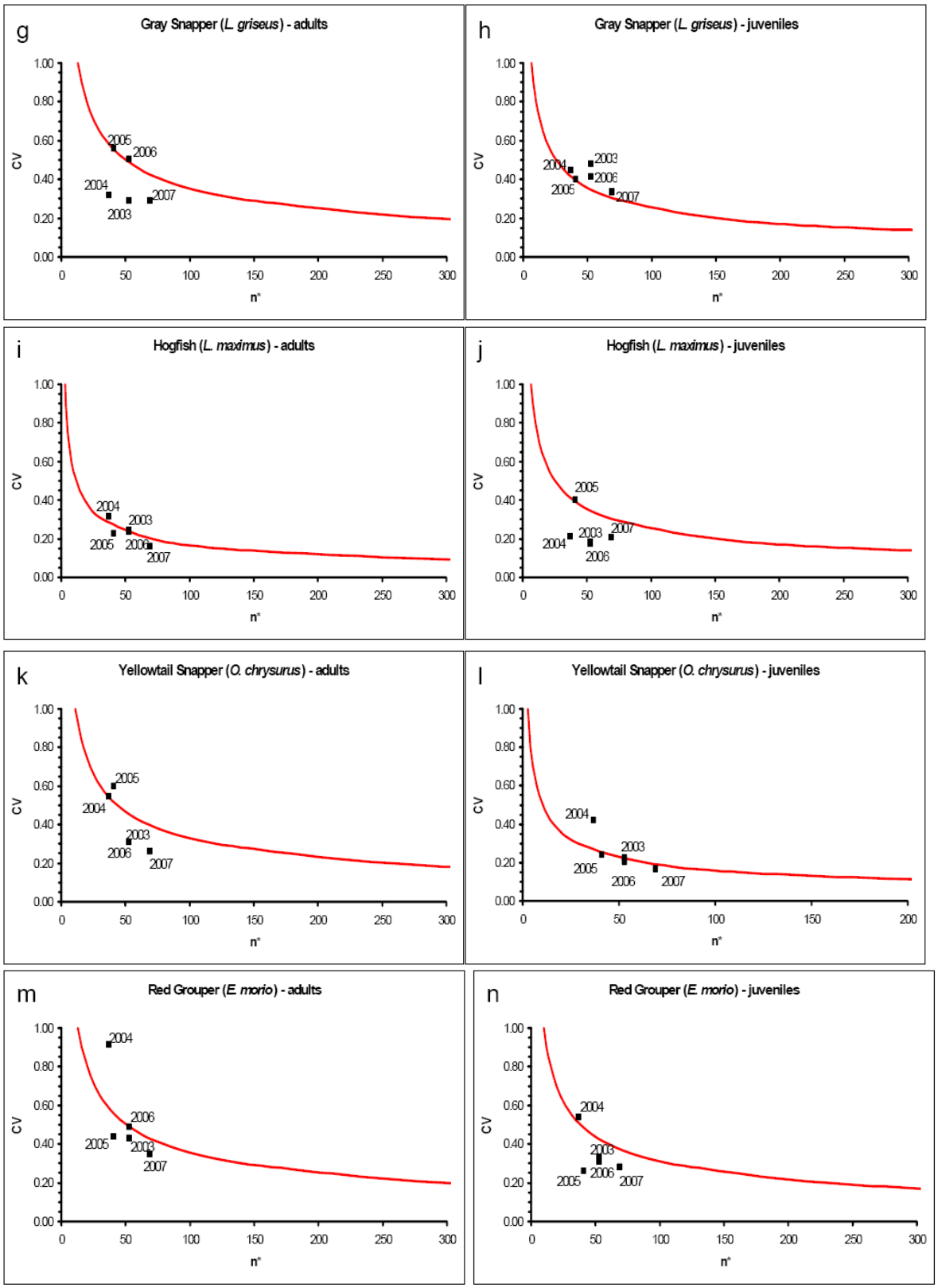
Example results: Examination of the CV vs. n^* graphs for each species/life stage (Figure A.4) shows that for white grunt, gray snapper, hogfish, yellowtail snapper, and red grouper additional sampling will lead to negligible gains in precision (Figure A.4: a, b, g – n). Additional sampling would, however, increase precision for bluestriped grunt and mutton snapper adults (Figure A.4: c, d, e). Mutton snapper juveniles and black grouper were so sparse during sampling that a large amount of additional sampling would be required to accomplish any major gains in precision

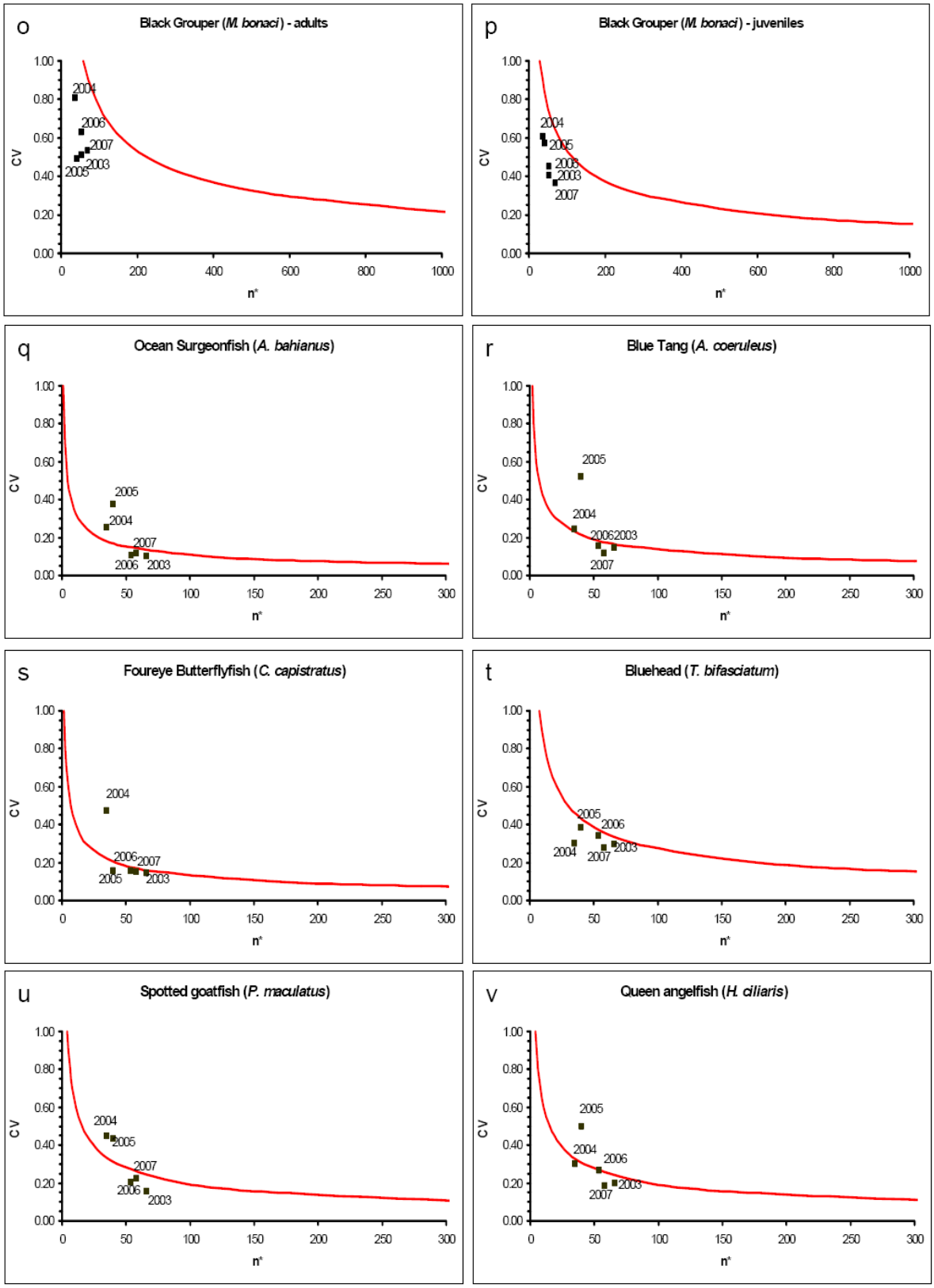
(Figure A.4: f, o, p). In comparison, for non-targeted species, sampling either occurred where the curve leveled out or along the straight part of the curve for all species, indicating that these species were well sampled.

Sampling in 2008 in BISC by the combined efforts of NOAA Fisheries, FWRI, and UM-RSMAS exceeded the calculated future optimal number necessary to detect differences in mean density of juveniles and adults of all eight targeted species at a CV level of 100%. In other words, current sampling exceeds that necessary to detect 3-fold difference between years in BISC in a future survey (Table A.4). With the exception of black groupers and juvenile mutton snappers, current sampling is also greater than the future optimal number necessary to attain a CV of at least 50% (ability to detect a 100% difference) for all species/stage (Table A.4). By doubling the sampling effort of 2008 (adding approximately 10 extra sampling days), a predicted CV of 30% can be achieved for most species and 20 or 10% in some cases (Table A.4). Although current sampling is fairly precise, a doubling of effort would result in a large improvement in the precision of estimates of density for most species.

Figure A.4. Performance data for annual estimates of fish density for eight focal species (a – p) and ten additional non-targeted species (q – z) in Biscayne National Park during 2005 – 2007. Annual estimates (black squares) are compared to the relationship of CV versus *n* for a stratified by benthic-habitat based survey design (red line).




g
Gray Snapper (L. griseus) - adults
h
Gray Snapper (L. griseus) - juveniles
i
Hogfish (L. maximus) - adults
j
Hogfish (L. maximus) - juveniles
k
Yellowtail Snapper (O. chrysurus) - adults
l
Yellowtail Snapper (O. chrysurus) - juveniles
m
Red Grouper (E. morio) - adults
n
Red Grouper (E. morio) - juveniles
CV
n*


o
Black Grouper (M. bonaci) - adults
p
Black Grouper (M. bonaci) - juveniles
q
Ocean Surgeonfish (A. bahianus)
r
Blue Tang (A. coeruleus)
s
Foureye Butterflyfish (C. capistratus)
t
Bluehead (T. bifasciatum)
u
Spotted goatfish (P. maculatus)
v
Queen angelfish (H. ciliaris)
cv
n*

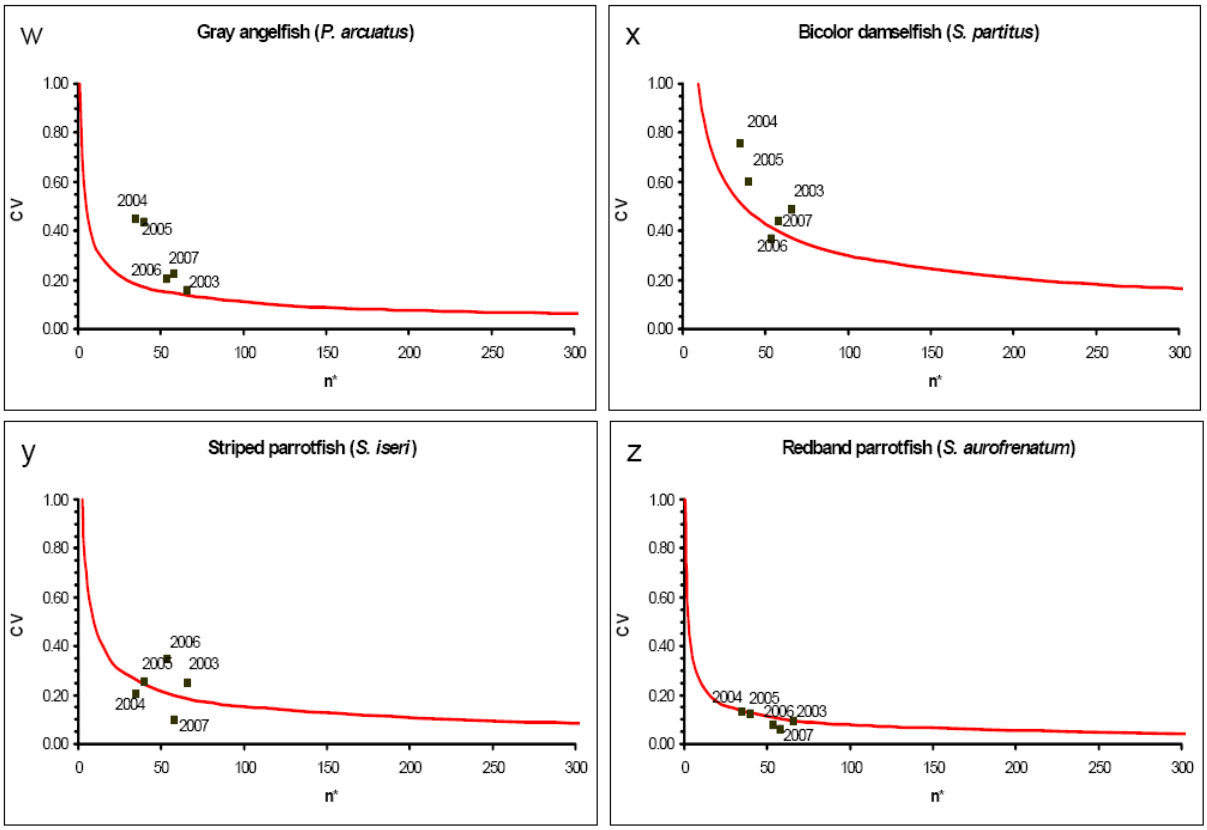

w
Gray angelfish (P. arcuatus)
x
Bicolor damselfish (S. partitus)
y
Striped parrotfish (S. iseri)
z
Redband parrotfish (S. aurofrenatum)
CV
n*
2003
2004
2005
2006
2007

Table A.4. Optimal primary unit sample number (n^*) for comparisons of fish densities between years in Biscayne National Park. D_{st} and CV[D_{st}] are mean fish density and the CV of mean fish density, respectively, in BISC in 2007 (n = 59). Data from 2005-2007 (n = 155) was used to make n^* calculations. Dark gray boxes indicate where sample allocation in BISC in 2008 (n = 68) was >= the calculated n^* for that level of CV. Yellow boxes indicate where doubling the 2008 allocation (to n = 136) would cause sampling to exceed or equal the calculated n^* for that level of CV.

Species	Life stage	$\overline{\overline{D}}_{st}$	$CV\left[\overline{\overline{D}}_{st}\right]$	n^*, CV=10%	n^*, CV=20%	n^*, CV=30%	n^*, CV=40%	n^*, CV=50%	n^*, CV=70%	n^*, CV=100%
white grunt	Adult	2.24	42%	757	221	101	58	37	19	9
(H. plumieri)	Juvenile	6.41	15%	132	34	15	9	5	3	1
bluestriped grunt	Adult	0.29	42%	1091	335	156	89	57	29	14
(*H. sciurus*)	Juvenile	2.66	41%	548	155	71	40	26	13	6
hogfish	Adult	0.42	16%	272	72	32	18	12	6	3
(*L. maximus*)	Juvenile	0.73	20%	556	153	69	39	25	13	6
mutton snapper	Adult	0.06	39%	584	173	80	45	29	15	7
(*L. analis*)	Juvenile	0.24	41%	2051	667	314	180	116	60	30
gray snapper	Adult	0.51	29%	968	295	136	78	50	26	13
(*L. griseus*)	Juvenile	1.02	33%	528	153	70	40	26	13	6
yellowtail snapper	Adult	0.68	26%	899	262	120	68	44	22	11
(*O. chrysurus*)	Juvenile	1.30	16%	245	64	29	16	10	5	3
red grouper	Adult	0.05	35%	1016	302	139	79	51	26	13
(*E. morio*)	Juvenile	0.06	28%	834	233	106	60	39	20	10
black grouper	Adult	0.01	53%	2684	1134	578	343	225	117	58
(*M. bonaci*)	Juvenile	0.02	37%	1916	644	306	176	114	59	29

Standard Operating Procedure B: Participant Training

(Version 1.0)

Revision History Log

Previous Revision No.	Revision Date	Author	Change Made	Reason for change	New Version No.

B.1 Initial Participant Training

The following are guidelines for the training of new fish counters prior to participation. Failure to follow these guidelines may result in inaccurate and unusable data.

Species identifications - All participants should be competent in the identification of reef fish to the species level before conducting in-water training. Participants should utilize resources including, but not limited to, the most recent edition of Humann and Deloach (2002), the Reef Fish ID: Florida, Caribbean, Bahamas – Interactive Edition CD/DVD field guide[1], and the Reef Environmental Education Foundation on-line fish identification quizzes[2]. It is the responsibility of the program leaders for NOAA, FWRI, UM-RSMAS, and NPS to ensure that all participants from each respective agency or institution possess the necessary identification skills.

Habitat characterization - All participants should be familiar with the habitat classification scheme used in the stratified survey design. They should be capable of distinguishing habitat types and classifying the different abiotic characteristics of the habitat that are measured. Participants should understand the metrics and terms used to assess major benthic groups and show familiarity with their identification. Guides for identification of major benthic groups and commonly misidentified organisms can be found in Appendix 2. It is suggested that these guides be printed and laminated and brought into the field as a reference.

In-water Training - In-water training is intended to assess the accuracy of a diver's estimates of fish size and distance from diver, as well as measure the ability of the diver to collect habitat data. Training should occur according to the following steps:

a. Models of fish that are typically observed during RVC surveys (optimally, both fishery-targeted and non-targeted species) are prepared for deployment in the field.

[1] Available from ReefNet Inc.: http://reefnet.ca/products/fishes/caribbean/

[2] http://www.reef.org/resources/quizzes

b. A suitable test area is located (reef habitat, relatively shallow depth). Visibility must exceed 10 meters and the current should be minimal.
c. A measuring tape transect (30m or longer) is extended in a straight line within the test area. Fish models (~20-30) are placed at varying distances (within the limits of visibility and at 0.5-m intervals) from the transect tape at predetermined and marked distances along the tape.
d. For each fish model, a test administrator measures and records the (1) fish species, (2) model size (fork length to nearest cm) and (3) distance from the mark on the transect tape to the fish model (to nearest 0.5-m) for each model and (4) habitat data.
e. Examinees enter the water with SCUBA gear, a reference measuring tool and clipboard. The reference measuring tool will be a marked t-stick/APT (see SOP C, Section C.1 for description of the APT). For each fish model, examinees estimate and record the (1) fork length (to nearest cm) and (2) distance from the center point (to nearest 0.5-m) and (3) complete the habitat data section of the fish/habitat data sheet.
f. The estimated total length and distance from the transect tape for each model and habitat data are entered by each examinee into electronic format and compared with actual values to assess examinee-specific errors or consistent biases. This assessment may range from (1) an instructor or instructors assessing each examinee's results, with subsequent reporting of results to, and discussion with, each examinee to (2) self-assessment by examinees, with subsequent group discussion of each examinee's results.
g. In all cases, additional training should be provided for examinees that exhibit consistent and considerable (> 20%) error, on average, in size or distance estimation, until error rates are less than 20%. Additional training should also be provided until the examinee has attained 100% accuracy in fish identifications. Habitat data should be examined by an instructor or instructors and determined if examinee needs more training.

A new diver's first RVC dives should occur with an experienced fish counter. The experienced fish counter should provide guidance, answer questions, and help the new diver with any fish identification skills. The new diver should also be calibrating their size estimates by comparing their size estimates to non-mobile reef components that can be measured exactly. Data taken during these first few dives and until the diver demonstrates competency with all necessary data taking skills should be marked as "Training – Observer" dives by selecting this from the "Sample Type" drop down list on the Sample Data screen upon entry into the RVC data entry program (SOP D.2.ii.a) .

B.2 Annual Refresher Training for Previous Participants

Each year, prior to the start of annual surveys, all fish counters, including those who have previously participated in surveys, should attend out-of-water training meetings that can be held either jointly or independently depending on the needs and abilities of the agencies. These out-of-water training meetings should cover the sampling

design, survey logistics, RVC methods, habitat characteristics, and data entry and proofing methods so that participants are familiar with all steps of the monitoring program. Presentations given at these training meetings will be posted online so that they are accessible to all participants throughout the field season.

In-water training should be organized by each agency independently and focus on method execution, proper equipment handling, species identification and size estimation, and proper habitat characterization. Participants are also encouraged to independently use computer programs and books to practice species identification.

B.3 Data Entry and Proofing Training

Prior to surveying, all participants should be proficient in the use of the RVC data entry program (SOP D, Section D.2.i). Designated data managers from each agency should also be familiar with the steps involved in collating the data and producing proofing reports for individual divers to check their data (SOP D, Section D.5.iii) and for submitting final data files for data verification (SOP D, Section D.5.iv). This may require individual training when a new data manager is appointed and an experienced data manager from one of the agencies should be appointed to train the new data manager in the steps involved.

Standard Operating Procedure C: Field Data Collection

(Version 1.0)

Revision History Log

Previous Revision No.	Revision Date	Author	Change Made	Reason for change	New Version No.

C.1 Equipment

Diver equipment – Each diver will be equipped with a data sheet and underwater slate, pencil(s), dive watch, and reference measuring tool (a marked PVC "t-stick" consisting of a 1m shaft marked at 10cm intervals and 30cm cross-piece marked at 1cm intervals – Figure `C.1). The reference tool/t-stick is hereafter referred to as an All-Purpose Tool or APT. In addition to the APT divers may use tools such as a ruler affixed to a clipboard or slate, measuring tape, or gradations marked directly on a clipboard or slate. Preferably, divers will also be equipped with a digital camera for habitat documentation and to record images for subsequent verification or identification of fish or invertebrates, as necessary.

Each dive team will be equipped with a reel and line. Attached to the line is a surface buoy/dive flag and GPS unit used to record the sampling location of the buddy pair. The time displayed on each diver's watch should be set to within ±15 seconds of the local time as indicated on the GPS unit. One member of each dive team may also be equipped with a Secchi disc. The Secchi disc may be attached to the weighted reel connected to the surface dive flag.

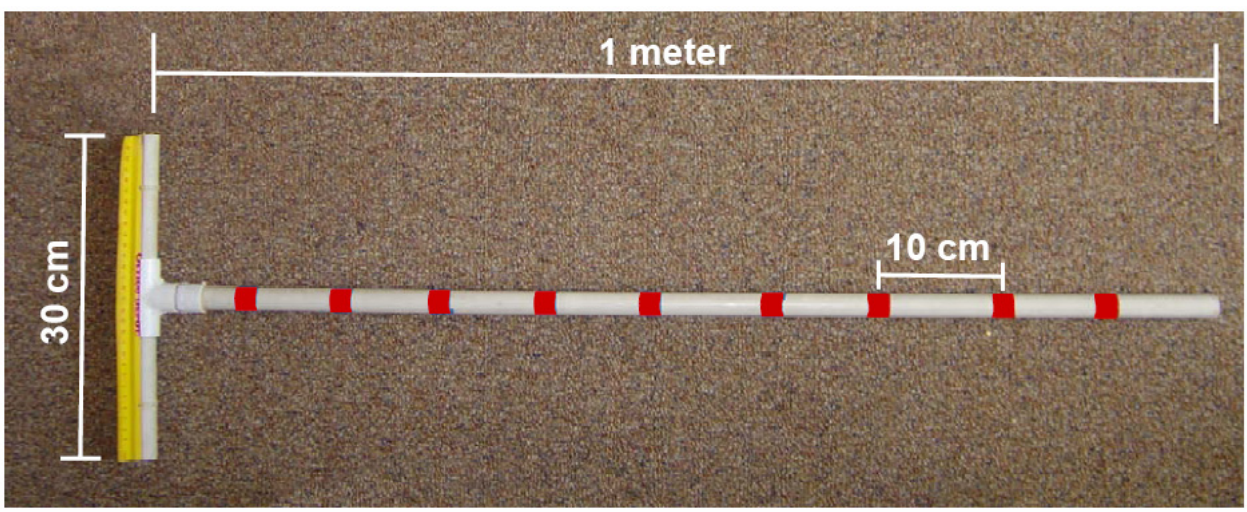


Figure C.1. The RVC All Purpose Tool (APT) used as a reference device for measuring habitat vertical relief, estimating fish lengths and the location of the center and outer edge of the sample cylinder.

C.2 Sequence of Events in the Field

Sampling teams should sample groups of sites within the same vicinity on the same sampling day to maximize sampling efficiency. Teams should also strive to sample sites across multiple habitat types each day to avoid temporal biases in fish-habitat characterizations that could arise by sampling multiple sites within 1-2 habitat types on a given day.

C.2.i Locating and Assessing the Sample Site (Primary Unit)

Sample sites are located using a vessel-mounted or hand-held GPS unit. Upon arrival at the sample site, divers should attempt to determine (e.g., via interpretation of depth finder display, battiscope, or snorkeling) whether the benthic habitat at the survey location is reef habitat. If the pre-assigned habitat type cannot be located, the sampling should proceed at the initial site coordinates, with divers recording the new habitat type on the Field/Boat Log. However, there are 3 cases when the divers should move around to actively locate the type of reef habitat indicated on the sample site list, (1) Contiguous reef structure: high relief spur and groove, (2) Isolated reef structure: Pinnacle, and (3) marine protected areas (MPAs). Once reef habitat is located, then the sampling should proceed, with divers noting whether or not they moved on the Field/Boat Log.

If the benthic habitat is not reef habitat, the divers can do a short count and should note this on the Field/Boat Log. They should then prepare to dive the next site for that habitat on a list of alternate sites provided at the start of the field season. The alternate site does not need to be surveyed in the same day as the original site.

C.2.ii Diver Deployment, Descent, and Location of Survey Sites

At each sample site, two sets (replicates) of two paired surveys occur (each set is a replicate within the primary unit). Optimally, the two sets of surveys should be spatially separated by approximately 20 to 60m. Efforts should be made to deploy both sets of survey divers within the same primary unit. Spatially, a primary unit is equivalent to a square shaped area 200 meters on each side. The latitude-longitude site positions provided in the annual RVC survey plan mark the centers of the targeted primary units. The GPS unit used for vessel navigation should have waypoints stored for each RVC site listed in the annual plan. Vessel distance from a given stored waypoint can be used to determine that the sampling occurs within the targeted primary unit. The sampling would occur in the targeted primary unit if the distance from the waypoint is less than 100 meters (0.054 nautical mile) in a north, south, east, or west direction; or less than 141 meters (0.076 nautical mile) in a northeast, northwest, southeast or southwest direction.

One of the following two approaches is utilized for diver deployment, descent, and location of diver-specific survey sites:

C.2.ii.a Approach 1 – Live Boating:
The field worker piloting the vessel will deploy two teams of two divers, with the teams separated by no less than ~30m and no more than ~75m. If necessary, during descent, divers will swim to appropriate habitat (e.g., if divers enter the water over sand, they will swim to nearby reef habitat for sampling). On reef habitat, each diver haphazardly chooses a sampling location such that each diver is within the distance of accepted "dive buddy" separation standards of his/her buddy. As described in Section C.1, each dive team will be equipped with a reel with line attached to a surface buoy and GPS unit. The reel can be secured to the bottom and serve as a starting point to measure the radius of the sampling cylinder using the APT (i.e., 7.5m or 5.0m depending on visibility), as a visual aid to measure visibility, as a point of reference (e.g., edge of cylinder) during data collection and as a point of return for both divers following data collection.

Preferably, the live boating approach is utilized with 4-6 divers aboard the research vessel. When six divers are present; three teams of divers are formed for the days' sampling, and two of the three teams are deployed at each sample site in a rotating format such that each team remains at the surface to pilot the research vessel every third sampling site. When five divers are present, divers rotate teams at each sample site in a format such that each diver remains at the surface at every fifth sample site.

C.2.ii.b Approach 2 – Anchoring:
The anchoring approach is typically utilized by a 3- or 4-member team. A dive team consists of two divers with the other team members remaining in the boat. Team members will deploy an anchor over nearby non-reef habitat so that current or wind guides the research vessel over or near the area to be sampled. As described in Section C.1, each dive team will be equipped with a reel with line attached to a surface buoy and GPS unit. Both divers descend to the bottom either following the anchor line or proceeding directly to the reef if it can be seen from the surface.

On the bottom, the two divers determine the direction of the target habitat type. After a decision is made, the two divers swim to that habitat, secure the reel to the bottom, drop the weighted end of the tape next to the reel and begin to lay out the tape. If a distinct vertical reef edge is present, point counts should be conducted along the edge. If no distinct vertical edge is present, the divers should conduct the point count as completely within the predominant coral habitat in the area (i.e., low relief spur and groove, intermittent coral heads, hard bottom with soft coral, patchy encrusting coral, etc.) as possible. The first diver will lay out the tape across the habitat to be surveyed stopping at the 20m mark. The first diver then conducts a point count at the 20m mark while the second diver conducts a point count at the 35m mark. At the completion of the first set of point counts, the divers reel in the tape then lay it out on suitable habitat in the opposite direction and conduct a second set of point counts at the 20m and 35m marks (Figure C.2). If the habitat is patchy and by stopping at a predetermined mark the point count will not include the characteristic habitat, then

the center points can be adjusted accordingly. This approach will allow a minimum 25 meters distance between samples.

> NOTE: Special consideration should be given to bottom times when sampling in deep waters (> 70') using two divers to conduct all 4 point counts. Dives occurring at depths of 70' or greater may take over 20 min to conduct and run the risk of putting divers breathing air into possible decompression status. We recommend having a minimum boat crew of four divers for sampling sites with depths of 70' or greater. This will allow two separate dive teams to conduct the two sets of point counts and reduce the amount of time spent at depth. If a deep site is encountered and only three divers are onboard the boat, then only one set of point counts should be conducted at the site and a second visit to this site should be planned to complete the second count. Prior to each sampling season, representatives of FWRI and NOAA will determine which sites are better to be sampled by the 5-6 diver team (i.e., NOAA/RSMAS).

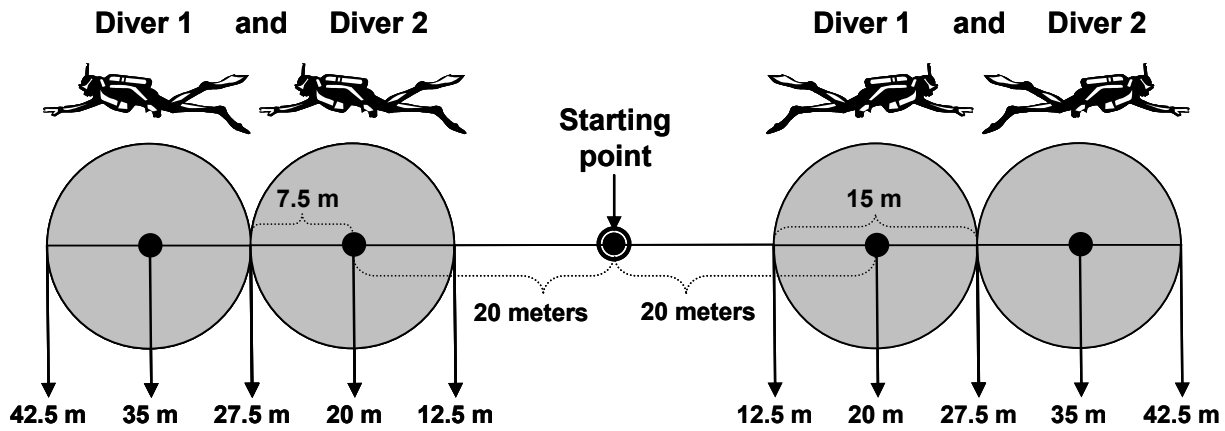


Figure C.2. Schematic representing location of counts along deployed measuring tape. If visibility is low, the radius of each diver's cylinder should be reduced to 5 m (10 m diameter).

C.3 Details of Observations Made in the Field

Data will be recorded on three data forms: (1) the Field/Boat Log, (2) the Water Quality/Environmental Log, and (3) the Fish/Habitat data sheet. Data for forms (1) and (2) are recorded at the surface by a surface support worker/diver. Data for form (3) are collected and recorded underwater at the sample site by divers.

C.3.i Field Forms

C.3.i.a Field/Boat Log

This form (Figure C.3) serves as a record of where, when and by whom sites were sampled each day (a printable version of the form is included in Appendix 3). Two lines of data (one for each replicate pair of surveys) should be recorded for each sample site. The following information is recorded on the form:

a. Dive of day: cumulative site number (e.g., 1, 2, 3…). This number will be the same for each of the two lines of data recorded at each site.
b. Site ID: this is a three-character code listed on the sample site list. This number will be the same for each of the two lines of data recorded at each site.
c. Estimated time: estimated time of beginning of dive. For divers using the anchoring method, the estimated time for the second set of paired surveys will be the time immediately preceding those surveys.
d. Diver team: when the live boating method is used, this number corresponds to the first or second set of paired samples for a given sample site (i.e., divers performing the first set of paired samples are diver team 1; divers performing the second set of paired samples are diver team 2). When the anchoring method is used, only one diver team will be present.
e. Latitude and longitude in degrees and minutes: position of surface vessel when divers enter the water.
f. Habitat code: the diver's consensus of the habitat type that was sampled; the suite of habitat codes is listed at the bottom of the Field / Boat log (Figure C.3); habitat types are defined in the Section C.3.iv.
g. GPS #: when the live boating method is used, each dive team will have a GPS with number label; the GPS number is used to subsequently match GPS position with the data collected by each dive team. When only two divers are available for deployment at a given site, one GPS number would be used.
h. Comments: any additional information judged to be important by the surface data collector (e.g., notation of a specific camera used by a diver).

Reef Fish Visual Census (RVC) FIELD/BOAT LOG DATE _____

Page _____ of _____

Dive of Day	Site ID	Est. Time	Diver Team	Buddy Team (Diver A / Diver B)	LATITUDE deg.	LATITUDE minutes	LONGITUDE deg.	LONGITUDE minutes	Habitat Code *	GPS#	Comments

* Habitat Codes

1 - Contiguous reef, Spur-Groove
2 - Contiguous reef, Other
3 - Isolated reef structure(s)
4 - Reef Rubble
5 - Sand-Seagrass-HB matrix
6 - Artifical reef
0 - Sand

Figure C.3. Field/Boat Log form. Printable version in Appendix 3.

C.3.i.b Water Quality/Environmental Log

This form (Figure C.4) serves as a record of water quality and environmental data associated with each set of paired surveys at each sample site (a printable version of the form is included in Appendix 3). The following information is collected by a surface support worker (either measured directly or communicated to the surface support worker by divers) and recorded on the form:

a. Dive of Day: identical to dive of day column on Field / Boat Log; see preceding section.
b. Site ID: identical to Site ID column on Field / Boat Log; see preceding section.
c. Surface temperature (°C) *: water temperature measured in top 1m of water column.
d. Surface salinity (ppt) *: water salinity measured in top 1m of water column.
e. Bottom temperature (°C) *: water temperature measured 1-2m off the bottom.
f. Bottom salinity (ppt) *: water salinity measured 1-2m off the bottom.
g. Underwater visibility (ft or m): horizontal visibility, measured at depth by divers.

h. Wind direction (N, NE, E, SE, S, SW, W, or NW) and speed (mph): estimated by surface support worker(s).
i. Percent cloud cover: estimated by surface support worker(s).
j. Bottom current: estimated by divers for each paired survey; categories as follows: None (none), Mod. (diver is able to stay in same position with a gentle kick), High (diver struggles to stay in same position).
k. Comments / notes: any additional information judged to be important by the surface data collector.

*All measured from the research vessel using a salinity probe (e.g., YSI) with extension cable or refractometer or salinity probe and water retrieved from depth in a sample vial.

Reef fish Visual Census (RVC) - Water Quality and Environmental Log

Date:

		WATER QUALITY DATA				ENVIRONMENTAL DATA					
Dive of Day	SiteID	SurTemp (° C)	Sur Sal (ppt)	BotTemp (° C)	Bot Sal (ppt)	UW Visibility (ft) or (m)	Wind dir	Wind mph	Clouds (% cover)	Current (N,M,H)	Comments/Notes

Figure C.4. Water Quality/Environmental Log form. Printable version in Appendix 3.

C.3.i.c Fish/Habitat Data Sheet

Fish and habitat data are entered on the Fish/Habitat Data Sheet (Figure C.5; a printable version of the form is included in Appendix 3). Prior to each dive, divers should enter their name (name of observer / diver), name of dive buddy, and date on the data sheet. After entering the water, choosing a specific survey site, and recording dive and sample start times (time of beginning of dive and time of beginning of data collection, respectively; Figure C.5), each diver begins collection of fish, habitat, and sample-specific data as described in the following section.

Diver: ____________________ Date: __________ Field Number:

Buddy: ____________________ Sample Start Time: __________

Dive Start Time: ____________ Sample End Time: __________

Dive End Time: Max Dive Depth: ______ ft

Station Depth: ______ ft

Fishing Gear:

Habitat type:		Underwater visibility: _____ ft m
1. Contiguous S&G	4. Rubble	Water temperature: _________ F
2. Cont. Not S&G	5. (Matrix)	Radius of cylinder: 7.5m 5.0m
3. Isolated	0. (Sand)	Current: None Mod. High

Substrate Slope		
Max depth _____________ft		
Min depth _____________ft		
Max vertical Relief		
Hard Relief ____________m		
Soft Relief ____________m		
Surface Relief Coverage %		
	Hard	Avg. of Soft
< 0.2 m	%	%
0.2-0.5 m	%	%
0.5-1.0 m	%	%
1.0-1.5 m	%	%
> 1.5 m	%	%
TOTAL	100%	100%

Abiotic Footprint	
SAND	%
HARD-B	%
RUBBLE	%
Total	100%

Biotic Cover - Dominant Biological Cover %			
SAND		HARDBOTTOM	
"Bare"		~~Crustose Algae~~	
~~Algal Turf (<1cm)~~		Algae (<1cm)	
Macro Algae		Algae (>1cm)	
Sea grass		Live Stony Coral	
Sponge		Octocoral	
________ Other 1		Sponge	
________ Other 2		_________ Other 1	
		_________ Other 2	
TOTAL	100%		100%

Species	N	Avg	Min	Max	Species	N	Avg	Min	Max

Comments:

Presence of: *A. palmata* *A. cervicornis* Black Coral

Spiny Lobster # Conch # Diadema #

Figure C.5. Fish/Habitat Data Sheet. Printable version in Appendix 3.

C.3.ii Collecting Fish Data

The Reef fish Visual Census (RVC) methodology is modified from Bohnsack and Bannerot (1986), and occurs with the diver remaining at a fixed site. Fish are surveyed within an imaginary cylinder centered on the diver and extending from the

reef substrate to the limits of vertical visibility, usually the surface (Figure C.6). If horizontal visibility is greater than or equal to 7.5m, then the radius of the cylinder will be 7.5m. If the horizontal visibility is less than 7.5m but greater than 5m, then the radius of the cylinder will be 5m. If the horizontal visibility is less than 5m, then further data collection will not occur.

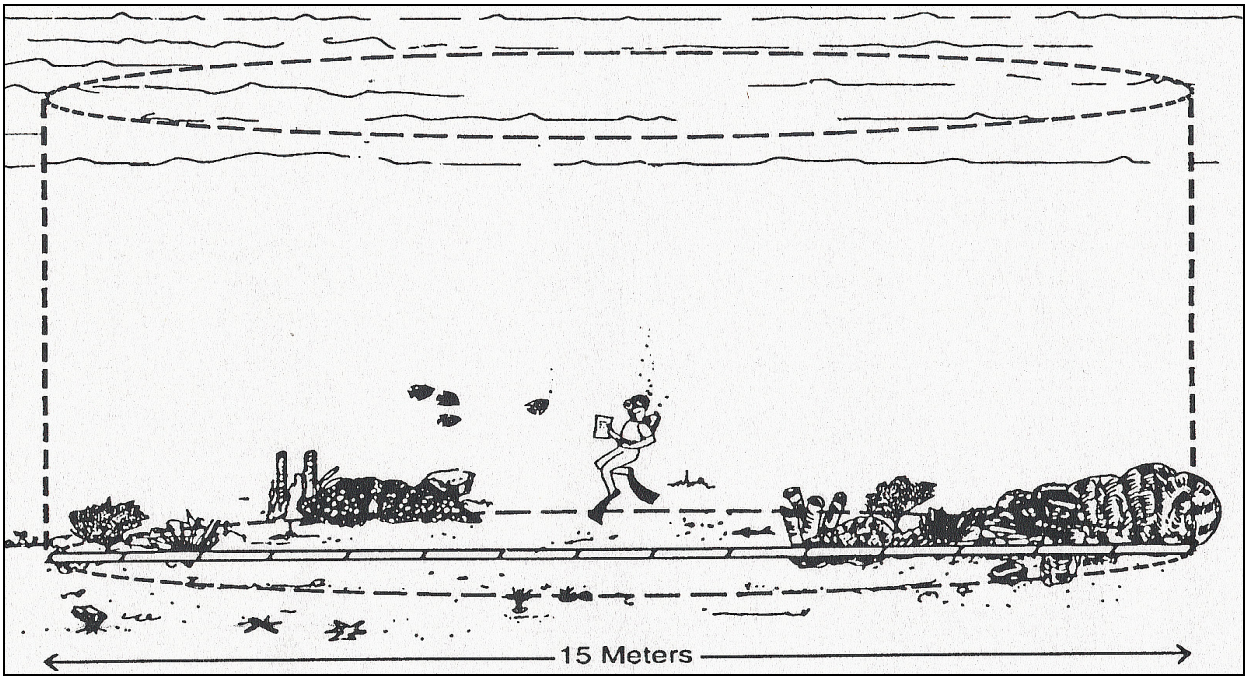


Figure C.6. Conceptual diagram of RVC diver within 7.5m-radius survey cylinder (from Rogers et al. 1994).

Once horizontal visibility has been measured and the appropriate cylinder radius has been established, the RVC survey begins. Divers establish an imaginary fixed point on the bottom to serve as the center of the sample cylinder, and hover above the point (maintaining neutral buoyancy) to avoid damaging the benthic habitat. Divers record the sample start time on the Fish/Habitat Data Sheet and begin a timed count, using the stopwatch function on the diver's watch to keep track of time. For a five-minute period, divers record all fish species observed. During this period, divers should rotate their position (while remaining above the imaginary fixed point) to ensure that all portions of the cylinder are surveyed. The diver should treat the survey as if they are taking a snapshot in time of all species and their associated densities and size distribution that they observe in the cylinder.

After five minutes have elapsed, data are collected by each diver on the abundance ("N" column in Figure C.5) and sizes for each species. Individual fork lengths are recorded for the following species: all groupers (including graysbys, coneys and hinds), snappers, and hogfish (*Lachnolaimus maximus*). When 10 or less individuals of any of these species are present in a survey, individual lengths for all individuals will be recorded. When more than 10 individuals of any of these species are present,

data are collected by each diver on the abundance ("N" column) and mean, minimum and maximum lengths ("Avg", "Min" and "Max" columns in Figure C.5). For all other species, abundance ("N" column) and mean, minimum and maximum fork lengths ("Avg", "Min" and "Max") are recorded.

For species with few individuals (e.g. angelfish, barracuda, hogfish) or for highly mobile species (e.g., sharks and Carangids), individuals are enumerated and their sizes are estimated when first observed. For enumeration and size estimation of other species (e.g. damselfish, wrasses, grunts, etc.), one 360-degree rotation is typically made for each species.

Concurrent with the species enumeration and length estimation described above, new species that are observed after the initial five-minute observation period and until completion of all data collection are also recorded, as are estimates of their abundance and minimum, mean, and maximum lengths. These species are noted on the Fish/Habitat Data Sheet as having been observed "Between 5 and 10 minutes" or "After 10 minutes", depending on the time elapsed at time of observation. If an individual or individuals of a species observed in the initial five-minute observation period is observed after data on the abundance, mean, minimum and maximum fork lengths for that species have been recorded, the diver should exclude these individuals from the count and continue recording only new species data.

During the survey, the reference measurement tool (APT) is used to aid in measuring habitat vertical relief, estimation of fish lengths and the location of the center and outer edge of the sample cylinder. To the extent that conditions (e.g., current) permit, the diver should remain at the center of the survey cylinder for the entirety of the fish data collection portion of the survey.

C.3.iii Sample-Specific Data

Following fish data collection, the following sample-specific data are recorded on the Fish/Habitat data sheet: water temperature, current speed (None, Mod, or High), maximum dive depth, and station depth (bottom depth at the diver's survey location). The horizontal visibility will have been measured and recorded prior to the RVC survey.

C.3.iv Habitat Data

Following the sample-specific data collection, habitat data are collected and recorded on the Fish/Habitat data sheet. The following variables are measured and recorded:

<u>Habitat type</u>: chosen from the following categories (circle one on the Fish/Habitat data sheet). At the surface, the diver should discuss with their buddy and other team members and try to come to a consensus. If a consensus is not achieved, divers should note that in the Field/Boat Log.

Target habitats:

- Isolated reef structure(s): E.g., patch reefs, rocky outcrops, pinnacle (Figure C.7-A)
- Contiguous reef structure with distinct spur and groove formation: E.g., low or high relief spur and groove (Figure C.7-B)
- Contiguous reef structure – Other: contiguous reef with no distinct formation; e.g., low relief hard bottom not spur and groove (Figure C.7-C)
- Reef Rubble (Figure C.7-D)

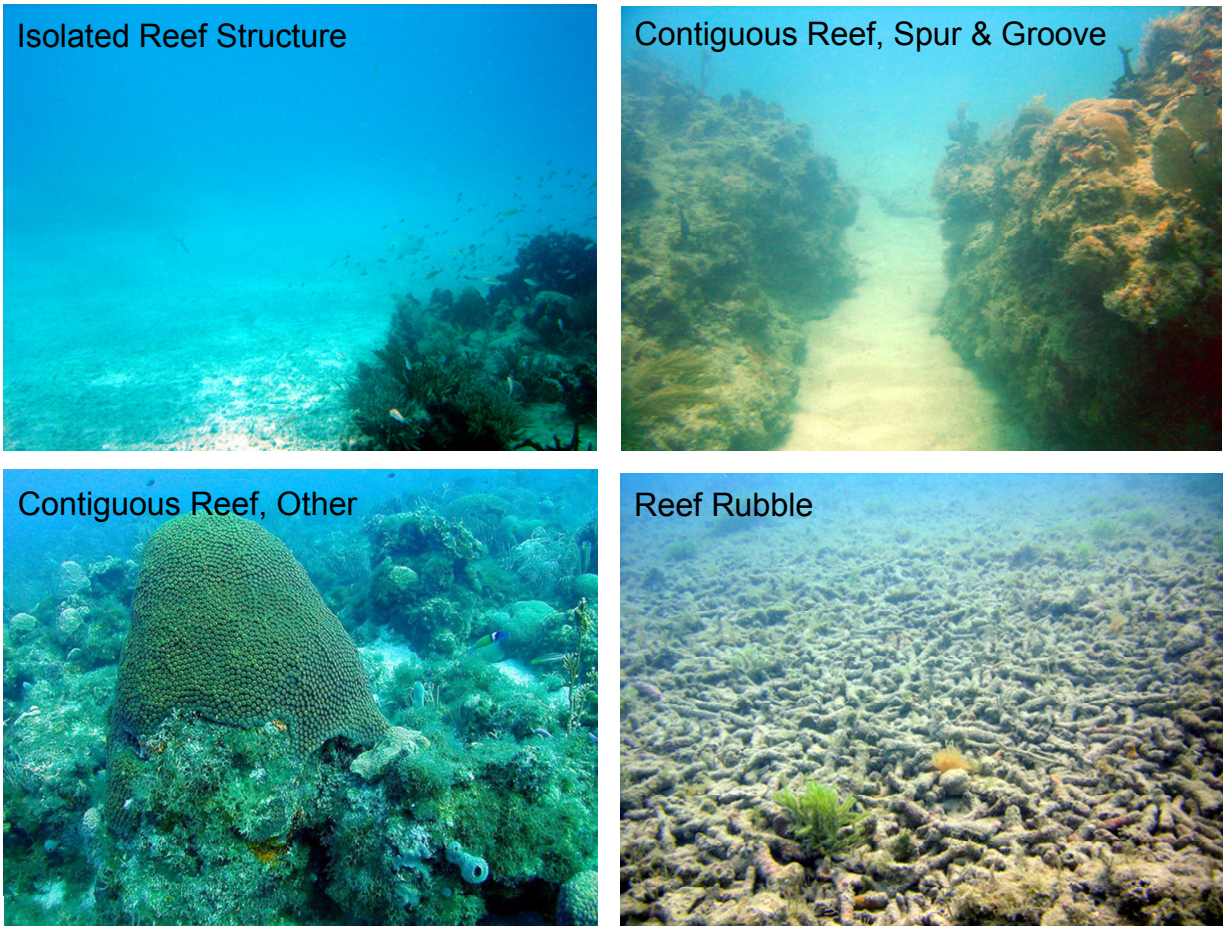


Figure C.7. Example photos of target habitats.

Water temperature, Secchi visibility and Current: temperature and visibility at the bottom; water current estimated by divers for each paired survey; categories as follows: None (none), Mod. (diver is able to stay in same position with a gentle kick), High (diver struggles to stay in same position).

Non-target habitats: if after diving for 5 minutes divers fail to find any of the target habitat types, divers should conduct a count in one of the non-target habitats noting the habitat type on the Field/Boat Log.

- Sand
- Sand-seagrass-hard-bottom matrix: mostly soft bottom, non-reef habitat

- Artificial reef (e.g., wrecks)

Substrate Slope: the maximum and minimum depths within the sample cylinder. These values refer to the maximum and minimum depths on the imaginary plane underlying the sample cylinder. If there is a slope these depths will be different (Figure C.8).

Max Vertical Relief: the maximum vertical relief within the sample cylinder of both hard (e.g., coral structure, coralline spur, rocky outcrop) and soft (e.g., octocorals, sponges and macroalgae) substrate (Figure C.8). These values should not be zero.

Surface Relief Coverage for Hard Vertical Relief (e.g., coral structure, coralline spur, rocky outcrop and sand): the estimated percentages of hard relief that fall into the following categories (all values in meters): < 0.2, 0.2-0.5, .05-1.0, 1.0-1.5, and >1.5. These values should sum to 100% (Figure C.8).

Surface Relief Coverage for Soft Vertical Relief (e.g., octocorals, sponges and algae): the category (< 0.2, 0.2-0.5, .05-1.0, 1.0-1.5, and >1.5m) representing the average vertical relief of all soft relief should be indicated by writing "100%" by that category (Figure C.8).

Abiotic Footprint: the percentage of the cylinder comprised of sand, hardbottom and rubble. These percentages should sum to 100%. Sand is defined as coarse biogenic or oolitic sand (grain sizes typically between 0.5-2 mm) and finer silt sized particles (< 0.2 mm). Sand is considered the substratum when sediment depth is usually 2-3 cm in depth or greater. It excludes a surface "dusting" of sediment particles overlying a consolidated substratum. Rubble ranges from coarse gravel (> 5 mm) to unconsolidated and moveable rocks (e.g. dislodged and moveable coral fragments). This category differs from consolidated hard-bottom because of its loose and moveable nature. Consolidated hard-bottom includes solid, consolidated lithogenic or biogenic substratum, including living and dead coral, and non-coral hard-bottom. Areas covered by seagrass should be coded as sand, since the biotic "grass" is growing in the abiotic sand substrate.

Biotic Cover - SAND: the percentage of the sand substrate that corresponds to the following categories: bare, under / supporting growth of macroalgae, under / supporting growth of seagrass, under / supporting growth of sponges, and other (e.g., Sargassum; see Appendix 2 for more examples). These values should sum to 100%. See preceding section for sand definition.

Biotic Cover – HARDBOTTOM: While looking at an aerial, canopy view of the cylinder, the percentage of the hardbottom substrate covered with algae < 1 cm height (e.g., turf algae, *Lobophora*), macroalgae > 1 cm height (e.g., *Halimeda, Dictyota*), live coral, octocoral, sponge, and other (e.g., *Palythoa*, *Cliona*; see Appendix 2 for more examples). These values should sum to 100%.

Comments: Under the "comments" section, divers should record information such as economically important species observed before or after the RVC survey (e.g., while descending or ascending), presence of *Acropora palmata* and/or *Acropora cervicornis* (if present circle), presence of black coral, number of

Spiny Lobster, Conch and/or *Diadema antillarum*, and camera number used. If present, divers should also record the type and amount of fishing gear or debris (e.g., monofilament line, traps or trap debris including buoy line, etc.) within the cylinder in the "Fishing gear" section of the Fish/Habitat Data Sheet (see Figure C.5). Additionally, any comments relative to the sampling or conditions encountered should be recorded in the "Comments" section of the data sheet.

Following fish and habitat data collection, sample end time is recorded and divers ensure that all sections on the Reef / Habitat data sheet are completed. Dive end time is recorded after all data have been collected and immediately prior to dive ascent.

C.4 Post-Collection Data Sheet and Logs Processing

Once all data collection has been completed underwater, divers deployed from an anchored vessel then return to the research vessel, while divers deployed from a live boating vessel ascend to the surface immediately adjacent to their surface dive flag and wait for the research vessel to approach. Immediately upon returning from a dive, initial QA/QC should include discussions between buddy teams to ensure agreement on variables such as habitat type, bottom current, and other variables of interest. Data sheets are maintained in a secure area aboard the research vessel. Once on land, data sheets are redistributed to data collectors for data entry. Copies (electronic or paper) of all data sheets should be made before redistribution to data collectors in case of loss of original data sheets. These copies should be maintained in a single storage location.

Information recorded at-sea on the Boat/Field and Water Quality/Environmental logs should be entered into spreadsheet files customized for this data. Latitude-Longitude positions are entered into the Boat/Field log Spreadsheet file after surface buoy GPS unit tracklogs have been downloaded and sampling positions for each dive team determined. It is suggested that Latitude-Longitude positions be recorded in the form of degrees and minutes to three decimal places (dd° mm.mmm').

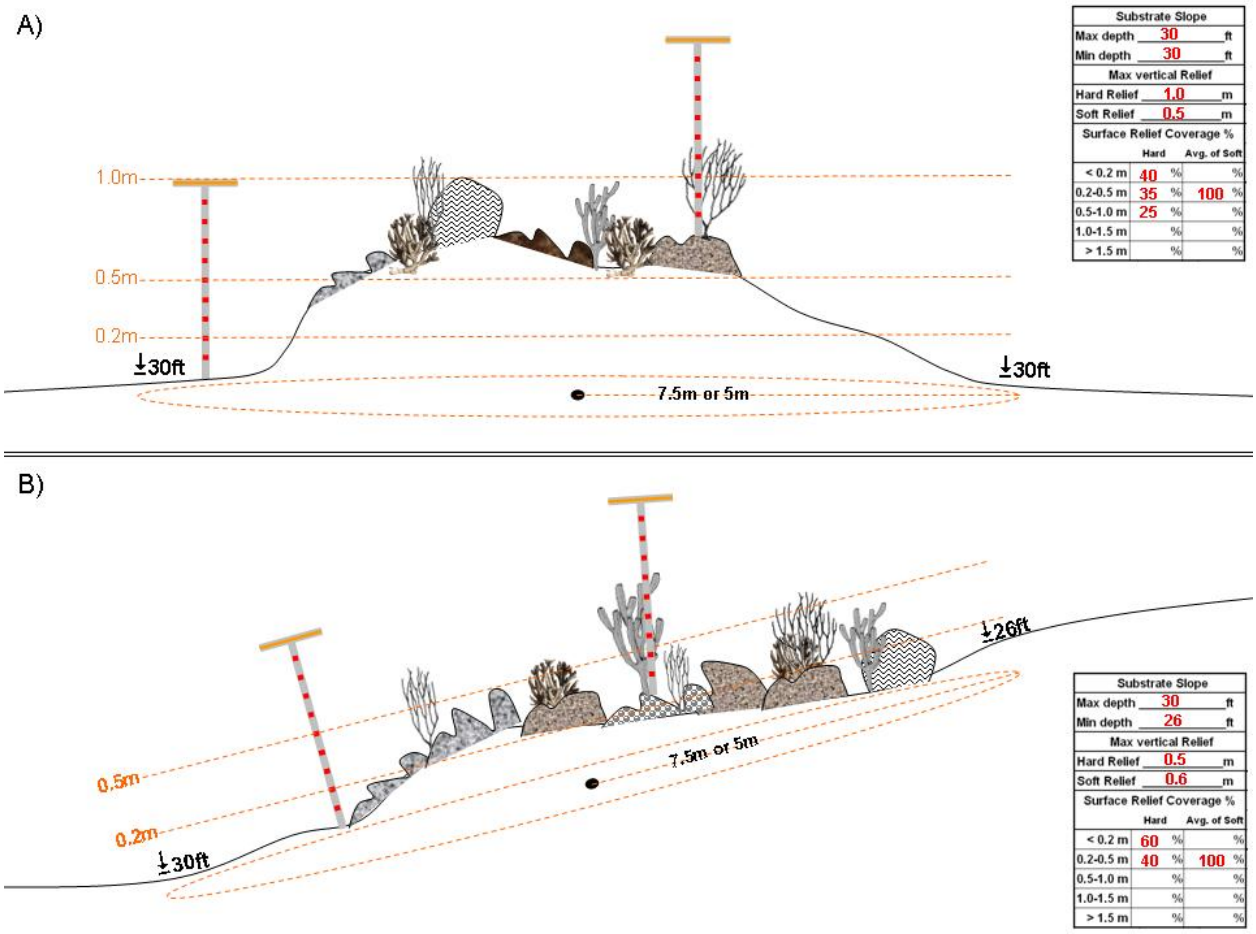


Figure C.8. Diagram showing how to measure substrate slope, max vertical relief and surface relief coverage. If there is NO slope then Max Depth = Min Depth (**A**). If there is a slope, then Max Depth > Min Depth (**B**). Soft Relief is measured from base of attachment to maximum height. Surface relief coverage (%) for the hard substrate components (e.g., coral structure, coralline spur, rocky outcrop and sand) is estimated by determining the percentages of the cylinder area that occupy the following vertical height categories (all values in meters): <0.2, 0.2-0.5, .05-1.0, 1.0-1.5, and >1.5. *Average* surface relief coverage (%) for soft substrate components (e.g., octocorals, sponges and algae) is estimated as the vertical height category within the cylinder representing the average vertical relief of all soft substrate components in the cylinder (including macroalgae). This should be indicated by writing "100%" in that vertical relief category.

Standard Operating Procedure D: Data Entry and Proofing

(Version 1.0)

Revision History Log

Previous Revision No.	Revision Date	Author	Change Made	Reason for change	New Version No.

D.1 Introduction

Management of the data is an important and multi-level process. Steps that should be taken to manage the data once it has been collected include data entry, proofing and storage. The specific steps and those responsible for each step are outlined in Table D.1 and explained in detail in the following sections.

Table D.1. Data management overview.

Steps	Responsible person	Forms/Programs used
1) Field data collection	Diver	1-Fish/Habitat data sheet 2-Field/Boat log 3-Water Quality/Environmental log
2) Enter/collate data	Diver	Fish/Habitat data entered into RVC2.3.exe Data Entry program
3) Check and merge data files	Agency data manager	Merge2.0.exe
4) Generate proofing reports	Agency data manager	SAS and Word Mail Merge
5) Proof and edit data	Diver	Visual comparison of original data sheets to proofing report
6) Create preliminary RVC Annual Master Excel file	Agency data manager	Excel
7) QA/QC and verification procedures	Statistician (UM-RSMAS)	SAS
8) Create final RVC Annual Master Excel file	Statistician (UM-RSMAS)	SAS
9) Storage of data in Oracle database	Statistician (UM-RSMAS)	Oracle

D.2 Data entry

D.2.i The RVC Data Entry Program

Reef fish Visual Census (RVC) fish and habitat survey data are entered into an electronic database using the RVC Data Entry Program. This program was designed to standardize data entry and minimize the potential for error during the data entry process. Data are entered into the RVC program through three 'window' or data

entry screens, focusing on sample identifier information, habitat data, and fish and invertebrate species, size, and abundance data.

The RVC Data Entry Program consists of one executable program (RVC2.3.exe) written in the C++ computer program language along with several, user modifiable, support files. Entered data are output as tilde (~) delimited ASCII files into one of three individual subfolders. The three subfolders are named "sample", "substrate" and "species" and must be present on the computer hard drive in the same folder in which the RVC2.3.exe and support files are located.

D.2.ii Directions for Use of the RVC Data Entry Program

In order to properly use the RVC2.3.exe program for data entry, a folder containing the following files must be present on the user's PC:

RVC2.3.exe
computerlist.noaa
currentcomputer.noaa
diverlist.noaa
habitatlist.noaa
otherspecieslist.noaa
samplelist.noaa
specieslist.noaa
speciessizelist.noaa

To open the RVC2.3.exe program and begin entering recorded data, double-click on the RVC2.3.exe filename or desktop icon.

D.2.ii.a Entering Sample Data

The first window in the program is titled "RVC Data Entry (Sample Data)" (Figure D.1). This is where general information about the diver's sample is entered. The following directions should assist the user with data entry into the "Sample Data" window.

- The data entry field labeled "Computer Name," located in the top left corner of the window, should already contain the previously assigned name of the user's pc. This name is listed in the "currentcomputer.noaa" file.
- Enter the last name of the "Diver" and "Buddy" by clicking the drop-down arrow in each data field, and choose the appropriate name from the given list of divers. The "Diver" and "Buddy" data fields must not be left empty.
- Choose the appropriate sampling method and habitat type using the drop-down arrows in both the "Sample Type" and "Habitat Type" entry fields. For RVC surveys, the sample type will be "Bohn-Bannerot Point". If the diver is training, "Training – Observer" should be selected from the dropdown list instead.

- Enter the date of the dive, the time when the dive started and ended, and the time when the sample started and ended in the appropriate entry fields. It is important that the date and times be entered in the proper, indicated format. The hour must be a number between 0 and 23, and the minutes must be a number between 0 and 59. The "Dive End Time" must be greater than the "Dive Start Time", and the "Sample End Time" must be greater than the "Sample Start Time." Additionally, the "Sample Start Time" and the "Sample End Time" must fall between the "Dive Start Time" and the "Dive End Time." Warning windows will pop up when very early start times and very late end times for the dive are entered.
- Enter the maximum depth of the dive and the depth of the sampling station (bottom depth at center of sampling cylinder) in the "Max Dive Depth" and "Station Depth" entry fields. These entries must be integers greater than zero.
- The "Fishing Gear" entry field is a comment box where any fishing gear located within the sample area should be listed. Possible types of fishing gear include lobster traps, trap line, and monofilament fishing line.
- The value of the "Field Number" will be provided by the diving coordinator / data manager.
- Enter the "Under Water Visibility" in measurement units of feet. This entry should be an integer greater than zero.
- Enter any important remarks regarding the dive and/or sample into the "Comments" entry field.
- Throughout the data entry process, dynamic evaluations of the data input into entry fields are performed by the program. Upon leaving an entry field, the program checks the validity of the data automatically. Prior to moving on to the next window, the information entered into the current window must be checked for errors once more by the program. This is accomplished by clicking on the "Check Data" icon. If no errors are detected, the program will generate the "Master Sample number", and the second data entry window will open. The "Master Sample number" is the unique relational linking index with the Substrate data and Species data (see sections below).The "Master Sample Number" is composed of the following information: year+month+date+sample start time+diver number; The year, month, day, and sample start time are derived from entered data for a sample and the diver number is determined from the number (4 digit) assigned to each diver last name in the RVC data entry support file = diverlist.noaa.

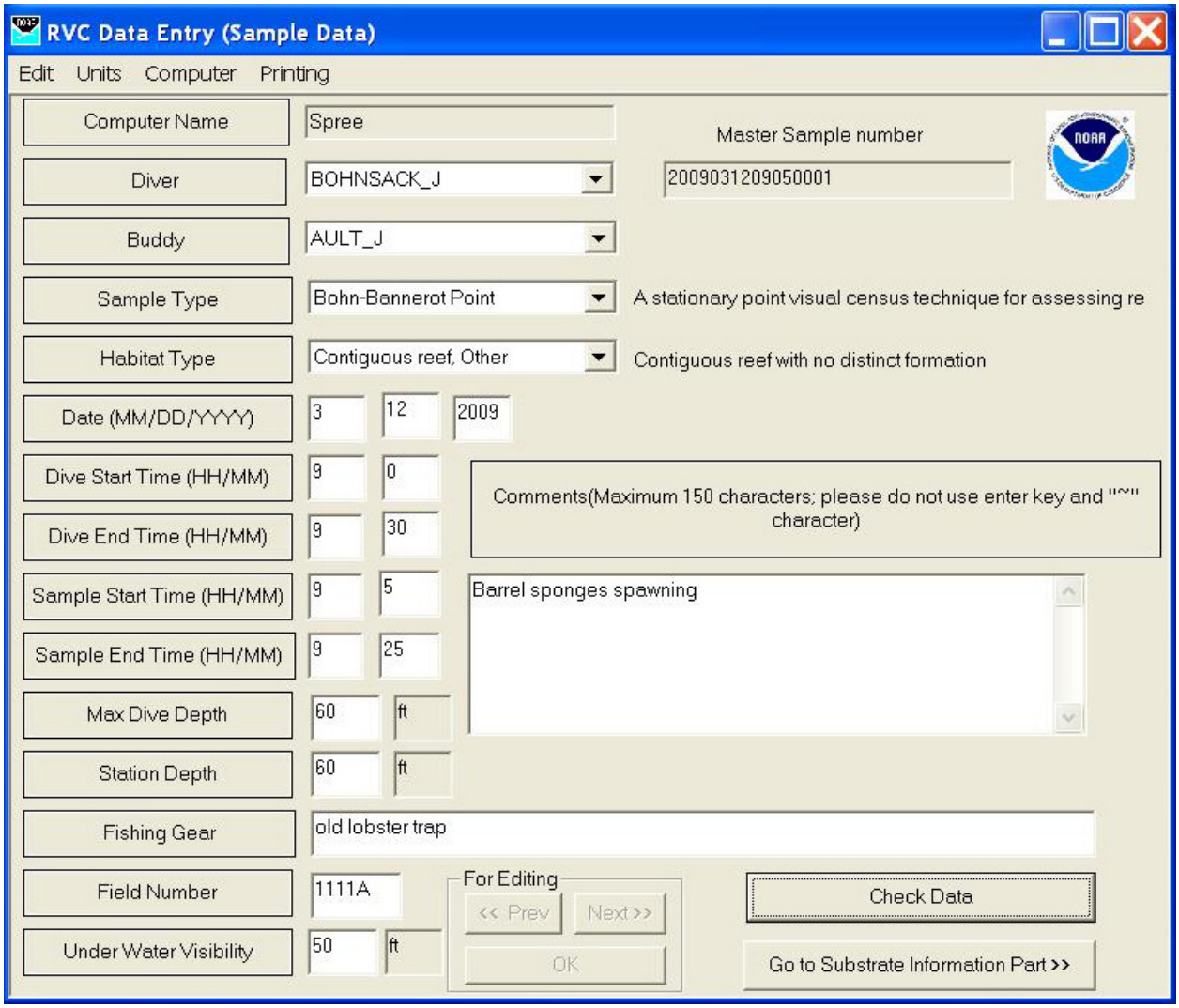


Figure D.1. The "Sample Data" window.

D.2.ii.b Entering Habitat Data

The second window of the RVC2.3.exe program is titled "RVC Data Entry (Substrate Data)" (Figure D.2). This is where the user enters information about the substrate of the sampled habitat. The generated "Master sample number" should now appear in the top right side of the window. The user has the option to either enter data into this window or to skip this window by clicking the "Skip" icon. As data is entered, the program evaluates the data dynamically in a manner similar to that of the first window. The following directions should assist the user with data entry into the "Substrate Data" window.

- Enter the recorded "Max Depth" and "Min Depth" of the slope of the substrate in the respective entry fields. The maximum depth must be an integer greater than zero, and the minimum depth must be less than or equal to the maximum depth.

- Enter the measured maximum vertical relief of the "Hard Substrate" and "Soft Substrate" in the respective entry fields. The relief of the hard and soft substrate must be greater than zero.
- The estimated percent of the intervals of vertical relief that comprise the surface of the sample area must be entered into the "Surface Relief Coverage %" section. This section is divided into the intervals of "Hard" vertical relief and "Soft" vertical relief. The data entry fields that are activated depend on the values entered in the "Max vertical relief" section. For example, if the value of the maximum vertical relief of the soft substrate equals zero (i.e. no soft substrate was found in the sample area), then the entry fields for the "Soft" vertical relief in the "Surface Relief Coverage %" will not be activated. The total percent coverage of both "Hard" and "Soft" vertical relief must equal 100%.
- The percent of sand, hard-bottom, and rubble that comprises the "Abiotic Footprint" of the sample area must be entered into the fields labeled "Sand", "Hard-B", and "Rubble" respectively. The values entered into these fields must add to 100%. If the percent of "Sand" in the "Abiotic Footprint" is not equal to zero, then the "Sand" portion of the "Biotic Cover" section will be activated. Likewise, if the percent of "Hard-B" in the "Abiotic Footprint" is not equal to zero, then the "Hardbottom" portion of the "Biotic Cover" section will be activated. Click the icon labeled "Input Data to Biotic Cover" to begin entering data into the "Biotic Cover" section.
- Values for the estimated percent of various categories of biota covering both the "Sand" and "Hardbottom" must be entered into the "Biotic Cover – Dominant Biological Cover %" section. Any category that is not listed in this section, but was present in the sample area may be entered in one of the fields labeled "Other". All values entered in the "Sand" portion of the section must add to 100%, and all values entered in the "Hardbottom" portion of the section must add to 100%.
- As in the previous window, the information entered into the current window must be checked for errors by the program prior to moving on to the next data entry window. This is accomplished by clicking on the "Check Data" icon. If no errors are detected, the third and final data entry window will open.

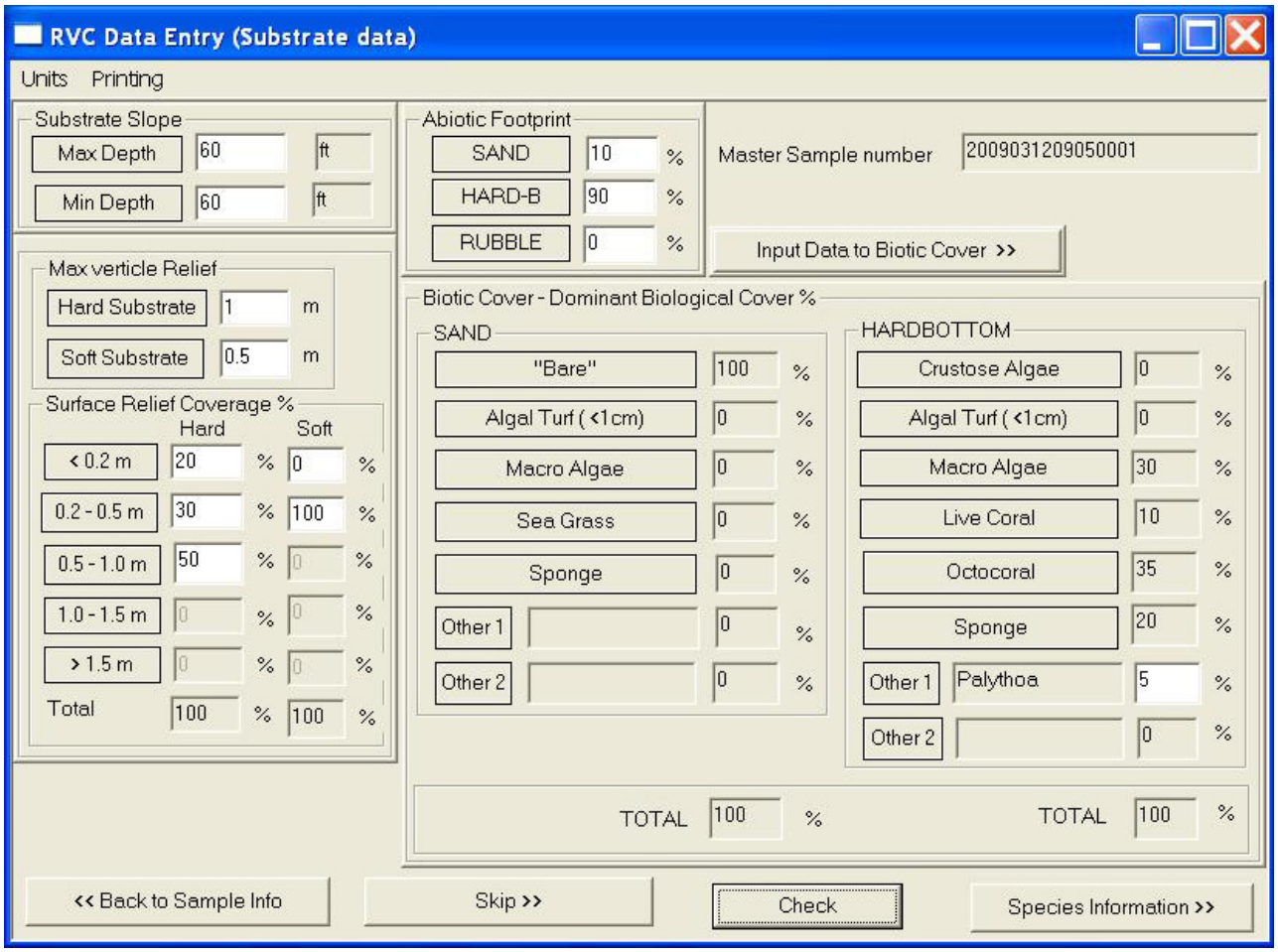


Figure D.2. The "Substrate data" window.

D.2.ii.c Entering Fish Species Data

The third window of the RVC2.3.exe program is titled "RVC Data Entry (Species data)" (Figure D.3). This is where data about the species observed and recorded in the sample area is entered. As in the previous two windows, dynamic data checking is also implemented by the program in this window. The following directions should assist the user with data entry into the "Species Data" window.

In order to differentiate between species observed during the first five minutes of the sampling period and species observed during the 5-10 and > 10-minute periods, click the "Time period" icon in the top left corner of the window. Species observed after the first five minutes but before ten minutes have passed will be identified with the following notation "(**)". The notation for species observed after ten minutes will be "(***)".

- Click the icon labeled "Species/Common" in the top left corner of the window in order to choose to enter the data according to either the species name or the common name. If the species name is selected, then the program will search for and provide the corresponding common name and vice versa.

- By default, the program is automatically ready to enter "Reef fish" records into the data window. In order to input a species that is not a "Reef fish", click on the icon labeled "Species type" at the top of the window, and select "Others." "Others" includes lobster species, stone crab, urchins, conch, and various abiotic objects such as concrete, etc.
- To begin entering records of observed species into the "Species data" window, click the drop-down arrow in the "Species" entry field or in the "Common" entry field, depending on the method of data entry chosen previously. Choose the appropriate species from the given list. Next, enter the observed number of individuals of that particular species in the field labeled "N." If "N" is equal to one (i.e. only one or two individual(s) of that species were observed), for the estimated length is entered in the "Average" field. If "N" is equal to two, the estimated lengths are entered in the "Min" and "Max" fields. If "N" is equal to three or more, enter the average size of the individuals, and the minimum and maximum observed size in the "Average", "Min", and "Max" field, respectively. The "Average" value must be greater than the "Min" value and less than the "Max" value.
- If a species is observed that is not on the species list, first check with the data manager to confirm that the species is not on the list and has not been seen in a previous RVC. If it is confirmed that the species has not been seen before, enter data for this species using "Other" from the species name drop down list or "New species" from the common name drop down list. Identify the species in the "Comments" entry field of the "Sample Data" window. It is possible, however extremely unlikely, to add up to three new species for a site. Therefore, confirmation with the UM-RSMAS data manager and statistician should always occur prior to adding a new species.
- When the record for a particular species is complete, click the icon labeled "Add," and the data record will appear in the box below the entry fields. Data for additional species may be added in the same manner. In order to delete a record, highlight the particular record and click the "Clear" icon. In order to edit a previously input species record, double-click on the record of interest.
- The program is designed to allow the user to input multiple size classes within the same species. Therefore, multiple records for the same species may be created, but the "Min" and "Max" size values for each record must not overlap.
- If it is necessary to go back and edit the "Substrate Data," click the icon labeled "Back to Substrate Info." Data must be re-checked "via the "check data" button when proceeding forward through data screens after moving back to previous screens. When all of the recorded data has been entered and no further editing is required, click the "Save" icon. This operation will save the entire data record.

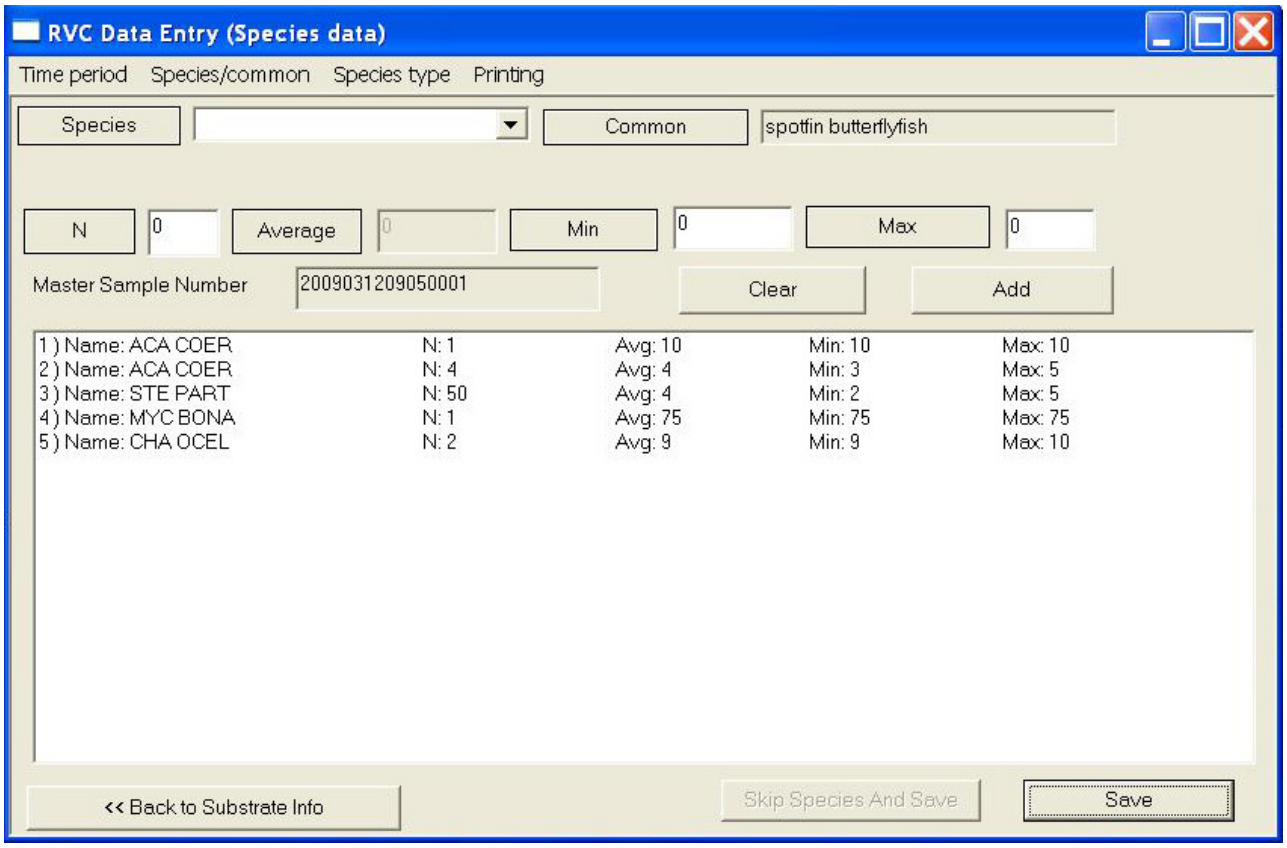


Figure D.3. The "Species data" window.

D.3 Editing Saved Data

The first window in the program provides an option to edit previously saved data records. The user must click the "Edit" icon on the top left corner of the "Sample Data" window and select "Edit." When this function is chosen, the program opens the "Sample", "Substrate", and "Species" files corresponding to the specified "Diver" and the "Computer Name." The user must scroll through the available records in order to find the record to be edited. When the user selects a particular record, the data in the "Sample," "Substrate," and "Species" files corresponding to that record will be deleted. At this point the user is able to change the previously entered data in each of the three windows. In order to move from the "Sample Data" window to the "Substrate Data" window, the user must click the "Check Data" icon. Likewise, in order to move from the "Substrate Data" window to the "Species Data" window, the user must again click the "Check" icon. When the editing is complete, the user must click the "Save" icon in order to save the record. If the user exits the program without saving, then the data in the edited record ***WILL BE LOST***.

- Entered data (sample, fish and environmental data) will be submitted for storage on the FWC FTP site, which can be accessed by FWC, NOAA, NPS, and UM-RSMAS staff.
- All data entry should be completed by Dec. 1 each sampling year.

- Subsequent to collation at NOAA, all raw data will be available to all agencies.
- Data are made available to all agencies as soon as annual QA/QC is completed.
- All groups agree on data release to outside data requests prior to actual release.

D.4 Data Cataloguing

All data should be catalogued and backups created such that several independent copies of the data are held in different physical locations but where they are accessible to all groups involved. These locations will include UM-RSMAS, NPS, NOAA, and FWRI.

D.5 Data QA/QC and Verification

Data proofing and verification are important steps in a monitoring program and there are a series of tasks that must be followed to accurately proof, correct, and verify the data before analysis. If errors are not caught during this phase they will likely go undetected, introducing error into the database. The most crucial data proofing is carried out by each diver immediately following each dive and at the time the diver enters his data in the RVC Data Entry Program. There is much more to proofing than simply verifying that the values for each variable were entered correctly. The proofers must be aware of the procedures and guidelines related to the data and recognize situations where the variables entered do not seem reasonable.

D.5.i Initial Diver Proofing

These are the most crucial proofing steps to ensure the accuracy of the data. Initial data proofing should be carried out by each diver immediately following each dive, and should involve reviewing the data sheet for errors and missing data, as well as discussing subjective data collection variables (e.g., habitat type and bottom current) with dive buddy.

Following this, the diver is responsible for providing the agencies with the most correct data. The diver will make a conscious effort to enter the data into the RVC Data Entry Program as accurately as possible. This should include counting the number of species on the field data sheet and comparing it with what was entered into the program immediately after entering the data, as well as going back through the three windows and checking for any errors prior to saving the record.

D.5.ii Participant-Level Proofing

D.5.ii.a Data Proofing Criteria

Each agency will be responsible for maintaining the integrity of data collected and entered by their participants. A minimum of 10% of the data collected by any participant and entered into the RVC database should be proofed after it is entered.

This proofing shall consist of comparing data collected on underwater datasheets to that entered into the database which should be printed out as a proofing report. If there is any inconsistency between data recorded on the data sheet and that entered into the system, that sample should be recorded as an error. The number of samples recorded as an error divided by the number of samples proofed is the accuracy for that participant. A minimum accuracy level of 90% should be maintained for any participant. Each agency should follow their own steps to assure that all participants maintain this level of accuracy.

D.5.ii.b Proofing Report Procedure

Proofing reports can be created for a specific diver after data for that diver has been entered. The proofing report creation process involves the use of a SAS program to read the ASCII data entry files and output this data into an Excel file suitable for input into a Mail Merge template document created in Word. The SAS program can generate proofing reports in the common species name style (Figure D.4), or the RVC species code style (Figure D.5) depending on the diver's recording of species on the underwater data sheet. After a proofing report has been printed, the information on the proofing report should be compared to the data on corresponding underwater data sheets as per the data proofing criteria described previously. Each agency should accomplish necessary corrections or changes discovered during the proofing report process using the "Edit" function of the RVC Data Entry Program.

Diver: BANNER S	Date: 1/4/2009	Field Number: 6152A
Buddy: JONES T	Sample Start: 9:12	Vis: 40
Dive Start: 9:10	Sample End: 9:30	Habitat: Contiguous reef, Other
Dive End: 9:33	Max Depth: 30	Comments:
	Stat Depth: 30	Fish Gear: Lobster trap slats

Substrate Slope		
Max depth: 30		
Min depth: 30		
Max vertical relief		
Hard Relief: 0.5		
Soft Relief: 0.9		
Surface Relief %		
	Hard	Avg. soft
<.2	30	0
.2-.5	70	100
.5-1	0	0
1-1.	0	0
>1.5	0	0

Abiotic Foot	
Sand	25
Hard-b	70
Rubble	5

Biotic Cover %			
Sand		Hardbottom	
Bare	100	Algae(<1)	20
Macro Algae	0	Algae (>1)	30
Sea grass	0	Live Coral	5
Sponge	0	Octocoral	35
1:	0	Sponge	10
2:	0	1:	0
		2:	0

Period	Species	N - Avg - Min - Max		Period	Species	N - Avg - Min - Max
1	bluehead	25 --- 5 - 3 - 7				
1	white grunt	5 --- 20 - 20 - 20				
1	bicolor damselfish	15 --- 4 - 3 - 5				
1	gray snapper	1 --- 27 - 27 - 27				
1	gray snapper	1 --- 29 - 29 - 29				
1	French angelfish	1 --- 29 - 29 - 29				
1	graysby	1 --- 23 - 23 - 23				
1	bridled goby	4 --- 3 - 1 - 4				
1	yellowtail snapper	2 --- 25 - 25 - 25				
1	yellowtail snapper	1 --- 29 - 29 - 29				
1	reef butterflyfish	2 --- 10 - 10 - 10				
2	Atlantic trumpetfish	1 --- 40 - 40 - 40				
2	yellow jack	1 --- 34 - 34 - 34				
2	yellow jack	1 --- 37 - 37 - 37				

Figure D.4. Example proofing report sheet in common species names style.

Diver: BANNER S	Date: 1/4/2009	Field Number: 6152A
Buddy: JONES T	Sample Start: 9:12	Vis: 40
Dive Start: 9:10	Sample End: 9:30	Habitat: Contiguous reef, Other
Dive End: 9:33	Max Depth: 30	Comments:
	Stat Depth: 30	Fish Gear: Lobster trap slats

Substrate Slope							
Max depth: 30							
Min depth: 30							
Max vertical relief				Biotic Cover %			
Hard Relief: 0.5				Sand		Hardbottom	
Soft Relief: 0.9			Abiotic Foot	Bare	100	Algae(<1)	20
Surface Relief %			Sand 25	Macro Algae	0	Algae (>1)	30
Hard	Avg.	soft	Hard-b 70	Sea grass	0	Live Coral	5
<.2	30	0	Rubble 5	Sponge	0	Octocoral	35
.2-.5	70	100		1:	0	Sponge	10
.5-1	0	0		2:	0	1:	0
1-1.	0	0				2:	0
>1.5	0	0					

Period	Species	N - Avg - Min - Max	Period	Species	N - Avg - Min - Max
1	THA BIFA	25 --- 5 - 3 - 7			
1	HAE PLUM	5 --- 20 - 20 - 20			
1	STE PART	15 --- 4 - 3 - 5			
1	LUT GRIS	1 --- 27 - 27 - 27			
1	LUT GRIS	1 --- 29 - 29 - 29			
1	POM PARU	1 --- 29 - 29 - 29			
1	CEP CRUE	1 --- 23 - 23 - 23			
1	COR GLAU	4 --- 3 - 1 - 4			
1	OCY CHRY	2 --- 25 - 25 - 25			
1	OCY CHRY	1 --- 29 - 29 - 29			
1	CHA SEDE	2 --- 10 - 10 - 10			
2	AUL MACU	1 --- 40 - 40 - 40			
2	CAR BART	1 --- 34 - 34 - 34			
2	CAR BART	1 --- 37 - 37 - 37			

Figure D.5. Example proofing report sheet in RVC species code style.

D.5.iii Agency-Level Proofing

D.5.iii.a Data Merge and Verification

After proofing of all diver entered data for an annual sampling cycle has been completed, the RVC Annual Master Spreadsheet file can be created. The data contained in this spreadsheet file includes: the ASCII sample, substrate and species data output from the RVC entry program along with entered data from the combined Boat/Field and Water Quality/Environmental log forms. Each of the four datasets becomes an individual worksheet in the RVC Annual Master Spreadsheet file.

D.5.iii.b Merge of Diver-Entered ASCII Files

The Merge2.0.exe program is used to "merge" the numerous ASCII files created by the RVC Data Entry application into tilde (~) delimited files containing the sample, substrate, and species RVC data. These three files are imported as the first three worksheets of a Spreadsheet file. With the inclusion of the fourth dataset (combined Boat/Field and Water Quality/Environmental logs) the creation of the RVC Annual Master Spreadsheet file has been completed.

D.5.iii.c Preliminary Annual Master Spreadsheet File Verification

After the creation of the RVC Annual Master Spreadsheet file, verification that all RVC counts have been entered by divers can occur. This task is accomplished via a series of record checks of the sample diver entered data against the Boat/Field Log data. If missing diver samples are discovered during this check, divers will need to be contacted and resolution of missing data accomplished. The resolution may include a revision to Boat/Field Log or entry of missing RVC sample data. In addition to the missing data check, some preliminary checks of certain data elements such as Field Numbers, outliers in lengths or numbers of fishes, sampling dates, etc. is performed. The data proofing procedures described previously should reduce or eliminate occurrences of questionable data elements. However, should questionable data elements be discovered during this preliminary check, individual divers may need to be contacted for resolution.

D.5.iv Final Verification and Oracle Database

After the Preliminary Master Spreadsheet File Verifications has been completed, the RVC data undergoes a more rigorous software application program verification procedure(s) overseen by statisticians at UM-RSMAS. A detailed description of all procedures involved in this final verification, including SAS code can be found in Smith et al. (in prep b). This procedure systematically checks the data files created at the agency level and uses other files to produce Oracle database tables (Figure D.6). Variables associated with each file used in the verification process are listed in Tables D.2-D.8. The variables in the Oracle tables and their descriptions are listed in Table D.9. and a schema diagram for the Oracle database is also provided (Figure D.7).

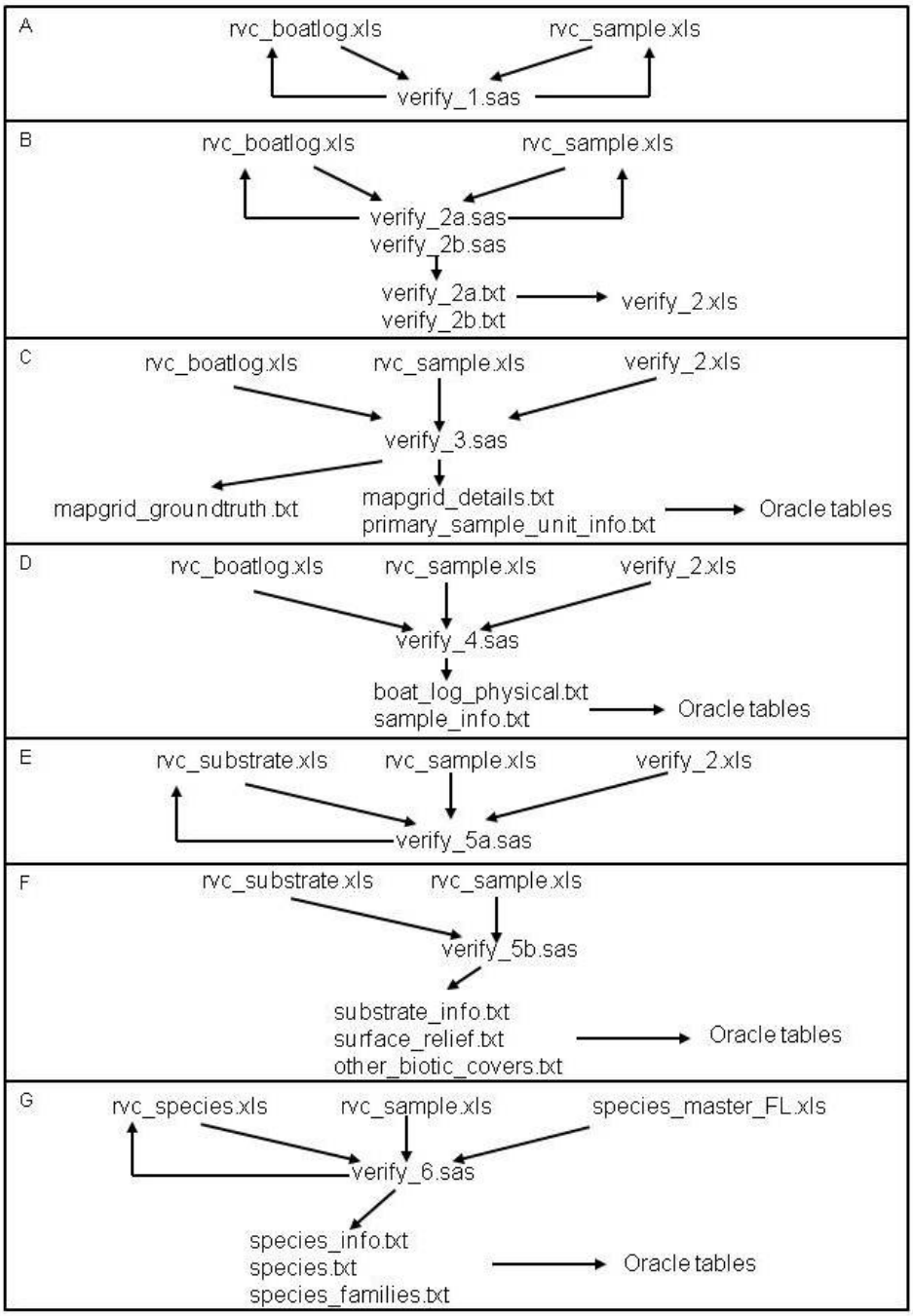


Figure D.6. Flow chart of verification procedures and production of oracle tables from Excel files.

Table D.2. Variables in the sample output file (rvc_sample.xls).

variable #	SAS/Excel name	Oracle Name
1	mastersampcd	MASTER_SAMPLE_CD
2	divnum	DIVER_NR
3	budnum	BUDDY_NR
4	samptype	SAMPLE_TYPE_NR
5	divhab	
6	habname	HABITAT_TYPE
7	year	YEAR
8	month	MONTH
9	day	DAY
10	divbegh	DIVE_START_TIME_HOURS
11	divbegm	DIVE_START_TIME_MINUTES
12	divendh	DIVE_END_TIME_HOURS
13	divendm	DIVE_END_TIME_MINUTES
14	sampbegh	SAMPLE_START_TIME_HOURS
15	sampbegm	SAMPLE_START_TIME_MINUTES
16	sampendh	SAMPLE_END_TIME_HOURS
17	sampendm	SAMPLE_END_TIME_MINUTES
18	divdepth	DIVE_DEPTH
19	sampdepth	SAMPLE_DEPTH
20	fishgear	FISHING_GEAR
21	fieldid	
22	vis	UNDERWATER_VISIBILITY
23	sampdescr	SAMPLE_DESCR
24	sppbeffive	NR_OF_UNIQUE_SPECIES_BEFORE_FIVE
25	sppaftfive	NR_OF_UNIQUE_SPECIES_AFTER_FIVE
26	sumbeffive	SUM_OF_INDIVIDUAL_FISH_BEFORE_FIVE
27	sumaftfive	SUM_OF_INDIVIDUAL_FISH_AFTER_FIVE
28	subswitch	SUBSTRATE_SWITCH
29	specswitch	SPECIES_SWITCH

Table D.3. Variables in the boat log output file (rvc_boatlog.xls).

variable #	SAS/Excel name	Oracle Name
1	fieldid	
2	year	YEAR
3	month	MONTH
4	day	DAY
5	diveofday	
6	logbegh	
7	logbegm	
8	divnum	DIVER_NR
9	lat_deg	
10	lat_min	
11	long_deg	
12	long_min	
13	lat	LAT_DEGREES
14	lon	LON_DEGREES
15	temp_s	SURFACE_TEMPERATURE
16	sal_s	SURFACE_SALINITY
17	temp_b	BOTTOM_TEMPERATURE
18	sal_b	BOTTOM_SALINITY
19	comments	LOG_COMMENTS
20	mapgrid	MAPGRID_CD
21	maphab	
22	depcat	
23	region	REGION_NR
24	subreg	SUBREGION_NR
25	mpa	MPA_NR

Table D.4. Variables in the substrate output file (rvc_substrate.xls).

variable #	SAS/Excel name	Oracle Name
1	mastersampcd	MASTER_SAMPLE_CD
2	submaxdep	SUBSTRATE_MAX_DEPTH
3	submindep	SUBSTRATE_MIN_DEPTH
4	vrel_h	HARD_VERTICAL_RELIEF
5	vrel_s	SOFT_VERTICAL_RELIEF
6	h_relcat_0	TYPE, INDEX, VALUE
7	h_relcat_1	TYPE, INDEX, VALUE
8	h_relcat_2	TYPE, INDEX, VALUE
9	h_relcat_3	TYPE, INDEX, VALUE
10	h_relcat_4	TYPE, INDEX, VALUE
11	s_relcat_0	TYPE, INDEX, VALUE
12	s_relcat_1	TYPE, INDEX, VALUE
13	s_relcat_2	TYPE, INDEX, VALUE
14	s_relcat_3	TYPE, INDEX, VALUE
15	s_relcat_4	TYPE, INDEX, VALUE
16	p_sand	SAND_PERCENTAGE
17	p_hb	HARDB_PERCENTAGE
18	p_rub	RUBBLE_PERCENTAGE
19	s_pcov_bare	SAND_BARE
20	s_pcov_algturf	SAND_ALGAL_TURF
21	s_pcov_macalg	SAND_MACRO_ALGAE
22	s_pcov_sg	SAND_SEAGRASS
23	s_pcov_sponge	SAND_SPONGE
24	s_pcov_oth1_lab	TYPE, DESCRIPTION
25	s_pcov_oth2_lab	TYPE, DESCRIPTION
26	s_pcov_oth1	TYPE, PERCENTAGE
27	s_pcov_oth2	TYPE, PERCENTAGE
28	h_pcov_crust	HARDBOTTOM_CRUSTOSE_ALGAE
29	h_pcov_algturf	HARDBOTTOM_ALGAL_TURF
30	h_pcov_macalg	HARDBOTTOM_MACRO_ALGAE
31	h_pcov_coral	HARDBOTTOM_LIVE_CORAL
32	h_pcov_octo	HARDBOTTOM_OCTOCORAL
33	h_pcov_sponge	HARDBOTTOM_SPONGE
34	h_pcov_oth1_lab	TYPE, DESCRIPTION
35	h_pcov_oth2_lab	TYPE, DESCRIPTION
36	h_pcov_oth1	TYPE, PERCENTAGE
37	h_pcov_oth2	TYPE, PERCENTAGE

Table D.5. Variables in the species output file (rvc_species.xls).

variable #	SAS/Excel name	Oracle Name
1	mastersampcd	MASTER_SAMPLE_CD
2	species	SPECIES_CD
3	catch	NUMBER_OF_INDIVIDUALS
4	meanlen	AVERAGE_LENGTH
5	minlen	MIN_LENGTH
6	maxlen	MAX_LENGTH
7	time_seen	TIME_SEEN
8	instance_field	
9	instance_key	

Table D.6. Variables in the verification file used (verify_2.xls).

variable #	SAS/Excel name	Oracle Name
1	fieldid	
2	stn	STATION_CD
3	rep	REPLICATE_CD
4	year	YEAR
5	month	MONTH
6	day	DAY
7	divnum	DIVER_NR
8	pr_num	
9	pr_mod	
10	hab	HABITAT_NR
11	divhab	
12	maphab	
13	sampdepth	SAMPLE_DEPTH
14	mapgrid	MAPGRID_CD
15	region	REGION_NR
16	subreg	SUBREGION_NR
17	mpa	MPA_NR
18	pr_unit	PRIMARY_SAMPLE_UNIT

Table D.7. Variables in the map grid groundtrouthing file (mapgrid_groundtrouth.txt) used in verification.

variable #	SAS/Excel name	Oracle Name
1	mapgrid	MAPGRID_CD
2	year	YEAR
3	month	MONTH
4	day	DAY
5	maphab	
6	obshab	HABITAT_NR
7	hab_chng	
8	depcat	
9	obsdepcat	
10	dep_chng	

Table D.8. Variables used in the Florida species master file (species_master_FL.xls) used in verification.

variable #	SAS/Excel name	Oracle Name
1	species	SPECIES_CD
2	latin	SCIENTIFIC_NAME
3	common	COMMON_NAME
4	family	FAMILY_NAME
5	com_fam	COMMON_FAMILY
6	specnum	SPECIES_NR
7	famnum	FAMILY_NR
8	max_size	MAX_SIZE
9	spectype	SPECIES_TYPE
10	bbtrawl	
11	nps_creel	
12	rvc_FL	

Table D.9. Variables associated with the Oracle tables and their descriptions.

Table	Variable#	Variable Name	Description	
SAMPLE INFO	1	MASTER_SAMPLE_CD	VARCHAR(16)	NOT NULL
	2	DIVER_NR	NUMBER(4)	NOT NULL
	3	BUDDY_NR	NUMBER(4)	NOT NULL
	4	YEAR	NUMBER(4)	NOT NULL
	5	MONTH	NUMBER(2)	NOT NULL
	6	DAY	NUMBER(2)	NOT NULL
	7	PRIMARY_SAMPLE_UNIT	VARCHAR(4)	NOT NULL
	8	STATION_CD	VARCHAR(1)	
	9	REPLICATE_CD	VARCHAR(1)	
	10	DIVE_START_TIME_HOURS	NUMBER(2)	NOT NULL
	11	DIVE_START_TIME_MINUTES	NUMBER(2)	NOT NULL
	12	DIVE_END_TIME_HOURS	NUMBER(2)	NOT NULL
	13	DIVE_END_TIME_MINUTES	NUMBER(2)	NOT NULL
	14	SAMPLE_START_TIME_HOURS	NUMBER(2)	NOT NULL
	15	SAMPLE_START_TIME_MINUTES	NUMBER(2)	NOT NULL
	16	SAMPLE_END_TIME_HOURS	NUMBER(2)	NOT NULL
	17	SAMPLE_END_TIME_MINUTES	NUMBER(2)	NOT NULL
	18	DIVE_DEPTH	NUMBER(6,2)	
	19	SAMPLE_DEPTH	NUMBER(6,2)	
	20	FISHING_GEAR	VARCHAR(50)	
	21	SAMPLE_TYPE_NR	NUMBER(4)	NOT NULL
	22	SAMPLE_DESCR	VARCHAR(150)	
	23	UNDERWATER_VISIBILITY	NUMBER(6,2)	
	24	LOG_COMMENTS	VARCHAR(100)	
	25	FISH_BEFORE_FIVE	NUMBER(5)	
	26	FISH_AFTER_FIVE	NUMBER(5)	
	27	SPECIES_BEFORE_FIVE	NUMBER(3)	
	28	SPECIES_AFTER_FIVE	NUMBER(3)	
	29	SUBSTRATE_SWITCH	NUMBER(1)	
	30	SPECIES_SWITCH	NUMBER(1)	
DIVERS	1	DIVER_NR	NUMBER(4)	NOT NULL
	2	DIVER_NAME	VARCHAR(20)	NOT NULL
SAMPLE TYPES	1	SAMPLE_TYPE_NR	NUMBER(4)	NOT NULL
	2	SAMPLE_TYPE	VARCHAR(20)	NOT NULL
	3	SAMPLE_TYPE_DESCRIPTION	VARCHAR(100)	NOT NULL

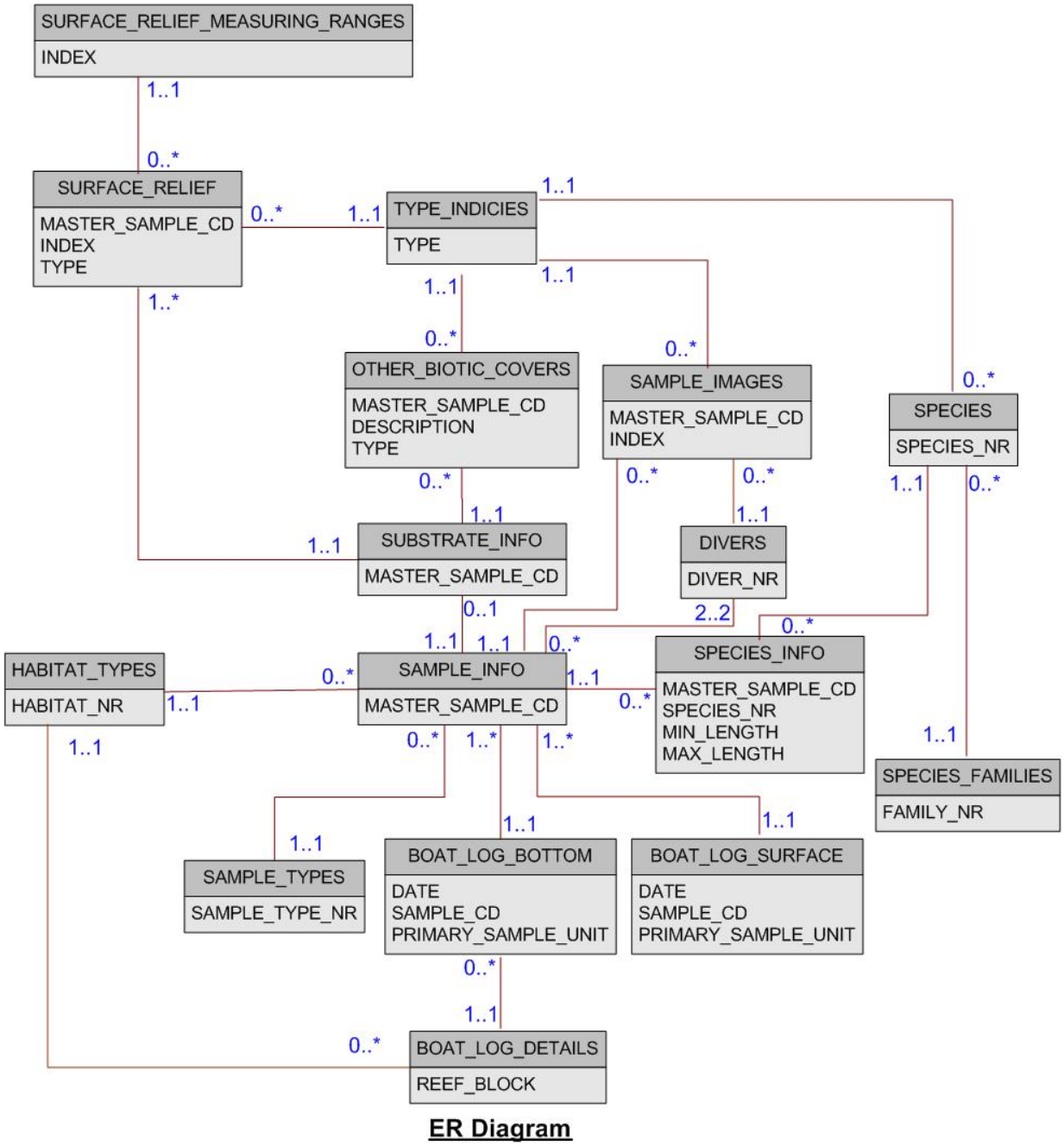
Table D.9 cont'd

Table	Variable#	Variable Name	Description	
BOAT LOG PHYSICAL	1	YEAR	NUMBER(4)	NOT NULL
	2	PRIMARY_SAMPLE_UNIT	VARCHAR(4)	NOT NULL
	3	STATION_CD	VARCHAR(1)	NOT NULL
	4	MAPGRID_CD	VARCHAR(10)	
	5	LAT_DEGREES	NUMBER(11,7)	
	6	LON_DEGREES	NUMBER(11,7)	
	7	SURFACE_TEMPERATURE	NUMBER(5,2)	
	8	BOTTOM_TEMPERATURE	NUMBER(5,2)	
	9	SURFACE_SALINITY	NUMBER(5,2)	
	10	BOTTOM_SALINITY	NUMBER(5,2)	
MAPGRID DETAILS	1	MAPGRID_CD	VARCHAR(10)	NOT NULL
	2	REGION_NR	NUMBER(3)	
	3	SUBREGION_NR	NUMBER(3)	
	4	MPA_NR	NUMBER(3)	
PRIMARY SAMPLE UNIT INFO	1	YEAR	NUMBER(4)	NOT NULL
	2	PRIMARY_SAMPLE_UNIT	VARCHAR(4)	NOT NULL
	3	HABITAT_NR	NUMBER(4)	NOT NULL
HABITAT TYPES	1	HABITAT_NR	NUMBER(4)	NOT NULL
	2	HABITAT_TYPE	VARCHAR(100)	NOT NULL
SUBSTRATE INFO	1	MASTER_SAMPLE_CD	VARCHAR(16)	NOT NULL
	2	SUBSTRATE_MAX_DEPTH	NUMBER(6,2)	
	3	SUBSTRATE_MIN_DEPTH	NUMBER(6,2)	
	4	HARD_VERTICAL_RELIEF	NUMBER(5,2)	
	5	SOFT_VERTICAL_RELIEF	NUMBER(5,2)	
	6	SAND_PERCENTAGE	NUMBER(3)	NOT NULL
	7	HARDB_PERCENTAGE	NUMBER(3)	
	8	RUBBLE_PERCENTAGE	NUMBER(3)	
	9	SAND_BARE	NUMBER(3)	
	10	SAND_ALGAL_TURF	NUMBER(3)	
	11	SAND_MACRO_ALGAE	NUMBER(3)	
	12	SAND_SEAGRASS	NUMBER(3)	
	13	SAND_SPONGE	NUMBER(3)	
	14	HARDBOTTOM_CRUSTOSE_ALGAE	NUMBER(3)	
	15	HARDBOTTOM_ALGAL_TURF	NUMBER(3)	
	16	HARDBOTTOM_MACRO_ALGAE	NUMBER(3)	
	17	HARDBOTTOM_LIVE_CORAL	NUMBER(3)	
	18	HARDBOTTOM_OCTOCORAL	NUMBER(3)	
	19	HARDBOTTOM_SPONGE	NUMBER(3)	
SURFACE RELIEF	1	MASTER_SAMPLE_CD	VARCHAR(16)	NOT NULL
	2	TYPE	NUMBER(2)	NOT NULL
	3	INDEX	NUMBER(4)	NOT NULL
	4	VALUE	NUMBER(3)	
TYPE INDICES	1	TYPE	NUMBER(2)	NOT NULL
	2	NAME	VARCHAR(20)	NOT NULL
SURFACE RELIEF MEASURING RANGES	1	INDEX	NUMBER(4)	NOT NULL
	2	LOWER_LIMIT	NUMBER(5,2)	NOT NULL
	3	UPPER_LIMIT	NUMBER(5,2)	NOT NULL
	4	ADDED_DATE	DATE	NOT NULL
	5	DESCRIPTION	VARCHAR(100)	
OTHER BIOTIC COVERS	1	MASTER_SAMPLE_CD	VARCHAR(16)	NOT NULL
	2	TYPE	NUMBER(2)	NOT NULL
	3	DESCRIPTION	VARCHAR(25)	NOT NULL
	4	PERCENTAGE	NUMBER(3)	NOT NULL

Table D.9 cont'd

Table	Variable#	Variable Name	Description	
SPECIES INFO	1	MASTER_SAMPLE_CD	VARCHAR(16)	NOT NULL
	2	SPECIES_NR	NUMBER(4)	NOT NULL
	3	NUMBER_OF_INDIVIDUALS	NUMBER(5)	
	4	AVERAGE_LENGTH	NUMBER(5)	NOT NULL
	5	MIN_LENGTH	NUMBER(5)	
	6	MAX_LENGTH	NUMBER(5)	
	7	TIME_SEEN	NUMBER(2)	
SPECIES	1	SPECIES_NR	NUMBER(4)	NOT NULL
	2	SPECIES_CD	VARCHAR(8)	NOT NULL
	3	SCIENTIFIC_NAME	VARCHAR(50)	
	4	COMMON_NAME	VARCHAR(50)	
	5	FAMILY_NR	NUMBER(4)	
	6	MAX_SIZE	NUMBER(4)	
	7	SPECIES_TYPE	NUMBER(2)	NOT NULL
SPECIES FAMILIES	1	FAMILY_NR	NUMBER(4)	NOT NULL
	2	FAMILY_NAME	VARCHAR(30)	NOT NULL
	3	COMMON_FAMILY	VARCHAR(50)	
SAMPLE IMAGES		MASTER_SAMPLE_CD	VARCHAR(16)	NOT NULL
		INDEX	NUMBER(2)	NOT NULL
		IMAGES	BLOB	NOT NULL
		IFS_LINK	VARCHAR(50)	NOT NULL
		IMAGE_TYPE	NUMBER(2)	
		PHOTOGRAPHER_NR	NUMBER(4)	

Figure D.7. The Entity-Relationship diagram (ER diagram) of the schema with relationships between different tables in Oracle.



Standard Operating Procedure E: Data Analyses and Reporting

(Version 1.0)

Revision History Log

Previous Revision No.	Revision Date	Author	Change Made	Reason for change	New Version No.

E.1 Introduction

The types of data analyses and reporting derived from the sample data will be specific to the types of management questions and resource goals that are being addressed. This section, however, describes some suggested analyses that should be applied to the data annually and before sampling commences in each subsequent season.

E.2 Descriptive Ecological Analysis

A basic descriptive ecological analysis should be completed annually based on that season's data that includes a basic inventory and frequency of occurrence of all fish species observed as well as indices of fish biodiversity. The inventory of fish species and their frequency of occurrence should be specified by sub-region and management zone, and plotted spatially if warranted. Species composition should be assessed using the indices fish species richness and diversity. Richness is calculated simply as the number of species observed, but several types of diversity indices exist, including the Shannon index (Shannon and Wiener 1948), Simpson index (Simpson 1949), and Pielou's J (Pielou 1966). These indices integrate the numbers of species with their relative abundance, and are typically more complex measures of fish biodiversity. Both species richness and some measure of diversity (typically the Shannon index) should be calculated annually and considered by sub-region, management zone, and habitat type spatially across the sampling domain.

E.3 Fishery Assessment and Calculation of Fish Stock Status Indices

A primary motivation of the reef fish monitoring program is to evaluate changes in the population structures of commercially-important fish species. The eight focal species include: White grunt (*Haemulon plumieri*), Bluestriped Grunt (*H. sciurus*), Hogfish (*Lachnolaimus maximus*), Mutton Snapper (*Lutjanus analis*), Gray Snapper (*L. griseus*), Yellowtail Snapper (*Ocyurus chrysurus*), Red Grouper (*Epinephelus morio*), and Black Grouper (*Mycteroperca bonaci*). These fish species are ecologically and economically important, but their populations fluctuate in response to changes in the environment and/or fishing pressure. Therefore, a key component of annual data analysis should consist of calculating population measures for each of these species and comparing among management zones, and relative to sampling in years past.

Robust estimators of population "health" for the focal species above include the average density of species at different lifestages and the average length of the exploited phase individuals, $\overline{L}$ (Ault et al. 2001; Ault et al. 2005b). These two biological indicators should be calculated annually and compared to previous years, and between management zones with consideration to habitat. Mean density of lifestages and $\overline{L}$ should also be considered spatially across the domain.

E.3.i Mean Density

Mean fish density can be estimated for the entire domain (i.e., Florida Keys) or for a specified stratum of interest (i.e., habitat class, management zone, geographic sub-region). Fish density, *D*, is the number of individuals observed per diver station (i.e., individuals observed/177m^2). However, because of dive safety considerations, the actual fish density for each diver station within a primary unit is actually the average density for the buddy team of divers (usually two, but sometimes three). There are typically two diver stations (second-stage units) sampled per primary unit. Therefore, the mean density within one primary unit *i* in stratum *h* is estimated as:

$$\overline{D}_{hi} = \frac{1}{m_{hi}} \sum_j D_{hij} \qquad \text{(Eq. E-1)}$$

where m_{hi} is the number of diver stations sampled in primary unit *i* and stratum *h*. Generally, this m_{hi} is equal to 2, but there are occasions where a station is not sampled because one of the buddy teams must abort the dive.

Mean fish density for an entire stratum *h* is then calculated as:

$$\overline{\overline{D}}_h = \frac{1}{n_h} \sum_i \overline{D}_{hi} \qquad \text{(Eq.E-2)}$$

Where n_k is the number of primary units sampled in stratum *h*.

To calculate the overall stratified mean density for the domain, stratum densities and a weighting factor are used:

$$\overline{\overline{D}}_{st} = \sum_h w_h \overline{\overline{D}}_h \qquad \text{(Eq.E-3)}$$

where w_h is the stratum weighting factor. This weighting factor is calculated for each stratum as:

$$w_h = \frac{N_h M_h}{\sum_h N_h M_h} \qquad \text{(Eq.E-4)}$$

where M_h is the total possible number of diver stations within a primary unit and N_h is the total possible number of primary units in a stratum. The area of a stationary point count cylinder is approximately 177m^2 and the total area of a primary unit is 40,000m^2 (200 x 200m); therefore, the total possible number of diver stations within a primary unit, M_h, is equal to 226 for all strata. The total possible number of primary units in a stratum, N_h, is dependent on the area that the stratum extends over, and so values for N_h are derived directly from the GIS habitat maps.

Overall stratified mean density and mean density for each stratum should be calculated separately for juvenile (size of first recruitment to the size of first maturity) and adult (size of first sexual maturity to maximum size) phases of each focal species, as these species are known to exhibit ontogenetic patterns among reef habitats through time. Calculations of mean densities should then be compared with consideration to changes through time and potential patterns in space.

E.3.ii Average Size in the Exploited Phase ($\bar{L}$)

The average size of an animal (length or weight) in the exploited phase of the stock (Beverton and Holt 1957) is a physiologically-based indicator that is sensitive to direct and indirect stress on marine ecosystems (Ault et al. 2005b). It is highly correlated with average population size, and so reflects the rate of fishing mortality operating in the fishery. As fishing mortality rate increases, $\bar{L}$ decreases at a rate proportional to the population-dynamic tolerance of a stock (Ault et al. 2005b). $\bar{L}$ will decrease until it is nearly equal to the minimum size of first capture regulated by fishery management. By its definition, there also exists a value of $\bar{L}$ corresponding to a population size that produces maximum sustainable yields on a continuing basis.

$\bar{L}$ at time t is defined as:

$$\bar{L}(t) = \frac{F(t)\int_{a_c}^{a_\alpha} N(a,t)L(a,t)da}{F(t)\int_{a_c}^{a_\alpha} N(a,t)da} \qquad \text{(Eq. E-5)}$$

where a_c is the minimum age at first capture, a_λ is the oldest age in the stock, $N(a,t)$ is the abundance for age class a, $L(a,t)$ is the length-at-age, and $F(t)$ is the instantaneous fishing mortality rate at time t.

E.3.iii Assessing Changes to Reef Fish Metrics

An advantageous property of statistical sampling theory is that survey design estimates, such as stratum density and the variance of stratum density, do not require knowledge of the underlying probability distribution (e.g., normal, gamma, etc.) of

the respective population metric, (e.g., observations of stratum animal density, y_{hi}) (Cochran 1977). A second property, based on large sample theory, is that survey design estimates (e.g., population means and totals) are normally distributed due to the central limit theorem if sample size is large. These properties facilitate the analysis of survey design estimates among times or areas (e.g., monitoring density over time, assessing MPA effectiveness).

A simple, straightforward approach to performing statistical tests for differences among survey estimates for a particular time or area is via inspection of confidence intervals (CI). If the sample is relatively large (n > 100) and has a Normal distribution, the survey mean, $\bar{y}_{st}$, will lie within a CI bounded by:

$$\bar{y}_{st} \pm t_{\alpha/k,df} SE[\bar{y}_{st}] \qquad \text{(Eq. E-6)}$$

With a probability of α, the Type I error rate, and where t is the critical value of Student's t-distribution, and degrees of freedom $d.f. = n_h$-1. Most commonly used reef metrics do not posses a Normal distribution which means the Type I error rate will not equal α. Cochran (1977) states α will be very close to what is expected if:

$$n > 25\ G_1^2$$

where G_1^2 is a Fisher's measure of skewness. If a sample is too small and the population is heavily skewed, transforming the data (e.g., $\log[y_{st} + 1]$, $[y_{st}]^2$) may help. With the cooperative effort of this program, this is typically not an issue.

CIs can be used to test the hypothesis that samples were drawn from the same population, as is done to assess temporal change or determine MPA effectiveness. Cochran (1977), Sokal and Rohlf (2001), and Zar (1996) describe methods using CIs to test for differences among means. A comparison of multiple CIs (e.g., a time series) requires a Bonferoni adjustment to α. The Bonferoni adjustment is necessary because the true Type I error rate of simultaneous multiple tests is not α, as it should be for a single test. As the number of means (e.g. years) increases, however, a different adjustment may be more appropriate, for instance Tukey's or SNK (Sokal and Rohlf 2001).

A useful relationship stemming from Equation E-6 is that the 95% CI for a population metric is approximately twice the CV, because the value of t for $\alpha = 0.05$ and $d.f. > 20$ is approximately 2. Thus, for example, a stratified random sampling survey that provides a domain-wide estimate of abundance with a CV of 15% would be able to statistically detect a minimum change of 30% in population abundance between survey time periods (with a Type I error rate = 0.05).

E.4 Multi-Species Fishery Stock Assessments

Periodically, it is important to quantitatively assess stocks of the exploited reef species across the sampling domain and evaluate their status relative to established Federal and International benchmarks for sustainable management of fishery resources. Calculation of mean fish density by lifestage and $\overline{L}$ for each of the focal species is described above. Population dynamic parameters such as natural mortality rate, fishing mortality rate, spawning stock biomass, and spawning potential ratio may also be derived from the data set annually or when needed. Methodologies for computing these parameters from the data can be found in the scientific literature; for example, in Ault and Ehrhardt (1991), Ehrhardt and Ault (1992), and Ault and Olson (1996).

E.5 Design Performance Analysis

An analysis of the performance of the sampling allocation should be completed after each season. This analysis also aids in determining sampling allocation for the subsequent year as described in Section A.3 of SOP A. The performance of a sampling design is ultimately the result of trade-offs between the cost of surveying (usually measured by the number of samples) and the precision of population estimates. The performance measure that is typically used by this program is the coefficient of variation (CV), which is defined and discussed in detail in Section A.3 of SOP A with an example detailed in Section A.5.

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Appendix 1: Glossary of Statistical Symbols and Computational Formulae Used In The Coral Reef Fish Sampling Survey.

Symbol	Definition	Computational Formula	Equation Number
h	Stratum subscript		
i	Primary sample unit subscript		
j	Second-stage sample unit subscript		
T_{hij}	Area of *j*th second-stage unit in primary unit *i* in stratum *h*		
M_{hi}	Total possible number of second-stage units in primary unit *i* in stratum *h*		
a_{hi}	Area of *i*th primary unit in stratum *h*	$a_{hi} = \sum_{j=1}^{M_{hi}} T_{hij}$	
N_h	Total possible number of primary units in stratum *h*		
A_h	Area of stratum *h*	$A_h = \sum_{i=1}^{N_h} a_{hi}$	
A	Area of entire survey domain	$A = \sum_h A_h$	
$N_h M_h$	Total possible number of second-stage units in stratum *h*		
w_h	Stratum *h* weighting factor	$w_h = \frac{N_h M_h}{\sum_h N_h M_h}$	Eq A-5
F_{hij}	Number of individuals observed in second-stage unit *j* in primary unit *i* in stratum *h*		
D_{hij}	Density (individuals m^{-2}) in second-stage unit *j* in primary unit *i* in stratum *h*	$D_{hij} = \frac{F_{hij}}{T_{hij}}$	
m_{hi}	Number of second-stage units sampled in primary unit *i* in stratum *h*		

$\overline{D}_{hi}$	Mean density in primary unit *i* in stratum *h*	$\overline{D}_{hi} = \frac{1}{m_{hi}} \sum_j D_{hij}$	
n_h	Number of primary units sampled in stratum *h*		
$\overline{\overline{D}}_h$	Mean density in stratum *h*	$\overline{\overline{D}}_h = \frac{1}{n_h} \sum_i \overline{D}_{hi}$	
s_{1h}^2	Sample variance among primary units *i* in stratum *h*	$s_{1h}^2 = \frac{\sum_i \left(\overline{D}_{hi} - \overline{\overline{D}}_h\right)^2}{n_h - 1}$	Eq. A-2
s_{2h}^2	Sample variance among second-stage units *j* in stratum *h*	$s_{2h}^2 = \frac{1}{n_h} \sum_i \left[\frac{\sum_i \left(D_{hij} - \overline{D}_{hi}\right)^2}{m_{hi} - 1} \right]$	Eq. A-3
$n_h m_h$	Number of second-stage units sampled in stratum *h*		
$\overline{\overline{D}}_{st}$	Domain-wide mean density for a stratified random survey	$\overline{\overline{D}}_{st} = \sum_h w_h \overline{\overline{D}}_h$	
nm	Number of second-stage units sampled in the survey domain		
n	Number of primary units sampled in the survey domain		
$CV[\overline{y}_{st}]$	Coefficient of variation of mean density	$CV[\overline{y}_{st}] = \frac{SE[\overline{y}_{st}]}{\overline{y}_{st}}$	Eq. A-7
s_{uh}	Sample standard deviation in stratum *h*	$s_{uh} = \sqrt{s_{1h}^2 - \frac{s_{2h}^2}{M_h}}$	Eq. A-4
m^*_h	Optimum number of second-stage unit samples per primary unit in stratum *h*	$m^*_h = \frac{\sqrt{s_{2h}^2}}{s_{uh}}$	Eq. A-6
V	Target variance for domain-wide mean density	$V\left[\overline{\overline{D}}_{st}\right] = \left(CV\left[\overline{\overline{D}}_{st}\right] \cdot \overline{\overline{D}}_{st}\right)^2$	Eq. A-8

n^*	Number of primary unit samples required to achieve a specified variance	$n^* = \dfrac{\sum_h w_h s_{uh}\left(\sum_h w_h s_{uh} + \sum_h \dfrac{w_h^2 s_{2h}^2}{m^*_h\, w_h s_{uh}}\right)}{V\left[\overline{\overline{D}}_{st}\right] + \sum_h \dfrac{w_h^2 s_{1h}^2}{N_h}}$	Eq. A-1
n^*_h	Optimal allocation of primary units among strata	$n^*_h = n^*\left(\dfrac{w_h s_{uh}}{\sum_h w_h s_{uh}}\right)$	Eq. A-9

Appendix 2: Habitat Information Sheets

The following pages are habitat information sheets formatted so that they can be printed directly onto sheets of underwater paper for use in the field. For this reason, no page numbers or headings are included.

1st page: Stony Corals

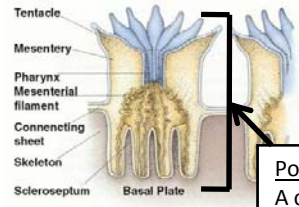
2nd page: Octocorals and Sponges

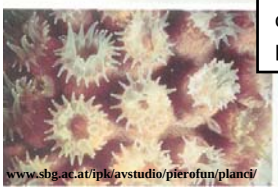
3rd page: Macroalgae, Seagrasses, and Other

4th page: Other (zooanthids), bottom of data sheet organisms, and living vs. bleached vs. recently dead coral identification

STONY CORALS

General coral anatomy:

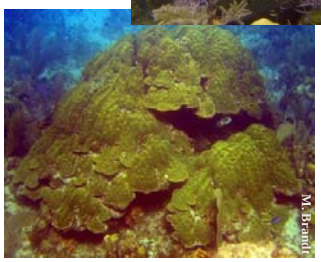


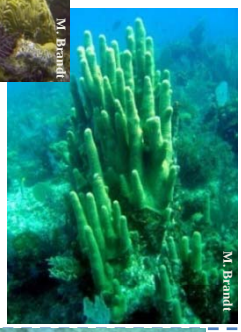


Polyp
A coral colony is made up of genetically identical polyps that are connected

Stony coral (scleractinia) morphotypes:

Massive:





All stony corals are rigid and leave behind reef framework when they die. Polyps vary in size and tentacles are typically retracted during the day (exception is pillar coral – bottom right photo)

Branching:

The presence/absence of either species should be noted at the bottom of the data sheet

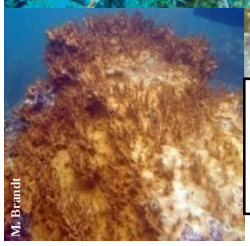
Small encrusting colonies of *A. palmata.* Note the white growing edges and prominent corallites

Leafy, platey:

Finger:

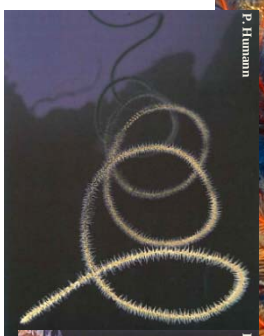
Other stony coral types:

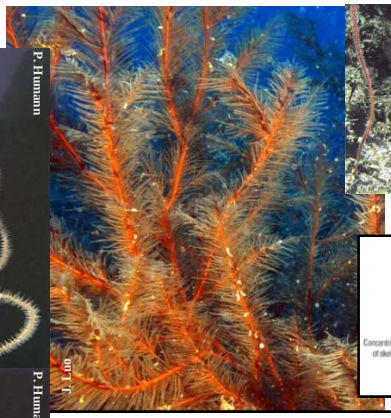
Fire corals

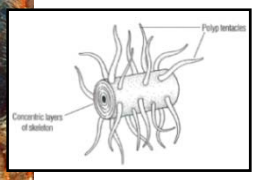


Tend to be orange/tan in appearance with white tips/edges. Stinging polyps look like sharp spines.

Black corals







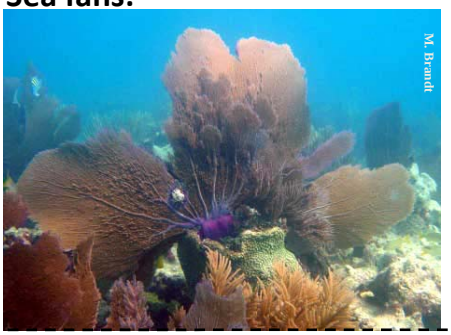
Unlike gorgonians, only tentacles come off of the branches (left close-up and diagram above), giving colonies a pine tree-like appearance. **Note the presence of black coral at bottom of data sheet!**

Sheets assembled by M. Brandt (mbrandt@rsmas.miami.edu)

OCTOCORALS

Octocoral morphotypes:

Sea fans:



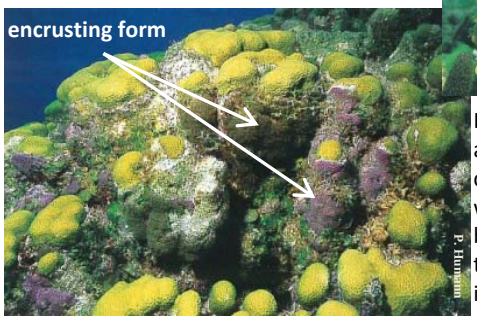
Sea rods and plumes:

Encrusting forms:

Erythropodium caribaeorum

Encrusting gorgonians often look like macroalgae. The two most common species of encrusting gorgonians are *Erythropodium caribaeorum* (left) and *Briareum asbestinum* (below). *Erythropodium* has brown tissue and long tentacles that make it look "hairy". *Briareum* has purple tissue with brown tentacles that also make it look hairy or furry. When the tentacles are retracted the ploys will often be apparent.

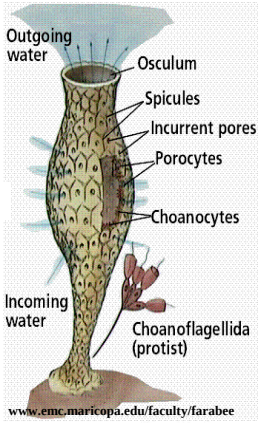
Briareum asbestinum

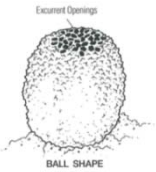


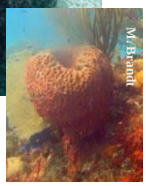
Encrusting form is the purple and brown on the bases of the colony. Top arrow indicates where tentacles are extended, bottom arrow indicates where tentacles are retracted. Yellow is live stony coral.

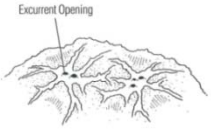
SPONGES

General sponge anatomy:

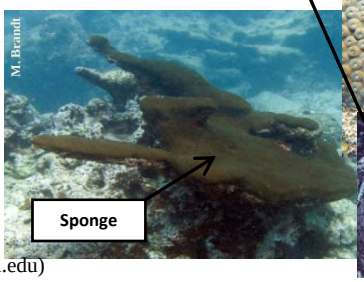


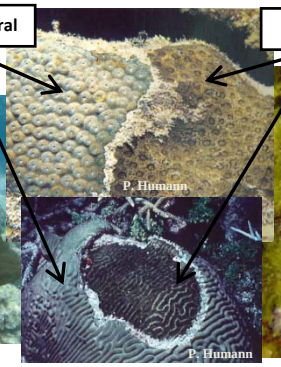


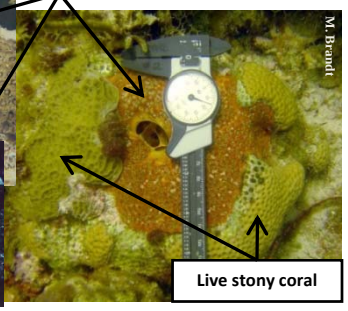




Encrusting sponges include two species of boring sponges, *Cliona langue* (left) and *C. delitrix* (right). *C. langue* is brown and appears smooth while *C. delitrix* is typically bright red with conspicuous pores and osculums.



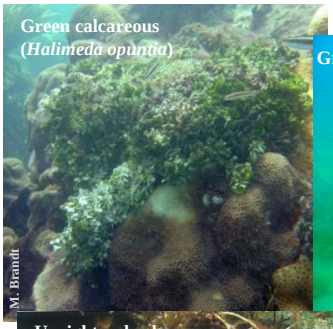


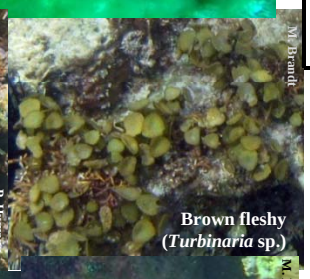


Sheets assembled by M. Brandt (mbrandt@rsmas.miami.edu)

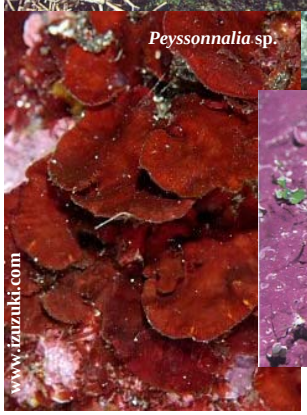
MACROALGAE

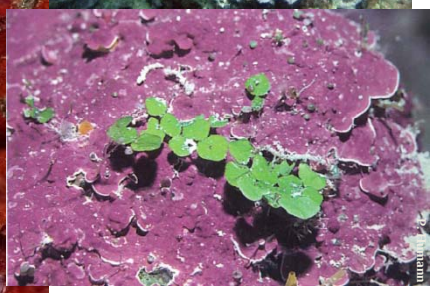
Macroalgae commonly found on hardbottom substrates:



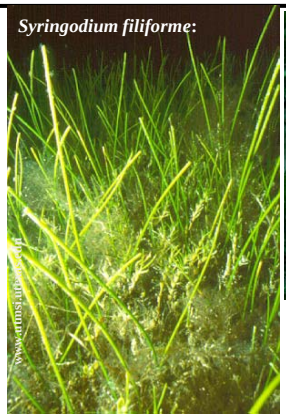


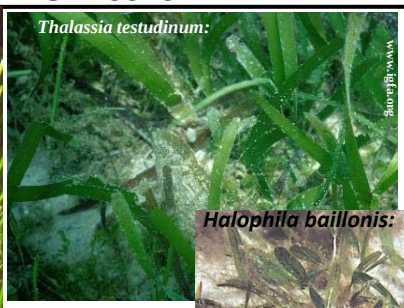
Crustose coralline algae ("algae <1cm"). Only found on hard substrates and is usually red or purple in color:

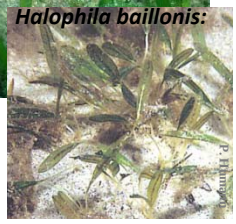




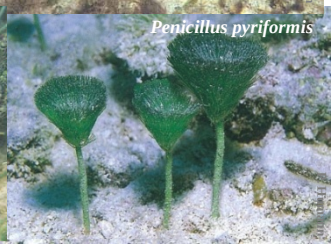
SEAGRASSES







Macroalgae commonly found on sand substrates:



"OTHER" (1)

Anemones:

Stichodactyla helianthus can occur in dense clusters and may look like stony coral. Look for flimsy edges of individuals.

Mat tunicate:

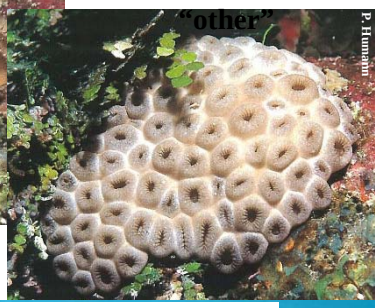
Can look like an encrusting sponge but it is a tunicate. Appears as a green mat with slits that are the excurrent openings.

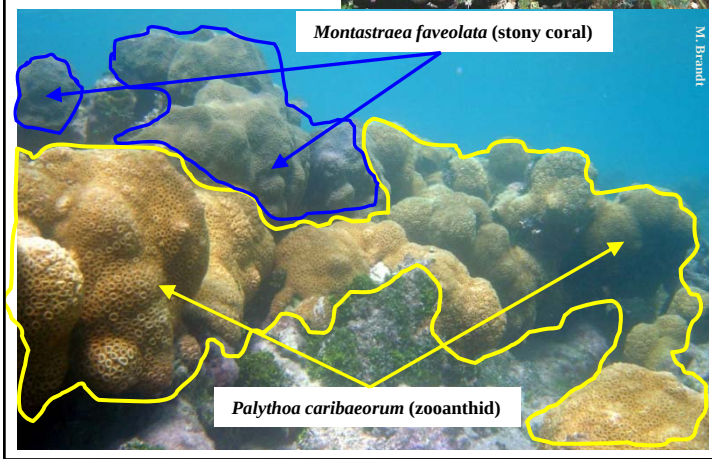
Sheets assembled by M. Brandt (mbrandt@rsmas.miami.edu)

"OTHER" (2)

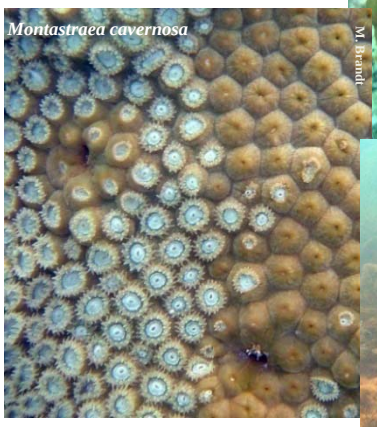
***Palythoa caribaeorum* (Order: Zooanthid):**

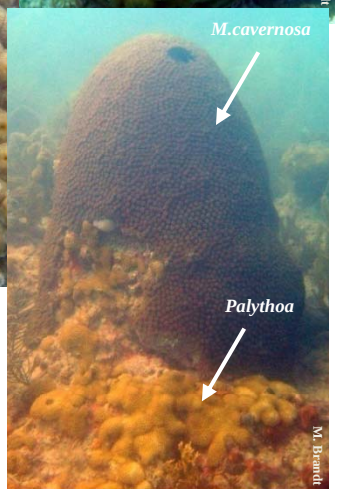
****Palythoa should be** classified as "other"**





The polyps of the stony coral *Montastraea cavernosa* (below and right) and the zooanthid *Palythoa caribaeorum* (left) look very similar.

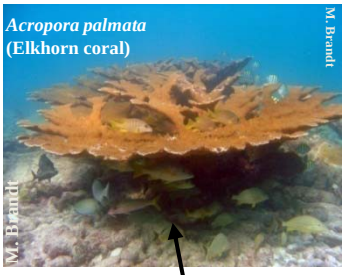


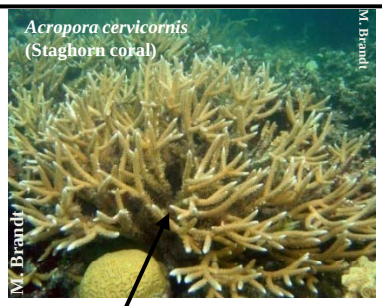


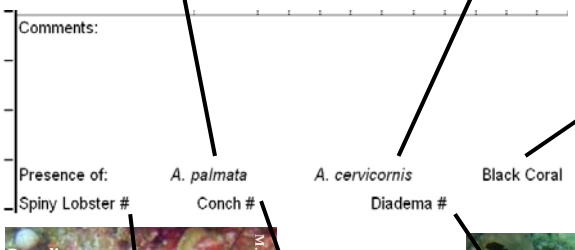
***M. cavernosa*: usually dark in color (unless bleaching). When polyps are open, the mouths are a light color. When touched, the colony feels hard and slimy.**

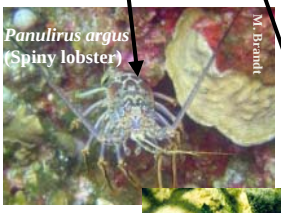
***Palythoa*: pale in color. When polyps are open, the mouths are hollow and deep. When touched, the colony feels soft and rubbery.**

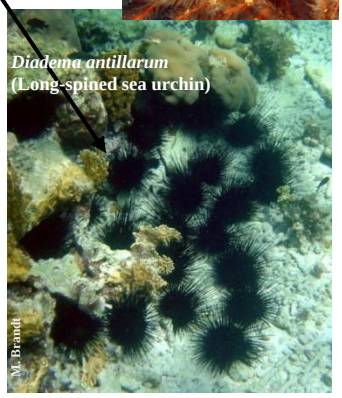
Bottom of the data sheet







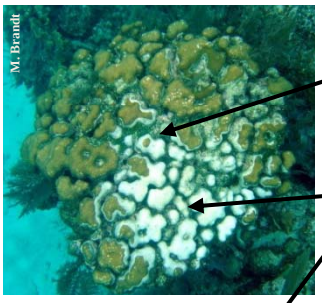




Sheets assembled by M. Brandt (mbrandt@rsmas.miami.edu)

Living vs. bleached vs. recently dead stony coral

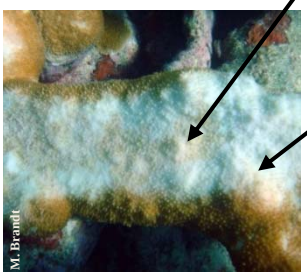
Living tissue: Corallites well defined, tentacles can sometimes be observed, no sediment on tissue.
Bleached coral: Tissue still present, algal symbionts absent or degraded giving colony a pale or bleached appearance.
Recently dead coral: Tissue absent. Sediment can settle and some algal colonization may have begun <1 day after death.
Old dead coral: Tissue absent, skeleton degraded, heavy sediment and algal colonization. Dead coral can appear alive if corallite structure not degraded (e.g., brain corals and *Montastraea cavernosa* often retain their corallite structure long after death).

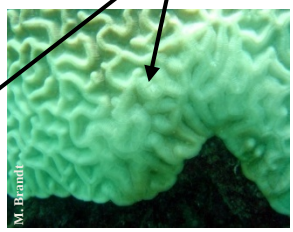


Normal living tissue

Recently dead

Bleached tissue





Appendix 3: Printable Data Sheets

The following pages are data sheets formatted so that they can be printed directly onto sheets of underwater paper for use in the field. For this reason, no page numbers or headings are included.

1st page: Field/Boat Log form

2nd page: Water Quality/Environmental Log form

3rd page: Fish/Habitat Data Sheet

Reef Fish Visual Census (RVC) FIELD/BOAT LOG

DATE _____

Page _____ of _____

Dive of Day	Site ID	Est. Time	Diver Team	Buddy Team (Diver A / Diver B)	LATITUDE deg.	LATITUDE minutes	LONGITUDE deg.	LONGITUDE minutes	Habitat Code *	GPS#	Comments

* Habitat Codes

1 - Contiguous reef, Spur-Groove
2 - Contiguous reef, Other
3 - Isolated reef structure(s)
4 - Reef Rubble
5 - Sand-Seagrass-HB matrix
6 - Artifical reef
0 - Sand

Reef fish Visual Census (RVC) - Water Quality and Environmental Log

Date:

Dive of Day	SiteID

WATER QUALITY DATA			
SurTemp (°C)	Sur Sal (ppt)	BotTemp (°C)	Bot Sal (ppt)

ENVIRONMENTAL DATA					
UW Visibility (ft) or (m)	Wind dir	Wind mph	Clouds (% cover)	Current (N,M,H)	Comments/Notes

Diver: _____	Date:	Field Number:	
Buddy: _____	Sample Start Time:	**Habitat type:**	Underwater visibility: _____ ft m
Dive Start Time: _____	Sample End Time:	1. Contiguous S&G / 4. Rubble	Water temperature: _____ F
Dive End Time:	Max Dive Depth: ft	2. Cont. Not S&G / 5. (Matrix)	Radius of cylinder: 7.5m 5.0m
	Station Depth: ft	3. Isolated / 0. (Sand)	Current: None Mod. High
	Fishing Gear:		

Substrate Slope	
Max depth _____ ft	
Min depth _____ ft	
Max vertical Relief	
Hard Relief _____ m	
Soft Relief _____ m	

Surface Relief Coverage %	Hard	Avg. of Soft
< 0.2 m	%	%
0.2-0.5 m	%	%
0.5-1.0 m	%	%
1.0-1.5 m	%	%
> 1.5 m	%	%
TOTAL	100%	100%

Abiotic Footprint	
SAND	%
HARD-B	%
RUBBLE	%
Total	100%

Biotic Cover - Dominant Biological Cover %			
SAND		HARDBOTTOM	
"Bare"		~~Crustose Algae~~	
~~Algal Turf (<1cm)~~		Algae (<1cm)	
Macro Algae		Algae (>1cm)	
Sea grass		Live Stony Coral	
Sponge		Octocoral	
_____ Other 1		Sponge	
_____ Other 2		_____ Other 1	
		_____ Other 2	
TOTAL	100%		100%

Species	N	Avg	Min	Max

Species	N	Avg	Min	Max

Comments:

Presence of: *A. palmata* *A. cervicornis* Black Coral

Spiny Lobster # Conch # Diadema #

Appendix 4: Benthic Habitats of the Florida Keys

The following is the metadata directly obtained from NOAA's website that accompanies the original thematic benthic habitat map layers of the South Florida region. These layers were developed by a cooperative effort between NOAA and the Florida Department of Environmental Protection and published as a Florida Marine Research Institute technical report (FMRI 1998). Further information can be found at: http://flkeysbenthicmaps.noaa.gov/welcome.html.

Benthic Habitats of the Florida Keys

Metadata for Florida Keys Benthic Habitats digital geography

last updated July 1998

Digital geographies are in geographic coordinates, datum = NAD83, spheroid = GRS1980.

GENERAL INFORMATION	
Name:	BENTHIC_G
Title:	FLORIDA KEYS AND BISCAYNE BAY BENTHICS
Library:	BENTHIC
Feature Type:	POLYGON
Geographic Extent:	THE FURTHERMOST WESTERN BOUNDARY OF THE FLORIDA KEYS NATIONAL MARINE SANCTUARY (DRY TORTUGAS) NORTH TO WHERE 215TH STREET NORTHEAST IN DADE COUNTY INTERSECTS BISCAYNE BAY
Creation Date:	UNKNOWN
Projection:	GEOGRAPHIC COORDINATES, DECIMAL DEGREES, NAD83
Precision:	SINGLE
Datum:	NORTH AMERICAN DATUM OF 1983
Accuracy:	ACCURACY OF DISCRETE POINTS IS WITHIN TWO METERS. SHORELINE AND REEF HABITATS HAVE AN ACCURACY OF FIVER METERS. SEAGRASSES AND OTHER LESS RESISTANT HABITATS HAVE AN ACCURACY OF 10 METERS.
Purpose:	TO VISUALLY REPRESENT GEOSPATIAL DATA.
Description - Abstract:	POLYGON GEOGRAPHY TO VISUALLY REPRESENT THE BENTHIC HABITATS GEOSPATIAL DATA OF SOUTH FLORIDA.
Report last modified:	19980521

DATA SOURCE INFORMATION	
Organization:	FISH and WILDLIFE RESEARCH INSTITUTE
Contact:	KATHLEEN O'KEIFE
Address:	100 8TH AVENUE S.E., ST. PETERSBURG, FL 33701-5095
Phone Number:	727/8968626
Electronic mail:	Kathleen.OKeife@MyFWC.com
Scale:	UNKNOWN

Projection:	GEOGRAPHIC COORDINATES, DECIMAL DEGREES, NAD83
Precision:	SINGLE
Datum:	NORTH AMERICAN DATUM OF 1983
Accuracy:	ACCURACY OF DISCRETE POINTS IS WITHIN TWO METERS. SHORELINE AND REEF HABITATS HAVE AN ACCURACY OF FIVER METERS. SEAGRASSES AND OTHER LESS RESISTANT HABITATS HAVE AN ACCURACY OF 10 METERS.
Source Format:	UNKNOWN.

DISTRIBUTION INFORMATION	
QA/QC Status:	COMPLETE
Distribution Status:	AVAILABLE
Data Format:	ARC/INFO EXPORT FILE (.e00), ARCVIEW SHAPEFILE
FWRI Contact:	KATHLEEN O'KEIFE
FWRI Address:	FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION, FISH AND WILDLIFE RESEARCH INSTITUTE, 100 8TH AVENUE S.E., ST. PETERSBURG, FL 33701-5095
FWRI Phone:	727/896-8626

Minimum mapping unit = 0.4 hectare (1 acre) for all habitat. Patch reefs may be <0.5 ha.

DATA DICTIONARY		
Polygon attributes used in Benthic Habitat geography		
01. Item: A_CODE	ALPHA CODE FOR THE BENTHIC HABITATS	
	Type: Character	
	Length: 5	
	Decimals: 0	
	Format: N/A	
	Mandatory: N	
	Default Values: N/A	
	Item Values:	
	BM	CARBONATE MUD
	BMd	CARBONATE MUD; DREDGED/EXCAVATED
	BO	ORGANIC MUD
	BS	CARBONATE SAND
	BSb	CARBONATE SAND; BANKS
	BSd	CARBONATE SAND; DREDGE/EXCAVATED
	BUd	BOTTOM UNKNOWN; DREDGED/EXCAVATED
	CB	BACK REEF
	CPA	AGGREGATED PATCH REEFS
	CPB	CORAL PATCHES IN BARE SAND

	CPH	HALO
	CPI	INDIVIDUAL PATCH REEF
	CPIH	INDIVIDUAL PATCH REEF AND HALO
	CPR	REMNANT REEF
	CPSD	REEF CONTAINING DROWNED SPUR AND GROOVE
	CPSS	REEF CONTAINING SHALLOW SPUR AND GROOVE
	CR	REEF RUBBLE
	h2o	UNCLASSIFIED OCEANIC WATER
	HC	SOFT CORAL,SPONGES,ALGAE
	HCb	SOFT CORAL,SPONGES,ALGAE; BANKS
	HS	HARDBOTTOM WITH PERCEPTIBLE SEAGRASS
	HSb	HARDBOTTOM WITH PERCEPTIBLE SEAGRASS; BANKS
	HSd	HARDBOTTOM WITH PERCEPTIBLE SEAGRASS; DREDGRED/EXCAVATED
	InW	UNCLASSIFIED INLAND WATER
	LAND	LAND
	SD	MODERATE TO DENSE, CONTINUOUS BEDS
	SDb	MODERATE TO DENSE, CONTINUOUS BEDS; BANKS
	SDd	MODERATE TO DENSE, CONTIUOUS BEDS; DREDGED/EXCAVATED
	SDdr	MODERATE TO DENSE, CONTIUOUS BEDS; DREDGED/EXCAVATED; RESTORATION
	SDr	MODERATE TO DENSE, CONTIUOUS BEDS; RESTORATION
	SDB	MODERATE TO DENSE, CONTIUOUS BEDS WITH BLOWOUTS
	SDBb	MODERATE TO DENSE, CONTINUOUS BEDS WITH BLOWOUTS; BANKS
	SDBd	MODERATE TO DENSE, CONTIUOUS BEDS WITH BLOWOUTS; DREDGED/EXCAVATED/RESTORATION
	SDBdr	MODERATE TO DENSE, CONTIUOUS BEDS; DREDGED/EXCAVATED; RESTORATION
	SDBr	MODERATE TO DENSE, CONTIUOUS BEDS WITH BLOWOUTS; RESTORATION
	SPA	LARGELY MACROALGAL COVER WITH SCATTERED SEAGRASS PATCHES
	SPAb	LARGELY MACROALGAL COVER WITH SCATTERED SEAGRASS PATCHES; BANKS
	SPH	DENSE PATCHES OF SEAGRASS (>50%) IN A MATRIX OF HARDBOTTOM
	SPHb	DENSE PATCHES OF SEAGRASS (>50%) IN A MATRIX OF HARDBOTTOM; BANKS
	SPHd	DENSE PATCHES OF SEAGRASS (>50%) IN A MATRIX OF HARDBOTTOM; DREDGED/EXCAVATED
	SPP	DOMINANTLY SAND OR MUD WITH SMALL SCATTERED SEAGRASS PATCHES (<50%)
	SPPb	DOMINANTLY SAND OR MUD WITH SMALL SCATTERED SEAGRASS PATCHES (<50%); BANKS
	SPPd	DOMINANTLY SAND OR MUD WITH SMALL SCATTERED SEAGRASS PATCHES (<50%); DREDGED/EXCAVATED
	SPS	DENSE PATCHES OF SEAGRASS IN A MATRIX OF SPARSE SEAGRASS
	SPSb	DENSE PATCHES OF SEAGRASS IN A MATRIX OF SPARSE SEAGRASS; BANKS

	SS	SPARSE, CONTINUOUS BEDS
	SSb	SPARSE, CONTINUOUS BEDS; BANKS
	U	UNMAPPABLE/UNKNOWN BOTTOM
02. Item: AREA_METER	AREA OF BENTHIC HABITAT IN SQUARE METERS	
	Type: Integer	
	Length: 16	
	Decimals: 0	
	Format: N/A	
	Mandatory: N	
	Default Values: 0	
	Item Values: N/A	

ADDITIONAL METADATA - 1	
Benthic Habitats of the Florida Keys Classification System (Data Dictionary)	
Cross Reference Table of ARCINFO benthic_g geography and the ArcView Project files.	
The benthic habitat types found in the ArcView project files are provided below. Listed in parentheses with each benthic habitat type is the equivalent a_code(s) found in the ARCINFO benthic habitat geography.	
Within the ArcView project, benthic habitat modifiers (b - banks; d - dredged/excavated; r - restoration) are provided as a separate thematic layer. As a result, they are not included in this list.	
Also within the ArcView project, land (LAND) is provided as a separate thematic layer. As a result, it is not included in this list.	
ArcView Shape File Polygon Type	A_CODE in the BENTHIC_G ARCINFO geography
Bare Substrate - Carbonate Mud	BM
Bare Substrate - Carbonate Sand	BS
Bare Substrate - Organic Mud	BO
Continuous Seagrass - Dense Patches in a Matrix of Sparse Seagrass (<50%)	SPS
Continuous Seagrass - Moderate to Dense	SD
Continuous Seagrass - Sparse	SS
Hardbottom - Perceptible Seagrass (<50%)	HS
Hardbottom - Soft Corals, Sponges, Algae	HC
Inland Water	InW
Patch Reefs - Aggregated	CPA
Patch Reefs - Aggregated with Halo	CPIH
Patch Reefs - Coral or Rock Patches with Bare Sand	CPB
Patch Reefs - Halo	CPH
Patch Reefs - Individual	CPI
Patchy Seagrass - Dense Patches in a Matrix of Hardbottom	SPH
Patchy Seagrass - Moderate to Dense with Blowouts	SDB
Patchy Seagrass - Predominantly Microalgae Cover with Scattered Seagrass Patches	SPA
Patchy Seagrass - Predominantly Sand and-or Mud with Small, Scattered Seagrass Patches (<50%)	SPP

Platform Margin Reefs - Back Reef	CB
Platform Margin Reefs - Drowned Spur and Groove	CPSD
Platform Margin Reefs - Reef Rubble	CR
Platform Margin Reefs - Remnant - Low Profile	CPR
Platform Margin Reefs - Shallow Spur and Groove	CPSS
Unknown Bottom	BU; U

More Metadata - 2					
Descriptions of Benthic Habitats found in both the benthic_g ARCINFO geography and the ArcView project files.					
I. Coral Reefs					
	A. Patch Reefs				
		Discrete coral communities, typically dome-shaped, usually outside of Hawk Channel, with a few inshore. Can be linear features where several or a series occurs. Mostly off Key Largo and Elliot Key (5,000) with a few off Big Pine, near Key West, and at the Dry Tortugas. Usually composed of hard corals Montastraea sp., Siderastrea sp., Diploria sp., and Colpophyllia sp.. Often surrounded by a whitish appearing halo.			
		1. Individual Patch (CPI)			
			Isolated, barely visible on aerial photography, with or without a halo.		
		2. Aggregated patch reefs (CPA)			
			More than one, usually too close together to map individually or where halos coalesce.		
		3. Halo (CPH)			
			Barren, essentially unvegetated, variable, whitish zone around patch reef resulting from grazing activity of urchins and fishes. Rubble from weathering of patch reef may allow attachment sites for corals to expand the colony. Not always present or large enough to be mapped.		
		4. Individual Patch Reef and Halo (CPIH)			
			Patch reef and halo combination too small to delineate directly on aerial photography. Delineations of reef and halo performed during compilation.		
	B. Platform Margin Reef				
		Generally, the "reef tract" or "barrier reef." Extends from northern boundary of the Florida Keys National Marine Sanctuary to west of the Marquesas Keys and also found at the Dry Tortugas. Diverse communities variable in morphology and species composition. Both high and low relief. Includes all coral/hardbottom features distinguishable from "patch reefs."			
		1. Spur and Groove			
			a. Shallow (e.g., Looe Key) (CPSS)		
				Well developed systems on "fore-reef" at major bank reefs on reef tract, with vertical relief to about 4m. Actively growing upward and outward. Distinctive signature on aerial photography due to shallow water (0 - 10m) and high vertical relief. Linear length to approximately 1000m or more.	
			b. Drowned (Transitional = older, drowned) (CPSD)		
				Older, not actively growing (probably eroding) features often being buried by sand migration from shallower zone of reef tract. Nearly typical spur and groove signature in aerial photographs, but sometimes with less resolution or definition. Usually low profile, about 0.5 - 1.5m. Visible to interpretable depth of photography (10m). Often greater linear length than shallow spur and groove.	
		2. Remnant - Low profile (CPR)			

			Coral/hardbottom features not exhibiting distinctive signature of spur and groove reefs. Usually parallel to line of reef tract, but may form transverse features perpendicular to the reef tract. Relief from less than 0.5m - 1 or 2m.
	C. Coral Patches in Bare Sand (CPB)		
		Very sparse features that are similar in nature to patch reefs, but are on the outer reef tract. These areas are dominantly sand or a veneer of sand over low relief rock. Scattered throughout are small patches ranging from a single gorgonian, sponge, or small coral head up to a low assemblage that may be a few meters to 10m across. These patches make up a low percentage of the total cover, yet are distinctive. This class is found mainly in the area from Big Pine Shoal to Sombrero Light, and may be associated with the lack of a developed forereef structure in this area.	
	D. Back Reef (CB)		
		Shallow (<2m) platform landward of spur and groove features on bank reefs, typically rubble zone colonized with numerous soft corals and pioneering staghorn, fire and other hard corals. Corals here are widely spaced individuals on a rubble platform.	
	E. Reef Rubble (CR)		
		Zone landward of bank reefs and other high energy reef tract areas where unstable rubble exists with little or no visible colonization. In relatively shallow water (1 - 6m) often in association with Thallassia or Syringodium. Signature on the aerial photographs is distinctive from other coral/hardbottom communities. May form transverse features perpendicular to line of reef tract.	
II. Hardbottom (Inshore only, stops at Hawk Channel for the Florida Keys National Marine Sanctuary)			
	Solid, flat, low-relief substrate composed of Key Largo limestone (from west end of the Newfound Harbor Keys off Big Pine to the north edge of the Florida Keys National Marine Sanctuary) or Miami oolite (Big Pine Key and west). Depth ranges from intertidal to approximately 7m in deep tidal channels and the inside edge of Hawk Channel. May include a thin veneer of carbonate sand or mud, too thin and unstable to support seagrass.		
	A. Soft Coral, Hard Coral, Sponge, Algae (HC)		
		Benthic community (no perceptible seagrass) is variable and typically a function of sediment, water, depth, and exposure to wind and current. May also include solitary hard corals, Porites sp., Sideratrea sp., and Manicina sp.. Shallowest zones (<1m) may include only attached or drift algae; soft corals are usually more common in deeper zones.	
	B. Hardbottom with perceptible seagrass (<50%) (HS)		
		Usually in patches, seagrasses occur in depressions and basins where adequate sediment has accumulated, but constitute <50% bottom coverage. Hard bottom may include solitary hard corals and soft corals, but most often sponges and benthic algae (attached or in draft).	
III. Bare Substrate			
	Open and essentially unvegetated, with no benthic community visible on photographs, due to unstable nature of substrate. Can be large seagrass blowouts or active erosional features. Largest areas are on reef tract, in the bottom of Hawk Channel and west of the Marquesas Keys. May have sparse, ephemeral benthic algae or diatom films that are not detectable on photography. Diatom films may develop in a few days.		
	A. Carbonate Sand (usually exposed locations) (BS)		
		Sand-size carbonate sediments, usually in areas exposed to current and wind energy that continually sort out and remove finer sediment fractions.	
	B. Carbonate Mud (usually protected location) (BM)		
		Fine carbonate sediments in deep water (Hawk Channel) or locations protected from wind and wave energy. More depositional than erosional.	
	C. Organic Mud (BO)		

			On windward shorelines where drift seagrass and algae builds up in intertidal and shallow water. Continual deposition and resuspension of organic matter limits development of benthic community on natural as well as disturbed shorelines. Especially common feature on windward shorelines of Big Pine, No Name, and Little Pine Keys.
IV. Seagrass			
	A. Moderate to Dense, continuous beds (SD)		
			Solid, continuous Thalassia, Syringodium, and Halodule, individually or in mixed beds. Widespread in occurrence with range in depth from intertidal (bank) to approximately 10m.
	B. Moderate to Dense, nearly continuous beds (seagrass>50%), with blowouts and/or sand or mud patches. (SDB)		
			Solid, continuous Thalassia or Syringodium, rarely Halodule, individually or in mixed beds. Widespread in occurrence with range in depth from intertidal (bank) to approximately 10m. Moderate to high energy regimes. Here, blowouts or patches are dispersed as holes in otherwise continuous seagrass beds. Usually found on reef tract and near entrances to tidal channels and passes. A common habitat in back country of middle keys with large water movements between the Gulf of Mexico and Atlantic Ocean.
	C. Sparse, continuous beds (SS)		
			Areas where seagrasses occur in low density (<50 shoots/m sq.). Typically in shallow protected bays where physical conditions or substrate limits development. May be hard to distinguish signature on aerial photographs from barren bottom, requiring ground truthing.
	D. Patchy		
			Typically the result of depressional basins or creek-like features in seabed that accumulate sediment or contain organic peat deposits from mangrove community occurring during lower sea level. This greater depth of sediment allows seagrass development in an area, or allows denser seagrasses compared to surrounding areas. Widespread feature in inshore areas throughout the Florida Keys National Marine Sanctuary and Biscayne Bay.
		1. Dense patches of seagrass (>50%) in a matrix of Hardbottom. (SPH)	
			One of the most common habitat types; patches occur in areas where a thin sediment layer over flat natural rock precludes development of seagrasses. Often numerous in number, highly visible on aerial photographs.
		2. Dense patches of seagrass in a matrix of sparse seagrass. (SPS)	
			Depressional features with deep sediment allow denser development of seagrasses than on surrounding bottoms where only a thin layer may be present. May be difficult to discern on aerial photographs from seagrass patches in hardbottom. May occur more in deeper water or protected bays.
		3. Dominantly sand or mud with small scattered seagrass patches (<50%). (SPP)	
			Large sand features with recognizable seagrass patches. Similar location to seagrass with blow-outs. Substrate may vary from sand to mud, and algae, either fixed or drift, may be a significant component. Offshore features tend to be more sandy, and inshore protected areas tend to be muddier in composition.
		4. Largely MacroAlgal cover with scattered seagrass patches. (SPA)	
			Scattered seagrass patches are a significant habitat component, but dominant is background of macroalgae. Algal cover is banks of Halimeda sp. or Pencillus sp. May be difficult to delineate on aerial photographs without ground truthing.
V. Special Modifiers			
	Special Modifiers are attached to a specific community type when applicable. Ex. SDb; BSDBr		
	A. Banks (Xb)		

		Intertidal seagrass and some hardbottom communities, even if only intertidal at spring low tides, often open water features or extending out from a shoreline. Distinctive signature on aerial photographs compared to surrounding bottom. Sometimes burned off patches are present on bank top. If these patches become large enough, they are mapped as separate bare areas.
	B. Dredged/Excavation (Xd)	
		Those locations where dredging or excavation has occurred for channels, rock mines, or anchorages.
	C. Restoration (Xr)	
		Site of fill placement or backfilling of dredged area to restore original elevations and intertidal or benthic community. Modifier applied to resulting benthic community. Local knowledge of restoration sites necessary.
VI. Bottom Unknown, Unmappable, or Uninterpretable (BU; U)		
	This refers to those areas that are beyond the depth threshold of the aerial photography (approximately 9m), and/or uninterpretable due to glare, or turbid waters. Most narrow or deep access channels such as Key West Harbor, Hawk Channel, or the deeper sides of the reef tract.	

(top)

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http://flkeysbenthicmaps.noaa.gov/data/gis_files/benthic_habitats.html

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