The Opportunities and Challenges in Development of a Multi-agency Program to Monitor and Assess Reef Fish Populations in the Florida Keys Coral Reef Ecosystem

MARILYN BRANDT[1,2,3*], NATALIA ZURCHER[2], ANDREA ATKINSON[3], ALEJANDRO ACOSTA[4], JERALD S. AULT[2], JAMES A. BOHNSACK[5], MIKE W. FEELEY[4], DOUGLAS E. HARPER[5], JOHN H. HUNT[4], GREGORY T. KELLISON[5], DAVID B. MCCLELLAN[5], MATT E. PATTERSON[3], and STEVEN G. SMITH[2]

[1]*University of the Virgin Islands,Center for Marine and Environmental Studies, 2 John Brewers Bay, St. Thomas, VI 00802*
[2]*University of Miami, Rosenstiel School of Marine and Atmospheric Science, 4600 Rickenbacker Cswy, Miami, FL 33149*
[3]*National Park Service, South Florida/Caribbean Network, 18001 Old Cutler Rd., Suite 419, Palmetto Bay, FL 33157*
[4]*Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, South Florida Regional Lab 2796 Overseas Hwy., Suite 119, Marathon, FL 33050*
[5]*National Oceanic and Atmospheric Administration, Southeast Fisheries Science Center, 75 Virginia Beach Drive Miami, FL 33149*

ABSTRACT

Reef fish populations are conspicuous and essential components of coral reef ecosystems, but monitoring strategies have historically varied across agencies in their objectives and designs. An unprecedented multi-agency reef fish monitoring effort involving NOAA Fisheries, the University of Miami, the National Park Service and the Florida Fish and Wildlife Conservation Commission was initiated across the Florida coral reef ecosystem in 2008. This collaboration builds directly upon a large-scale fisheries-independent survey that began in 1979. The methods are directed to address precipitous declines in fishery resources, understand variability in natural processes, and to evaluate new ecosystem-based management tools like MPAs. There is significant motivation to address the biological, political, economic, and legal issues of these objectives through a shared vision for monitoring and assessment. In this study, precise and cost-effective sampling was achieved by collaborative surveying across the heterogeneous reef landscape using a two-stage habitat-stratified random sampling design. The realized efficiencies and benefits of the multi-agency collaboration significantly outweighed the costs and difficulties encountered along the way.

KEYWORDS: Reef fish monitoring, fisheries-independent assessment, fish habitat relationships, multi-agency collaboration, ecosystem-based management

Oportunidades y Desafíos en el Desarrollo de un Programa Interinstitucional para el Seguimiento Poblacional de Peces en el Ecosistema Arrecifal de los Cayos de la Florida

Las conspicuas poblaciones de peces arrecifales constituyen un elemento esencial del ecosistema coralino. Sin embargo, las estrategias de seguimiento han variado históricamente en objetivo y diseño entre las instituciones responsables. En el año 2008, una iniciativa sin precedentes logró que instituciones como la Administración Nacional Oceánica y Atmosférica, la Universidad de Miami, el Servicio de Parques Nacionales y la Comisión para la Conservación de Peces y Fauna de la Florida se unieran con el objetivo de darle seguimiento a las poblaciones de peces en el ecosistema arrecifal de los cayos de la Florida. Esta iniciativa se apoya directamente en el programa de muestreos independientes de la pesquería que comenzó en 1979. La metodología busca explicar la marcada disminución de los recursos pesqueros, entender la variabilidad de los procesos naturales y evaluar las nuevas herramientas de manejo ecosistémicas, como las áreas marinas protegidas (AMPs). Existe una importante motivación para hacer frente a esta gama de aspectos jurídicos, políticos, biológicos y económicos a través de una visión conjunta de seguimiento y evaluación, a través del trabajo colaborativo para llevar a cabo un muestreo preciso y económicamente rentable, del heterogéneo relieve arrecifal a través de un diseño muestral aleatorio estratificado del hábitat a dos niveles. Este enfoque facilita la evaluación de la actividad pesquera sobre la sostenibilidad de la población y el uso de diseños innovadores de AMPs. Igualmente, permite una mejor comprensión de las relaciones espacio-temporales entre la variabilidad natural en las comunidades de peces de arrecife y la calidad del hábitat. Los beneficios y la eficiencia alcanzada gracias a la colaboración interinstitucional superan significativamente los costos y las dificultades encontradas a lo largo del camino.

PALABRAS CLAVES: Peces arrecifales, el programa de muestreos independientes, herramientas de manejo ecosistémicas

Les Occasions Et Défis Dans Le Developpement D'un Programme Multi-Agence de Surveillance Et D'évaluation des Populations de Poissons Coralliens Dans L'écosystème de Récifs Coralliens des Keys de Floride

Les populations de poissons coralliens sont visibles et des composants essentiels des écosystèmes de récifs coralliens, mais des stratégies de contrôle ont historiquement varié selon les organismes dans leurs objectifs et conceptions. Un effort sans précédent de surveillance de poissons coralliens multi-agence, impliquant la NOAA Fisheries, l'Université de Miami, le National Park Service et la Florida Fish and Wildlife Conservation Commission, a été initié dans tout l'écosystème des récifs coralliens de Floride en 2008. Cette collaboration se fonde directement sur une enquête indépendante de pêcherie qui a commencé en 1979. Les méthodes sont dirigées pour aborder la baisse précipitée des ressources de pêcherie, de comprendre la variabilité dans les processus naturels, et d'évaluer un nouvel écosystème basé sur les outils de gestion comme les AMP. Il y a une motivation importante pour remédier à ces questions juridiques, politiques, biologiques et économiques à travers une vision partagée pour le suivi et l'évaluation. Dans cette étude, un échantillonnage précis et économique a été obtenu par la réalisation d'une enquête collaborative à travers le paysage corallien hétérogène en utilisant un modèle d'échantillonnage aléatoire d'habitat stratifié de deux étapes. Cette approche d'enquête

facilite l'évaluation des impacts de pêcherie sur la viabilité de la population et les capacités de modèle innovatrices pour MPAs. L'approche tient compte aussi de la compréhension améliorée de rapports spatiotemporels entre la variabilité naturelle dans les communautés de poissons coralliens et la qualité de l'habitat. Les efficacités réalisées et les avantages de la collaboration multi-agence sont plus importantes que les coûts et les difficultés rencontrées en cours de route.

MOTS CLÉS: Surveillance de poisson corallien, évaluation indépendante des pêcheries, relations habitat poisson, collaboration multi-agence, gestion basée sur l'écosystème

INTRODUCTION

Although intensively managed, the Florida reef ecosystem is considered one of the most stressed ecosystems in the United States (Porter *et al*. 1999). Stressors in the last few decades have included hurricanes, coral bleaching events, and intensive coastal development due to the exponential growth of Florida's human population and a high volume of tourism (Porter *et al*. 1999). Fishing activities occurring in the waters of the Florida Keys include both commercial and recreational, but, 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). Reef fish populations represent one of the most valuable but also most threatened resources of the Florida Keys.

In the past, reef fisheries management has focused on attaining maximum yields for individual species. The failure of these schemes led to the evolution of the concept of ecosystem-based management where resources are sustainably managed through efforts aimed at maintaining the integrity of the entire ecosystem, not just one or two species of interest (Grumbine 1994). Implementing ecosystem-based management strategies has proved challenging because it can require significant changes in the thinking, communication, and organization of the agencies involved (Crowder *et al*. 2006). Key components of ecosystem-based management are interagency collaboration and data collection (Grumbine 1994), which are often complicated by a myriad of differing objectives, methods and operational requirements and a lack of funding and clear-cut linkages among government agencies (Nixon 1996). Yet the benefits of a regional collaboration ultimately outweigh the potential conflicts and difficulties encountered along the way (Rosenberg and McLeod 2005). These benefits are well known and include an increased understanding of ecosystems, research that is applied at appropriate scales, the opportunity to identify and advance shared priorities, and the maximization of limited resources (Coleman 2009). What is at stake is a multi-million dollar fishing and recreational industry dependent on the health and stability of coral reef fish communities. Here we document the successful collaborative effort among government and university groups to comprehensively monitor the reef fish populations of the Florida Keys and Dry Tortugas.

Background on Reef Fish Management and Monitoring in the Florida Keys

As with all coastal regions in the state of Florida, 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 areas with varying degrees of protection 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 (18 mi^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 (218 mi^2). Most recently, in 2007, the National Park Service designated a 119 km^2 (46 mi^2) area within Dry Tortugas National Park as a Research Natural Area, which also prohibits anchoring and extraction. Therefore, three primary governmental entities are responsible for fisheries monitoring on the Florida Keys reef tract: the Florida Fish and Wildlife Conservation Commission, the National Oceanic and Atmospheric Administration, and the National Park Service.

In 1979, the National Oceanic and Atmospheric

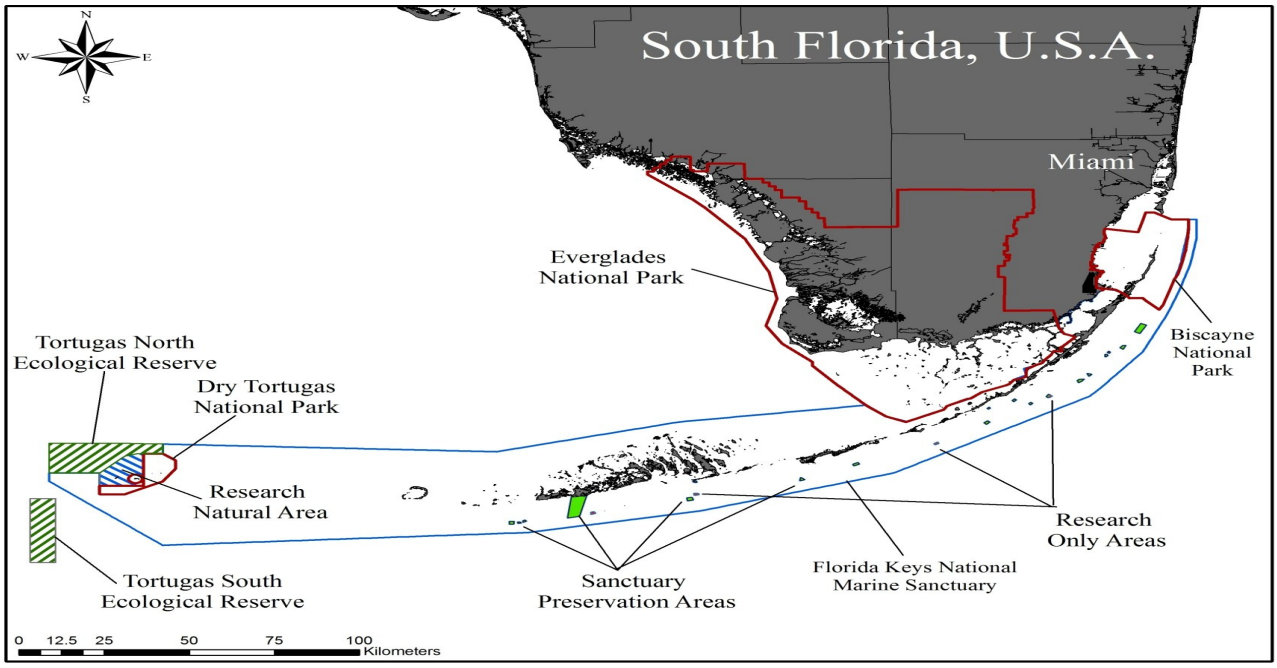

Figure 1. The multiple managed marine areas of the Florida Keys coastal marine ecosystem, including the Florida Keys National Marine Sanctuary and Biscayne National Park and Dry Tortugas National Park.

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; Ault *et al.* 2002). In 1999, the first multi-agency high-intensity survey of the Dry Tortugas took place, and approximately 941 RVC surveys 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 (given in Table 1.1 of Brandt *et al*. 2009).

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).

By 1999, the NOAA/UM-RSMAS collaboration and the FWC FIM program were independently implementing annual reef fish surveys along overlapping areas of the Florida Keys reef tract. Despite using the same foundation for collecting visual reef fish census data (the stationary point count method), some fundamental differences existed between the two methodologies and data were not shared or compared between agencies. Through time, it became clear that a combined effort would benefit both groups but there were significant challenges to collaboration at such a large scale. The process for identifying and overcoming these challenges and some details of the joint effort are documented here as an example of a successful collaborate effort aimed at providing scientifically sound data for ecosystem-based management.

Challenges Faced by the Project

Issues of scales — Reef fish populations exhibit variation in abundance and distribution at multiple scales. Management of the Florida Keys reef tract and its fisheries must be based on estimates that are relevant to the entire region, while also taking into account processes that manifest in

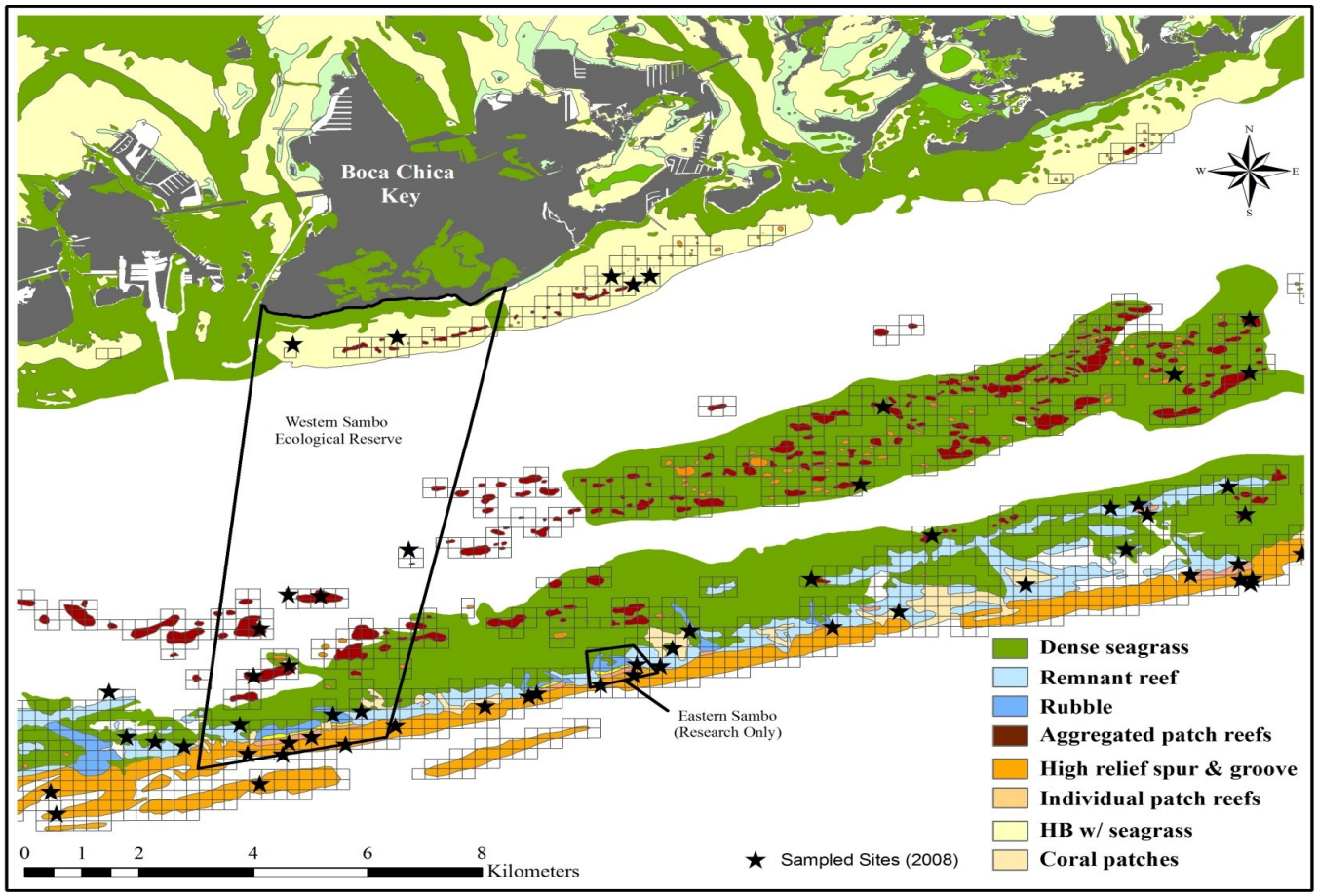

Figure 2. Benthic habitats and management zones of the reef area off of Boca Chica Key in the lower Florida Keys. The 200 x 200 m grid is laid over reef area. Stars indicate primary units that were sampled during the 2008 sampling season.

the variability in reef fish abundance and diversity observed at these multiple scales. Accomplishing sampling that is precise enough to discern changes or differences in abundance across spatial and time scales relevant to management both efficiently and with data outputs that are statistically sound requires a large-scale coordinated effort applied under a rigorous statistical design. This type of effort requires expertise, funding, and logistical abilities that are typically beyond the capabilities of a single operating agency (Marmorek and Peters 2002). However, including multiple participant agencies with differing objectives may lead to confusion, disputes, and ultimately unsuccessful outcomes (Marmorek and Peters 2002).

Issues of management — The Florida Keys coral reef ecosystem extends approximately 370 km (230 mi) from Key Biscayne near the city of Miami to the Dry Tortugas reef bank and is managed by multiple governmental agencies with numerous protected areas established within the region meant to conserve its integrity and function (Figure 1). These management areas vary in restrictiveness from those zones closed to all extraction and use with only a few exceptions (e.g., Sanctuary Preservation Areas (SPAs) in the Keys, Research Natural Area (RNA) in the Dry Tortugas) to zones that allow some limited usage (e.g., Dry Tortugas National Park, Biscayne National Park), and finally to areas almost entirely open to all extractive and recreational uses (e.g., Florida Keys National Marine Sanctuary general areas). The implementation of a system of managed areas provides the opportunity to understand the impact of various levels of management on the distribution and abundance of reef fish through time. Despite this opportunity, the difficulty in implementing synoptic surveying with statistically relevant results (i.e., high enough sample size) is high. Multiple agencies monitoring reef fish populations with varying methodologies means that each may have diminished power to detect changes early or even the possibility of presenting conflicting as constrained budgets cause different agencies to reduce sampling to only a few but often different habitats.

METHODS

Process for Achieving Consensus on Methods

Initial meetings — 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 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 (Acosta and Hunt 2008). 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. It was agreed that a common protocol would be written and shared among the agencies, and each group would begin working on specific components of the protocol.

Later in 2007, the National Park Service Inventory and Monitoring Program South Florida and Caribbean Network Office (NPS) added their cooperative support by collaborating with UM-RSMAS to fund a joint post-doctoral position whose primary focus would be protocol synchronization and writing with the aim of publishing the protocol document as part of the National Park Service Natural Resource Report series.

In early 2008, subsequent meetings were held where details of the methods for monitoring were debated and discussed with the intent to document them in the common protocol manual following the detailed guidelines of Oakley *et al*. (2003). Under these guidelines the manual would detail the shared guiding objectives of the program and the entire sampling methodology including the sample design, field preparations and training, field operations, measurements made in the field, and data entry, proofing, analysis, and finally storage and maintenance. These guidelines provided a basis for ensuring that all aspects of the effort were jointly and exhaustively identified, analyzed, agreed upon, and documented.

Barriers to method integration — At the beginning stages of collaboration, there were several sizeable roadblocks to integrating methodologies. These included aspects of how data were collected in the field, as well as how data were entered and later proofed. For example, in the field, FWC divers collected statistics on only a select list of reef fish, ignoring all others, and for these select fish species individual sizes were estimated. Meanwhile, NOAA/UM divers collected information on all fish species seen, but when more than three individuals for a species were observed, the diver then estimated the minimum, maximum and mean values for fish sizes. To continue to maintain consistency with past data from both programs, it was agreed that under the collaborative sampling methods all fish species would be identified and assessed for size following the NOAA/UM methods, but for a specific list of species (i.e., fishery-targeted species) individual sizes of fish would be recorded following the FIM methods. This would enable comparisons with previous data sets collected by both groups.

In all cases getting past the significant barriers to integration occurred through agreement to use the more detailed and/or rigorous of the two methods. By using the more detailed or rigorous of methods, the initial years of integrated sampling would be able to confirm their usefulness so that any potential modifications to simplify methods would be possible with established precedent for modification and with agreement from all groups. The use of more detailed combined methods also allowed for backward comparison with each group's existing datasets which was pivotal to the overall willingness to participate.

Year 1 implementation — The Keys-wide survey began immediately after the conclusion of the Dry Tortugas expeditions and continued into September 2008. Site surveying in the Keys consisted of daily boat trips aboard either a NOAA fisheries vessel or an FWRI vessel. Divers were predominantly NOAA fisheries personnel aboard the NOAA vessel or FWRI personnel aboard the FWRI vessel, however, intentional exchange and integration of one or two personnel from all of the agencies (including UM-RSMAS and NPS) between vessels occurred.

Protocol finalization — Throughout the field season of year one, comments and criticisms raised by field scientists and principal investigators were recorded. Most were minor and were related to misunderstanding parts of the methodologies that were not clearly defined in the protocol. Several minor issues with the data entry portal were also identified. Email exchanges during the field season and follow-up meetings focused on resolving the issues and updating the protocol elements and data entry portal to reflect any needed modifications.

Following year one implementation, the updated protocol draft was then circulated one last time to principal investigators of each agency before being sent out for review. The procedure for review followed the steps laid out for publishing in the National Park Service's Natural Resource Report series where the document was critically reviewed by three external scientist familiar with reef fish monitoring methods but not involved in the Florida Keys monitoring effort. While under review, the final draft was used as a guide to implement year 2 sampling in the

summer of 2009. Following year two implementation, reviewer comments and suggestions were incorporated, as were any minor changes suggested by field scientists. A final document was reviewed by an internal NPS administrative editor who confirmed that reviewer input was incorporated. The protocol was then accepted for publication by the Natural Resource Report series in October of 2009.

RESULTS

Joint Protocol

Common objectives — The guiding objectives of the joint reef visual census (RVC) project agreed upon by all groups are 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. Under these objectives, special attention is also paid to specific exploited reef fish species. While each agency may have their specific objectives that can vary by sampling year, the overall objectives guide the monitoring effort. These objectives and all details associated with the methodology are laid out in detail in the published protocol Brandt *et al*. 2009.

Sample Design and Methodology — The sampling domain of the project encompasses the entire Florida Keys reef tract and Dry Tortugas reef shelf, some 1153 km^2 (445 mi^2) of area (FMRI 1998). Executing a simple random survey that would result in precise enough data to detect meaningful trends would require enormous resources and time. Instead, knowledge of the system and the variance structure of existing data are used to optimize the sampling effort following a two-stage stratified random sampling design, using habitat measures and management zones to partition the domain into strata (Cochran 1977). This partitioning was accomplished by overlaying GIS spatial data layers that described the benthic habitats, bathymetry, and management domains of the Florida Keys and Dry Tortugas. A grid of 200 x 200 m cells was overlaid on top of these data layers (Figure 2), and each grid cell was assigned to a stratum based on the values of the reef data layers found within its area. The number of grid cells (primary units) to be sampled that were allocated to a stratum was based on the stratum's area and the variance structure of fish species densities developed from previous sampling (i.e., greater sample numbers were allocated to strata with higher variance and greater area). Once the number of samples for a stratum was determined, primary units were selected randomly from a list of all possible primary units for that stratum.

The *in situ* method of fish observing that is used in surveys is based on the stationary point count method of Bohnsack and Bannerot (1986), with some modifications and additions. Two sets of paired surveys take place per site, optimally separated by 20 - 60 m distance but always within the same primary unit (200 x 200 m grid cell). Diver deployment occurs either by live boating or by anchoring. Each buddy team carries a reel with a 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:

i) Field/Boat Log form data, which records where, when and by whom sites are sampled,
ii) Water Quality/Environmental Log data, which are records of the water quality and environmental data associated with each set of paired surveys, and
iii) Fish/habitat data, which are the RVC-specific data recorded by each diver.

Sequence of events in the field — In preparation for each field season, agency groups meet and determine the abilities and needs of each group for participation in field sampling. Each agency provides 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 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 are clarified early on so that all participants, regardless of agency, are aware of who should be contacted in the event of a question or issue.

A schedule is determined for all training activities that must take place prior to the start of sampling. All participants are trained in reef fish identification as well as in the ability to make the necessary habitat observations. Annual out-of-water training meetings and in-water training activities are held each year before sampling commences. Out-of-water meetings are held either jointly or independently depending on the needs of each agency and consist of overviews of sampling design, logistics, RVC methods, habitat characteristics, and data entry and proofing. In-water training is typically organized and executed by each agency independently, although exchange of personnel among agencies is encouraged.

At the start of the field season, each agency is provided a list of sites which they are responsible for sampling to the best of their abilities. Sampling schedules vary by agency and due to considerations of weather and equipment. A list of alternate sites is also 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.

Data that are collected are the responsibility of the participants and their respective agencies and are entered and catalogued by the end of the field season. Data

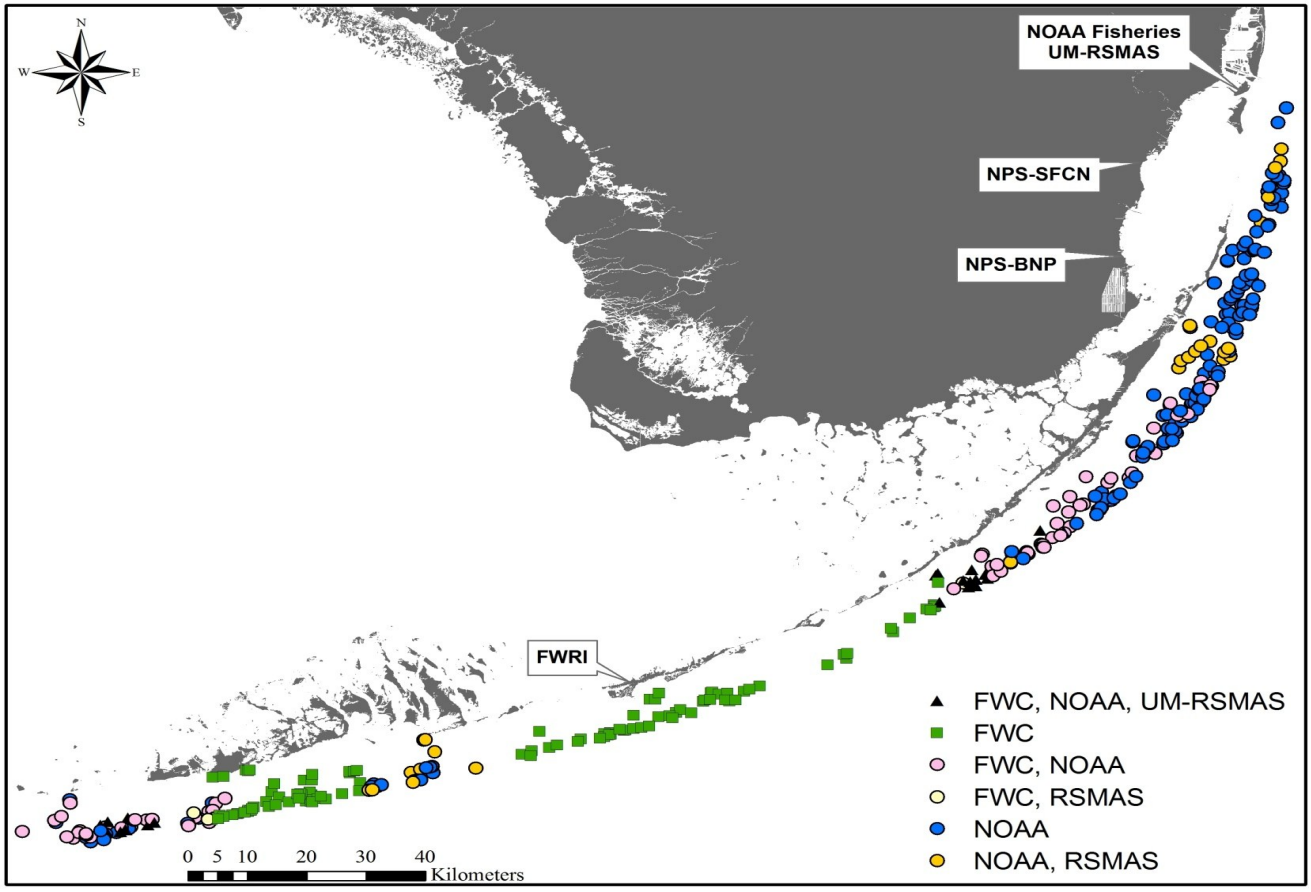

Figure 3 – Distribution of sites and the agency/agencies involved in surveying them in 2008. Locations of each agency's office are also indicated. NPS-SFCN indicates the office of the South Florida / Caribbean Network office of the National Park Service.

collected for each stationary point count are entered via the RVC Data Entry Program (RVC2.3.exe), a customized data entry portal designed for the RVC project. The computer code of RVC2.3.exe is not accessible to the user; all modifications of the program must go through a common source. Once data for the season are entered, each agency follows common proofing steps before submitting full data sets for final verification and entry into a central database.

Survey Statistics

The sampling effort by NOAA and UM-RSMAS one year prior to the collaboration consisted of 328 primary units sampled in the Florida Keys. Of these sites, NOAA surveyed 229 sites alone and 99 sites jointly with UM-RSMAS. Independently of this effort, FWRI surveyed 251 sites in the Florida Keys, all of which were surveyed aboard their own vessel under a separate sampling design. No data were shared between the NOAA/UM-RSMAS effort and the FWC effort in 2007.

In comparison, 387 primary units were surveyed in the Florida Keys in 2008, the first year of the collaborative effort. Of these sites, 258 were surveyed by members of one agency alone: 108 by FWC and 150 by NOAA. Two agencies working together surveyed 100 primary units: 69 by a joint FWC and NOAA effort, 28 by a joint NOAA and UM-RSMAS effort, and 3 by a joint FWC and RSMAS effort. The remaining 29 primary units surveyed in the Florida Keys were surveyed by FWC, NOAA, and UM-RSMAS together. Due to logistical constraints, the NPS group could not participate in the Florida Keys sampling in 2008.

Primary units were distributed to agencies in 2008 such that their locations were closer to their respective offices (Figure 3), reducing the amount of time and resources extended to survey the locations. In 2007, before collaboration, NOAA divers were on travel orders with lodging reimbursed for 25 nights during the Florida Keys summer sampling, and all sites were surveyed aboard the NOAA Fisheries research vessel. In comparison, the number of nights reimbursed to NOAA divers in 2008 was 16, and the NOAA fisheries research vessel was used to survey 236 sites primarily in BNP and the upper Keys

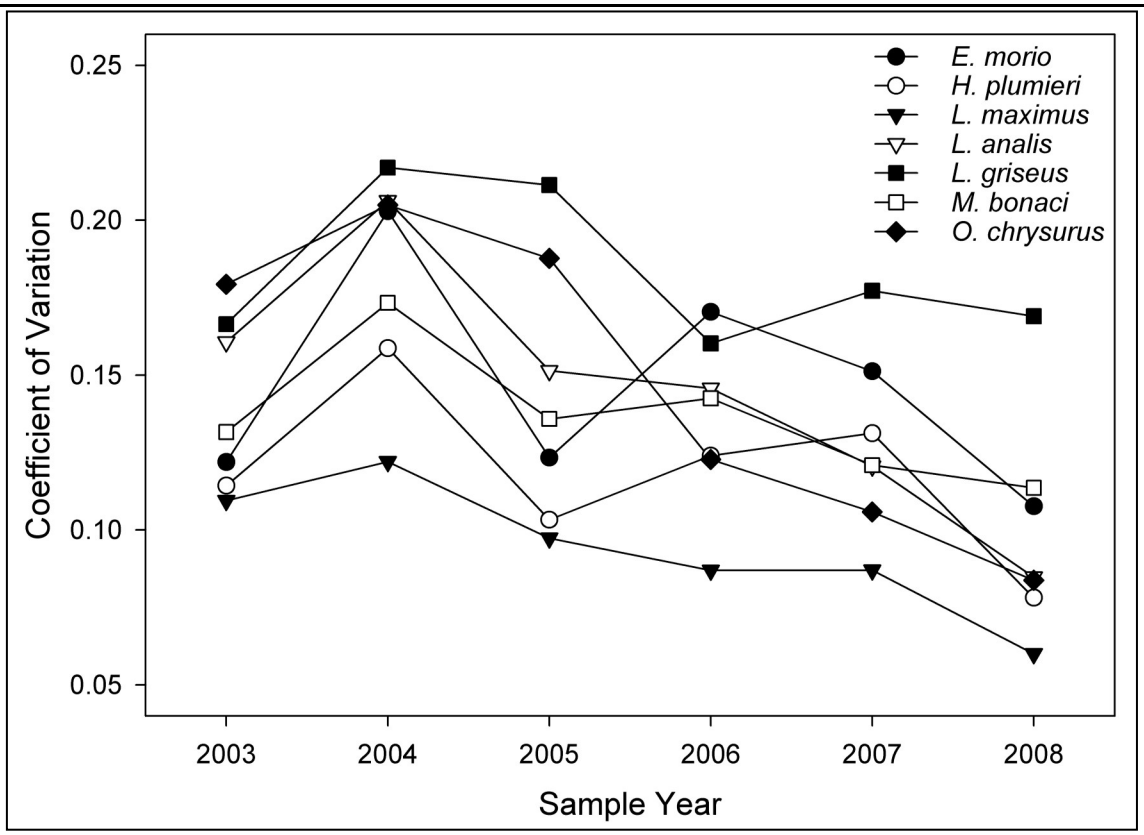

Figure 4. Calculations of the coefficient of variation (CV) for data collected by the RVC program in the Florida Keys from 2003 to 2007 for seven target economically-important species. CV is calculated as the standard error of an estimate as a proportion of the mean and is an indication of the precision of data estimates: the lower the CV the more precise the data. Data in 2003-2007 were collected by a collaboration of NOAA and UM-RSMAS while data in 2008 were collected under a collaborative multi-agency program that also involved FWC and NPS.

while the FWRI SFRL vessel was used to survey 151 sites primarily in the middle and lower Keys regions (Figure 3).

Thirty-eight scientists from all of the agencies participated in the two Dry Tortugas expeditions in 2008. A total of 343 primary units were sampled and over 1,700 scientific dives were completed. The diving effort was split fairly evenly among UM-RSMAS, FWRI, NOAA, and all other agencies. This sampling effort differed little from previous years because the time frames of the cruises and number of people that the vessel could accommodate did not change.

All data were collected, entered, and proofed using a common methodology. Final data verification took place in the spring of 2008 and the whole dataset was then subsequently distributed among all participating agencies. CVs of < 20% were achieved for seven target species in the Florida Keys in 2008 (Figure 4). These levels signified increases in precision over previous years of independent sampling by the NOAA-UMRSMAS program and FWC's FIM program (Figure 4). Yet both groups extended less effort than the previous year.

DISCUSSION

Why it Worked

Motivation — The demand for a better understanding of the extent and dynamics of the fishery resources of the Florida Keys reef tract is great in the face of increasing human pressure on the reef either directly through commercial and recreational fishing or indirectly through detrimental impacts on water quality and habitat. However, most governmental agencies tasked with managing these resources are simultaneously facing shrinking departmental budgets. Therefore, there is pressure at all levels of management to collaborate and share resources. Collaboration in this case increased the range of sampling with less effort and provided greater flexibility to meet the overall goals as a group.

Significant motivational impetus also came from the frustration of members of both groups observing the other sampling literally within meters of each other. There was an understanding that the methods of both groups were similar and that time and money could be saved through collaboration.

Common goals — Setting clear objectives is the first step to successful concurrent management of an ecosystem (Hansen *et al*. 1993). The overall objective of the RVC monitoring effort is fairly broad ("to document reef fish community composition, abundance, and size structure and determine changes in these parameters over time…"), but it envelopes the specific objectives of the involved agencies. Additionally, under the RVC program design, explicit objectives are specified in joint meetings prior to the start of the sampling season each year. This has proven to be critical to the success of a sampling year, as participation may wax or wane depending on whether an agency feels that their goals will be met by the sampling strategy for the season.

Similarly, the agencies shared common overlapping goals which aided in setting the overall objective for monitoring, which is crucial to the success of collaborative efforts (Kuska 2005). NOAA Fisheries is tasked with developing the scientific information required for fishery resource conservation and fishery development and utilization. FWC's Fisheries Independent Monitoring program is aimed at evaluating the abundance and trends of targeted commercial and recreational reef fisheries. Reef fish communities are also 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 SFCN. Therefore, all three government agencies are tasked with a responsibility to understand and report on the status and trends of exploited species in their jurisdictions. Although the jurisdictions of these agencies don't always overlap, the connectivity of the populations throughout the Florida reef tract requires that results of monitoring within one sub-region be evaluated with respect to the region as a whole. It was in the best of interests of all parties to collaborate with the sampling design lab at UM-RSMAS to efficiently and precisely assess the entire reef tract. Having common goals therefore led to the establishment of a clear objective for monitoring, and each group benefited significantly by obtaining data sets that were useful for them but which could not have been accomplished through their efforts alone.

Open communication, exchange of personnel and coordinated training — Clearly defined communication channels and opportunities to exchange experiences were also significant contributions to the success of the monitoring program. Joint workshops prior to the sampling season allowed participating divers to voice their questions and concerns on aspects of the methods. The joint cruise to the Dry Tortugas also required that members of each agency to work together, often in buddy teams, and reconcile differences in execution of the methods while in the field. This joint cruise also allowed for social interaction and trust building among members of each agency. The Florida Keys sampling, in contrast, was executed by day trips out to the reef on agency boats. All agency members were invited to participate in sampling on any boat going out, and in 2008, more than a quarter of sites were surveyed by joint efforts among 2 or more agencies (Figure 3). This joint surveying also allowed for the exchange of information and confirmation of consistent sampling among groups.

Well defined data management scheme — Uniform data collection and management standards are critical to the success of any large-scale monitoring program (Coleman 2009). In this program, the strict protocol and hierarchy for data collection, entry, proofing, storage and distribution assured a common and high standard for all data collected. Joint sampling and the exchange of agency divers during field sampling also assured that participants were following consistent data collection methods. The data entry portal used by all divers (RVC2.3.exe) was common and immutable and standardized the way in which data was archived and, more importantly, regulated for the introduction of common data entry errors. Data proofing at the level of the agency then caught many data entry mistakes, and common proofing techniques assured that all data were reviewed to the same level of intensity. Having data proofing occur at the agency-level also limited the responsibility and timing of proofing to each agency, therefore avoiding potential conflicts in distribution of work. Finally, the data verification process at the end of the season cross checked diver-entered data with boat logs and environmental logs, and with the original database of sites to be sampled. This final check ensured that sample times and locations were consistent across buddy and sample teams, and that all information was recorded for each sample. At the end, the full dataset distributed back to all agencies went through multiple checks following well-defined, highly regulated steps which ensured that the quality of the data was high. Clearly defined data managers for each agency were also found to be invaluable during the 2008 season. These designated agents became liaisons among agencies for questions, data handling, and distribution.

Protocol document — The background and all methodologies related to the joint collaborative effort were thoroughly described in the protocol document (Brandt *et al*. 2009). The formulation of this document began shortly after the completion of the 2007 workshop and was finalized in the summer of 2009. Unambiguous protocols and methods are often the most important component of large-scale monitoring efforts (Stanford and Poole 1996), and this was clearly the case here as well. The amount of time required

to prepare and finalize the document was indicative of the complexity involved in its development. Some differences in methodologies were straightforward in their resolution while others required much discussion, analysis, and ultimately compromise. The requirements laid out for documenting a protocol for use in the SFCN network of parks by Oakley *et al*. (2003) became the framework early on for how to document the steps of the monitoring program. These requirements forced the justification and description of all steps involved in the process, ultimately bringing any unacknowledged differences to light for resolution. The document was thoroughly vetted through its use during the 2008 sampling season. However, it is not assumed to be foolproof and as more information becomes available about the system or as minor issues come up, the protocol document has a list of contacts and an official process for how to update the document so that new information is recorded but old versions are properly documented.

CONCLUSIONS

The collaborative effort among government and university groups to document reef fish dynamics in 2008 marked the culmination of nearly 30 years of fishery-independent reef fish monitoring by multiple independent groups in the South Florida region. The realized efficiencies and benefits of the multi-agency collaboration significantly outweighed the difficulties of reconciling variations in methodologies and operations. The experience of this program shows that such large-scale multi-agency monitoring collaboration is possible and we hope the lessons learned about why it worked in this case study are useful to other similar efforts. Monitoring programs such as this assess the temporal and spatial patterns of change in reef fish communities at scales relevant to regional management programs and results can document and provide insight into ecosystem sustainability. The economic and ecological value of reef fish populations in the Florida Keys make this kind of understanding critical to addressing the range of biological, political, economic, and legal issues that face such valuable natural resources.

LITERATURE CITED

Acosta, A. and J. Hunt. 2008. Final Report: Development of a Comprehensive Coral Reef Ichthyofauna Research Plan. Marathon, Florida USA. 44 pp.

Ault, J.S., J.A. Bohnsack and G.A. Meester. 1998. A retrospective (1979-1996) multispecies assessment of coral reef fish stocks in the Florida Keys. *Fishery Bulletin* **96**:395-414

Ault, J.S., S.G. Smith, G.A. Meester, J. Luo, and J.A. Bohnsack. 2001. Site characterization for Biscayne National Park: assessment of fisheries resources and habitats. NOAA Technical Memorandum NMFS-SEFSC-468. 185 pp.

Ault, J.S., S.G. Smith, J. Luo, G.A. Meester, J.A. Bohnsack, and S.L. Miller. 2002. Baseline multispecies coral reef fish stock assessment for the Dry Tortugas. NOAA Technical Memorandum NMFS-SEFSC-487. 117 pp.

Bohnsack, J.A. and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Tech. Report NMFS 41 15 pp.

Brandt, M.E., N. Zurcher, A. Acosta, J.S. Ault, J.A. Bohnsack, M.W. Feeley, D.E. Harper, J.H. Hunt, T. Kellison, D.B. McClellan, M.E. Patterson, and S.G. Smith. 2009. A Cooperative Multi-Agency Reef Fish Monitoring Protocol for the Florida Keys Coral Reef Ecosystem National Park Service Natural Resource Report NPS/SFCN/NRR-2009/150. National Park Service, Fort Collins, Colorado USA.

Clark, C. 2006. Lobster fishermen stake it all on 2006 season. Miami Herald, Miami, Florida USA.

Cochran, W.G. 1977. *Sampling Techniques, 3rd Edition*. John Wiley & Sons, New York, New York USA.

Coleman, K. 2009. The Necessity of Establishing a Regional Marine Research Program for the US West Coast. *Coastal Management* **37**:136-153

Colvocoresses, J. and A. Acosta. 2007. A large-scale field comparison of strip transect and stationary point count methods for conducting length-based underwater visual surveys of reef fish populations. *Fisheries Research* **85**:130-141

Crowder, L.B., G. Osherenko, O.R. Young, S. Airame, E.A. Norse, N. Baron, J.C. Day, F. Bouvere, C.N. Ehler, B.S. Halpern, S.J. Langdon, K.L. McLeod, J.C. Ogden, R.E. Peach, A.A. Rosenberg, and J.A. Wilson. 2006. Sustainability - Resolving mismatches in US ocean governance. *Science* **313**:617-618

Davis, G.E. 1977. Anchor damage to a coral reef on the coast of Florida. *Biological Conservation* **11**:29-34

FMRI. 1998. Benthic habitats of the Florida Keys Florida Marine Research Institute Technical Report TR-4, St. Petersburg, Florida

Grumbine, R.E. 1994. What is ecosystem management? *Conservation Biology* **8**:27-38

Hansen, A.J., S.L. Garman, B. Marks, and D.L. Urban. 1993. An approach for managing vertebrate diversity across multiple-use landscapes. *Ecological Applications* **3**:481-496

Kuska, G.F. 2005. Strengthening federal interagency collaboration in the ocean policy arena: Learning from experience. Oceans 2005 Conference:1029-1036

Marmorek D. and C. Peters. 2002. Finding a PATH toward scientific collaboration: Insights from the Columbia River basin. *Conservation Ecology 5*.

Nixon, S.W. 1996. Regional coastal research - What is it? Why do it? What role should NAML, play? *Biological Bulletin* **190**:252-259

Oakley, K.L., L.P. Thomas, and S.G. Fancy. 2003. Guidelines for long-term monitoring protocols. *Wildlife Society Bulletin* **31**:1000-1003

Porter, J.W., S.K. Lewis, and K.G. Porter. 1999. The effect of multiple stressors on the Florida Keys coral reef ecosystem: A landscape hypothesis and a physiological test. *Limnology and Oceanography* **44**:941-949

Rosenberg, A.A. and K.L. McLeod. 2005. Implementing ecosystem-based approaches to management for the conservation of ecosystem services. *Marine Ecology Progress Series* **300**:270-274

Sale, P. 1997. Visual census of fishes. How well do we see what is there? *Proceedings of the 8th International Coral Reef Symposi*um 1435-1440.

Stanford, J.A. and G.C. Poole. 1996. A Protocol for Ecosystem Management. *Ecological Applications* **6**:741-744.