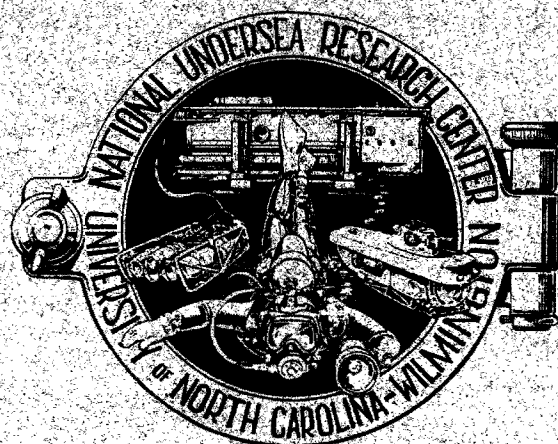




**RECOMMENDATIONS FOR  
LONG-TERM CORAL REEF MONITORING  
IN THE FLORIDA KEYS NATIONAL MARINE  
SANCTUARY**



**Panel Report**

**Key Largo, Florida  
April 12-13, 1994**

*Sponsored by*  
**The National Oceanic and Atmospheric Administration  
Sanctuary and Reserves Division**

**And**

**The National Undersea Research Center  
At the  
University of North Carolina at Wilmington  
Florida Keys Research Program**

**Prepared by Steven L. Miller and Alan W. Hulbert**





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Prepared by

Steven L. Miller  
The National Undersea Research Center  
University of North Carolina at Wilmington  
Florida Program

514 Caribbean Drive  
Key Largo, Florida 33037  
305-451-0233

and

Alan W. Hulbert  
The National Undersea Research Center  
University of North Carolina at Wilmington

7205 Wrightsville Ave.  
Wilmington, NC 28403  
910-256-5133  
1-800-UNCW-URC

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## **Preface**

New ideas and research initiatives are formulated by the Center through workshops and panel discussions. The report presented here resulted from a cooperative effort between the National Undersea Research Center at the University of North Carolina at Wilmington (NURC/UNCW) and NOAA's Sanctuaries and Reserves Division (SRD), which administers the Florida Keys National Marine Sanctuary (FKNMS). Questions about the health and status of coral reefs in the Florida Keys are among the most critical environmental science issues in the region. In response to Congressional recognition that nearshore ecosystems and coral reefs in the Florida Keys are of vital national interest, the Center expanded its Florida science program in 1991. As part of ongoing program activities, the Center asked a select panel to evaluate and recommend how best to implement a Keys-wide coral reef monitoring program. Recommendations of the panel are presented in the report.

## **Acknowledgments**

Administration and coordination of the panel meeting was expertly provided by Mrs. Leslie Forcucci and Mrs. Sandra Williams. Kevin Violette and Andy Shepard helped in final production of the document. Special thanks are due Ms. Darlene Finch, who helped conceive and implement the Center's role with SRD's coral reef restoration program. Dr. Jim Bohnsack and Gene Shinn reviewed a draft of the report and provided many helpful comments. Funding for the meeting and report was supplied by SRD and the Center.



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## 1.0 Introduction and Summary of Panel Recommendations

This report presents rationale and recommendations for conducting long-term monitoring of coral reef communities in the Florida Keys National Marine Sanctuary (FKNMS). Panel members included scientists with national and international experience in coral reef science, statistics, and experimental design (see Appendix). Sanctuary personnel participated with the panel and specifically helped define programmatic goals.

The detailed recommendations presented by the panel are not found in workshop reports previously conducted to assist the Sanctuary in design of a monitoring program (Miller 1988, Ray and Atwood 1991, Harwell 1991). Major panel recommendations related to program goals and methodology are summarized below:

Panel-recommended **program goals** are to:

1. Detect and describe change to coral reefs on a Keys-wide scale.
2. Maximize the number of monitored reefs on a Keys-wide scale, as soon as possible.
3. Incorporate geographic scale, management strategy, and habitat types into program organization. Patch reefs, hardbottom and sites in Florida Bay should be included.
4. Complete initial sampling within two years. Data analysis must be completed in a timely manner. This includes efforts to process data, manage data, and analyze data.
5. Publish results and establish video and slide archives.
6. Conduct independent program reviews on a regular basis.

Panel-recommended **methodologies and designs** include:

1. Video techniques because they provide the best use of time and effort to encompass the largest number of sites. Additional sampling techniques should be weighed against the added time it takes to collect more data, and the resulting decrease in ability to monitor more reefs.
2. Parameters to monitor, such as the number and percent cover of: 1) major coral species and other major benthic sessile invertebrates; 2) fleshy, coralline, and turf algae; 3) dead coral, sand, and hard bottom; and 4) number of species and relative abundance of fishes.
3. A repeated measures design at the among-reef and within-reef scales.

4. Power analyses to determine appropriate sample sizes to insure that statistically and biologically relevant within-reef and among-reef comparisons are possible.
5. Monitoring fishes: Point sample methods and strip transect methods should be evaluated to determine which techniques are best suited to detect change, Keys-wide.

## **2.0 Program Goals**

The panel recognized that there are presently data and ongoing efforts to quantify precise changes in reef communities at a few specific sites along the Keys reef tract. What is critically lacking is any ability to say what is happening to reefs Keys-wide. To acquire these data, many reefs must be monitored less intensely, rather than a few monitored in great detail. A recommended goal of the program is to provide sufficiently detailed information about a large number of reefs to document change over time throughout the Keys.

## **3.0 Rationale**

Long-term monitoring addresses the above recommendations because changes in coral communities can be described quantitatively; and processes that structure coral reefs are often slow and can't be detected in the short-term (Hughes 1992). However, monitoring alone will not ascribe causes to shifts in community structure or the underlying mechanisms of change. Research is required to explain why changes occur. The long-term monitoring program described below provides a basic design from which process-based research, short-term directed monitoring, and more intense monitoring of additional variables can be based.

A Keys-wide effort is particularly valuable because differences observed in the rate of change among sites will lead to testable hypotheses about the underlying causes of quantified changes. Effective management of reef ecosystems in the Keys depends on an understanding of natural system variability and human-caused changes. Long-term monitoring is essential to this understanding for several reasons (Hughes 1992): 1) many ecological processes are slow; 2) most ecological processes have high annual variability; 3) monitoring documents recent reef history and helps to explain events happening now; and 4) monitoring is essential to detect and study rare and episodic events (e.g. outbreaks, dieoffs, hurricanes).

## **4.0 Program Design: The Keys-wide Spatial Scale**

The power and robustness of statistical tests to detect change Keys-wide will be a function of the number of reefs included in the program, not of sampling effort or even sampling design within reefs (to some minimum standard). A high priority should be given to maximizing the number of monitored reefs on the Keys-wide scale. The design presented in Figure 1 recognizes subgroups (or levels in the nested design) that are designed to detect coral reef change at several levels, including geographic location, management strategy, and habitat type. Patch reefs, hardbottom, and Florida Bay sites are recommended as important selection criteria. Additionally, reefs with low coral cover and species diversity were

recommended for inclusion in the sampling program because it was considered important to know whether or not the system has the capacity to improve.

Terminology in Figure 1 labels managed reefs as a subset of three physiographic regions in the Keys. For purposes of program design, managed reefs might include Sanctuary Preservation Areas, Special-use Zones, or any designation related to management of Sanctuary resources. Since all reefs are managed within the framework of the Sanctuary Management Plan, reference or control sites are considered part of the nested design too, as a potential subset of managed reefs. The final shape of the nested program presented in Figure 1 will depend on what management strategies are implemented by the Sanctuary program and sufficient numbers of replicate reefs to maintain a balanced design. Some sites will require monitoring at multiple depths.

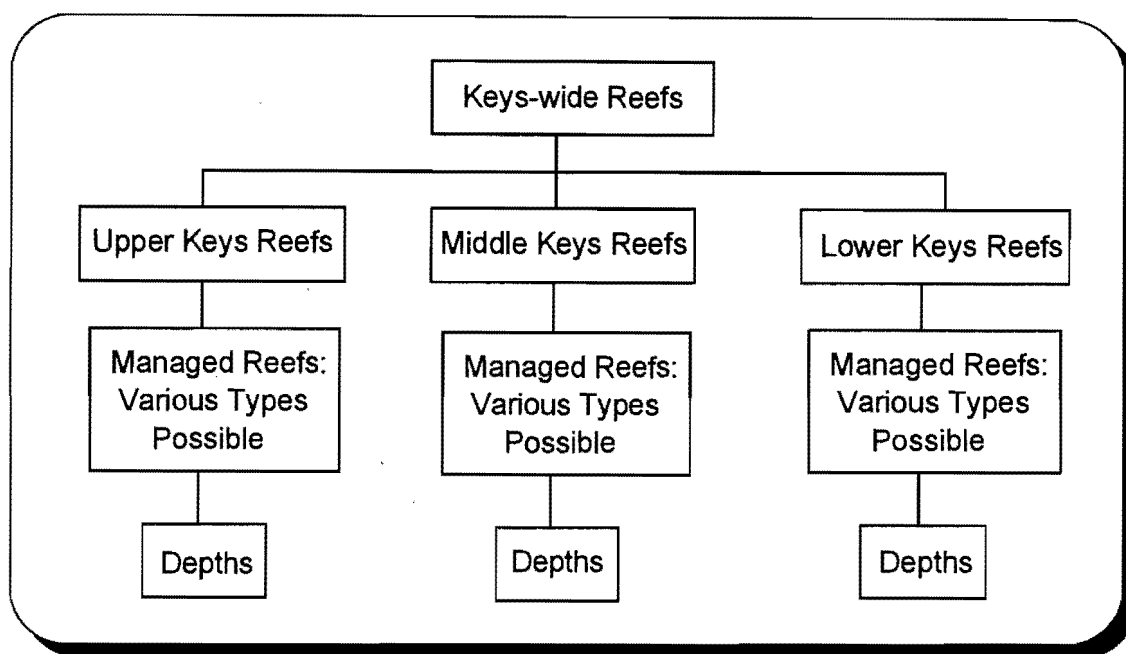


Figure 1. Nested design of panel-recommended Keys-wide coral reef monitoring program (see text for explanation).

Panel members were sensitive to the defined management needs of the Sanctuary. Accordingly, while randomness in selection of reefs was considered important, it is not an absolute requirement. However, randomized sampling within reefs is important. Reefs selected for study could be selected based on the following strategy: 1) produce lists that include all reefs within geographic areas or management strategy; 2) managers and scientists assign priority, based on predetermined criteria, to reefs within geographic regions and management strategies for inclusion in the program; 3) reefs not identified as highest priority are randomly ranked for inclusion in the program; 4) highest priority reefs are sampled first; 5) randomly ranked reefs are sampled according to time and funding limits; 6) flexibility to

sample additional reefs, as determined by management or scientific needs, should be maintained. Selection bias can be reduced by implementing hierarchical strategies to insure equal representation within geographic regions or category of management strategy. The panel emphasized that site selection should be based on discussion among managers and scientists and criteria established before the program begins. Final approval for site selection should come from the Sanctuary management.

In terms of data analysis, different statistical techniques can be used to examine the different levels of questions that are addressed by the design of the study. To look at among-site differences from the first year of sampling, principal components analysis (PCA) is recommended, followed by MANOVA of the PCA scores; Lewis (1986) provides an example of this approach applied to similar data in an experimental approach. Questions related to within-site changes over time and differences among sites in the rate of change can be evaluated using repeated measures analysis of variance: Green (1993) relates these techniques specifically to monitoring studies. Importantly, once the Sanctuary management plan is implemented it will be possible to include reef management type as a factor in such analyses.

#### **4.1 Within-site Spatial Scale**

Within-reef sampling strategies can be evaluated statistically using "power analysis" to determine the accuracy and the ability of the sampling effort to detect change over time and among sites (Green 1989). The panel recommended that power analyses be conducted to determine appropriate sample sizes to insure that statistically and biologically relevant within-reef and among-reef differences are detectable. Before the study begins, decisions must be made about what minimum differences in percent cover or species number will be considered ecologically relevant. These decisions are the ones that will ultimately be of most practical use to managers.

It will be useful to use existing data from ongoing monitoring efforts to obtain estimates of within-reef variability. For example, Aronson et al. (in review) conducted a study to determine appropriate sample sizes to compare video and topographic complexity data among reefs and among sites within reefs (Carysfort and Conch Reefs were included in the study). Minimal detectable differences of 5.2 percent cover and 9.8 percent cover were achieved in areas of low (Discovery Bay with approximate coral cover of a few percent) and high (Carysfort Reef with approximate coral cover of 20 percent) coral cover, respectively. The analyses applied by Aronson et al. (in review) have not typically been applied, and should be distinguished from tests such as species accumulation curves and other tests used to obtain stable means and standard deviations for commonly measured parameters.

#### **4.2 Temporal Component of the Design**

The panel recommended that a repeated measures design be adopted (Green 1993). This means that transects are randomly selected at each reef and then permanently marked at the initial time of sampling so that they can be re-sampled at subsequent times. There are

important statistical considerations that make this design advantageous for detecting change over time (Green 1993). Additional advantages of a repeated measures design are: 1) elimination of among-reef spatial variation from the error term that is used to test hypotheses about Keys-wide changes; 2) elimination of among-transect within-site spatial variation from the error term used to test hypotheses about changes at a site; 3) time trajectories for particular reefs and transects can be modeled; and 4) additional information can be extracted from each transect (for example, studies related to the population dynamics of corals and sponges, and growth rate measurements of selected species). The panel considered re-randomizing transects as each sample interval to include spatial variation as an error term in the design, but decided that this approach unnecessarily obscures differences in time trajectories.

After the initial sampling effort, a biennial program design is recommended that should be reviewed by an outside panel of experts before additional sampling efforts begin. The panel should provide practical advice to managers on how to use results of the monitoring. A goal of the panel evaluation might be to establish normal or acceptable boundary conditions for various parameters. That way, when a parameter exceeds normal (or acceptable) bounds managers can consider a closer look. For example, should managers be concerned about a 5 percent, 10 percent, or 50 percent change in a specific parameter? What about changes in coral versus algal cover, colony sizes, species composition, or age? Should a 95 percent confidence interval be used for monitoring purposes?

#### **4.3 Parameters to Monitor**

No single set of measurements will be ideal for all places and all times (Hughes 1992). It is essential that the amount of replication (e.g. the number of sites, transects, and quadrats) can be modified in response to change, to avoid under- or over-sampling. For example, as coral cover decreased, Hughes (1992) had to increase his sampling to maintain low variance and high precision. A sampling program must also have flexibility to add or drop variables in response to new conditions. Specific parameters recommended by the panel include number and percent cover of: 1) major coral species and other major benthic sessile invertebrates; 2) fleshy, coralline, and turf algae; 3) dead coral, sand, and hard bottom; and 4) number of species and relative abundance of fishes.

Sanctuary managers are looking to document changes in reef community structure, particularly those caused by human disturbance to the system. Accordingly, monitoring sites can and should be open for as broad a set of activities as can be accommodated without compromising the quality of the basic mission. This provides an excellent basic design upon which process-based research and short-term directed monitoring can be started. For example, recruitment and bioerosion, two issues of critical importance for understanding community structure and change, are research topics that require long-term information about community dynamics. Additionally, process-based research and short-term directed monitoring compliment results of long-term monitoring.

Finally, while coral monitoring is important, corals may not be the best indicator of community stress or change. From a management perspective, once corals decline it is too late. A goal of the monitoring program should be to include short-term parameters that are more sensitive indicators of change. Identification of short-term indicators might become possible as natural system variability becomes better known, or as directed research programs develop based on results of longer-term monitoring.

#### **4.4 Large Scale Habitat and Oceanographic Parameters**

An important consideration for selecting benthic monitoring stations is related to the oceanographic and meteorological data acquired through the SEAKEYS program, which enhanced a series of C-MAN (Coastal-Marine Automated Network) stations operated by NOAA's National Data Buoy Center along the reef tract and in Florida Bay. The stations collect data in real-time and at a geographic scale relevant to the Keys-wide benthic monitoring program; they provide essential long-term data to help evaluate biological system responses (Ogden et al. in press). Short-term, the C-MAN stations are also important because episodic events can be detected as they occur (the stations telemeter their data to satellites on an hourly basis to a processing facility that makes the data immediately available and easily accessible) so that research teams have the potential to study the effects of unusual oceanographic or climatic events on nearshore ecosystems. C-MAN stations should be considered an important criterion when evaluating sites for inclusion in the Keys-wide long-term monitoring program. An additional regional monitoring effort, with important biological and oceanographic results, is the University of Miami South and East Florida Caribbean Recruitment study (SEFCAR) (Lee et al. 1992, Lee et al., in press). One result of the SEFCAR program was to use satellite data to monitor large scale oceanographic events, like Gulf Stream gyres in the middle and lower Keys.

Monitoring projects that propose remote sensing at large spatial scales will benefit from the benthic monitoring recommended here. For example, new technologies such as LIDAR (Light Detection and Ranging), multiple spectral color scanners, and other remote sensing techniques might provide valuable regional information. However, these technologies must be considered as related baseline and assessment "research" activities that can provide valuable information, but should not detract from the in situ monitoring.

#### **5.0 Recommended Methods and Sampling Techniques for the Benthos**

The aim of the recommended program is to provide sufficiently detailed information about a large number of reefs to document change over time throughout the Keys. Techniques to quantify benthic community structure and change range from labor intensive in situ count-and-measure procedures to photographic and video techniques that efficiently record large areas of the reef each sampling effort. Because the scope of the Keys-wide program is unprecedented (except for work in the Great Barrier Reef where monitoring has been an element of management for over a decade), the panel recommended that detailed rationale and methods be presented for review by an independent group of scientists. Ideally, the program should be implemented based on competitive grant awards.

Publishable results, not a raw data bank, should be the ultimate aim of the program. However, a raw data bank should be maintained that includes videographic, photographic, and computer archives. Initial results of the program should be published in peer reviewed journals, such as Coral Reefs, Marine Biology, or Ecology. Keys-wide community assessments (through the first several sample efforts) should provide valuable data that warrants the effort required to publish in peer reviewed journals. Long-term, results of the program should be made available through technical reports or peer reviewed journals if warranted.

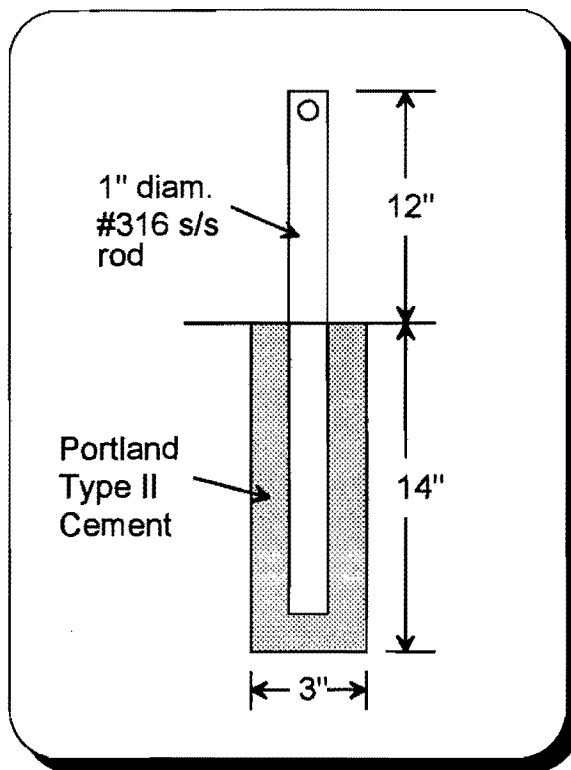
The design of the monitoring program must take into account the effort and cost of data analysis, and not just the field work. Even though the Keys-wide program assumes a long-term approach, prompt data analysis is required to respond to short-term results that are often interesting in their own right (Hughes 1992). The monitoring program should include multiple investigators in a team approach, at least during the first few years of the program to evaluate cost-effectiveness and productivity. Ultimately, the Sanctuary should manage the program (with EPA) using trained personnel and cooperative arrangements with regional experts and programs. For example, the NMFS is developing a formal agreement with the sanctuary program to provide technical research assistance. The Undersea Research Center at UNCW has already signed a Cooperative Agreement with the Sanctuary that emphasizes cooperative research and management efforts. Active and publishing scientists should direct initial program efforts, with graduate students and technicians helping in the field.

Video techniques are recommended because they provide the best use of time and effort to encompass the largest number of sites. Additional sampling techniques should be weighed against the added time it takes to collect more data, and the resulting decrease in ability to monitor more reefs. The panel felt that video techniques were the best way to efficiently and effectively sample large areas underwater, using scuba. Transects, where each end is randomly placed and permanently marked, can be repeatedly sampled by slowly swimming over a marked line or surveyors tape with a video camera. Increased resolution and enhanced color can be achieved when video lights are used to illuminate the bottom. Working distances considerably less than one meter are recommended: Hi-8 mm video cameras can tape a 40 cm path when positioned about 40 cm from the bottom (Aronson et al. in review). Longer working distances provide important general habitat information, but species identifications become increasingly difficult when the camera is moved further from the bottom. The video camera should be positioned perpendicularly over the transect line at a fixed distance with a rod and scale-bar to insure consistency. Video "trolley" mechanisms can be used to help guide the camera across the transect and are relatively easy to set up when permanent markers are already in place. An example of how to install permanent site markers was recommended by Harold Hudson, FKNMS, and is presented in Figure 2.

Analysis of photographic or video images for quantifying coral reef community structure can be accomplished many different ways. The panel recommended "low tech" approaches, rather than "high tech" expensive systems. Contrasts between random point count methods and planimetry suggest that planimetry is more accurate, but it is also more

time consuming. Questions about how many random dots to use per image can be analyzed to determine the minimum number required to obtain stable means and standard deviations. An important recommendation by the panel was that sufficient funds must be made available to handle the data analysis needs of the program. This includes effort to acquire data from the video images, data analysis, and publication of the results. It is likely that the data analysis costs will exceed the field expenses. Hughes (1992) reported that only 20 percent of his costs associated with his \$350,000, 12 year program were related to data collection in the field.

Figure 2. Permanent site marker for video transects. The 24 inch stainless steel rod is embedded in cement, 12 in. into the bottom in a 3 inch hole bored using a hydraulic underwater drill. A hand level is used to plumb the stake vertically (from H. Hudson).



Periodic evaluations and program reviews are recommended. Program reviews should be particularly concerned with providing practical advice to managers about whether or not to update monitoring protocols and, most importantly, how to use monitoring data. Managers will need advice about how to interpret changes in monitored parameters. For example, at what point should managers become concerned about changes in coral cover? Data related to abundance, colony size, and species composition should be considered when evaluating percent cover changes. Panel reviews should also recommend directed research to help answer management-related questions.

If time and money are available, other efforts related to determining topographic complexity, coral recruitment, and coral mortality might be included in design of the monitoring program. It should be noted that photographs yield higher resolution data than obtainable by video techniques, and are particularly useful for estimating coral recruitment. While photographs (and visual assessment techniques) for monitoring coral recruitment (and other parameters such as sponge, soft coral, algae and gastropod identifications) work well, they can be time consuming. In general, there will always be a trade-off between the level of detail obtained and time available to collect data. Whatever additional data are collected (and photography is a logical choice) the effort should be measured against the added time it takes to do the job and the resulting decrease in ability to monitor more reefs.

## 6.0 Recommended Methods and Sampling Techniques for Fish

Monitoring fish, which are mobile and seasonal in abundance, requires protocols and a sampling design different than those used to monitor sessile benthic organisms. Fish censuses depend upon visual counts made by divers and precision varies with water conditions, time of day, activities of the fish, and the ability of the diver to identify fish accurately and quickly. In general, precision deteriorates with the area of reef being scanned as the diver swims the transect, number of species simultaneously counted, and number of tasks required of the technique, such as identifying species and fish sizes. Two different techniques have been used most frequently by fish biologists, point sample methods and strip transect methods (Sale and Sharp 1983, Sale et al. 1984, Bohnsack and Bannerot 1986, Fowler, 1987). The following summaries discuss the advantages and disadvantages of both techniques. As a recommendation, regardless of technique, parameters to monitor for fish should include: 1) species present (frequency-of-occurrence); 2) abundance; 3) species composition; and 4) size.

### 6.1 Point Sample and Strip Transect Methods for Censusing Fish

In general, point census techniques are designed to collect site-specific data on species composition, abundance, frequency-of-occurrence, and biomass from any habitat or site. The advantages of point sample methods include: 1) extensive use in the Keys and the Caribbean; 2) samples are taken for a relatively small site instead of along a transect, which may extend across different habitat types; 3) data on species present, abundance, and size distributions can be obtained, if desired; 4) data are collected on all observed species; 5) bottom time and data collection time are maximized because of lower air consumption; 6) some sources of fish behavioral bias are removed by using stationary divers; 7) frequency data becomes statistically useful; 8) large sample sizes are more easily obtained which increase statistical power; 9) habitat disturbance is minimal, compared to line transects and markers; and 10) no time is wasted in setting up and retrieving transect lines. The disadvantages of point sample methods include: 1) they cannot be easily related to results of transect methods because a cross comparison of this method with others has yet to be done; 2) they are sensitive to individual diver capabilities because the tasks are demanding, including estimating the boundary of an imaginary seven meter cylinder, and counting all fish within that cylinder; 3) if all sampling is not done by the same investigators, careful cross-calibration of divers is needed; 4) in shallow sites with low relief, the presence of divers will affect survey data; 5) considerable variation exists among studies in details of the sampling protocol, even though authors always cite Bohnsack and Bannerot (1986) as the reference for the method; and 6) data provide an index of density but cannot be directly used to determine absolute density without extensive habitat-specific calibration.

In general, transects are best used in uniform habitats. The advantages of transect methods include: 1) wide use in the Caribbean and Pacific; 2) strips of defined width can be sampled with little variance among divers; 3) relating fish fauna to habitat type is possible when the substratum is also sampled; 4) precision can be increased by subsampling along the transect, counting certain groups/sizes of fish; 5) for sedentary fishes density measures can be closely approximated; 6) the technique can be adapted to the particular group of fishes being

studied (for example, a wider strip is needed for larger fish or a slower swim is needed for cryptic species). The disadvantages of transect methods include: 1) they have not been used extensively in the Keys; 2) considerable variation exists among studies in details of the sampling protocol; 3) multiple tasks must be done simultaneously, for example, several species must be counted simultaneously while keeping track of substrate type; 4) habitat boundary effects are more difficult to evaluate; 5) transect lines are difficult to position in some habitats; and 6) calibrating data can be complex because wider strips are used for larger species and slower swims or narrower bands are used for cryptic species.

A considerable amount of fish work has already been accomplished in the Keys, and more is planned in 1994. Most of this work uses point sample methodologies. Independent methods used, the panel recommended that the fish work be coordinated with the benthic sampling for maximum benefit to the program. A comparison between point sample methodologies and strip transect methodologies was recommended by the panel. However, determining what technique is best suited to detect change, "Keys-wide," is not a simple task, and may be a waste of time because there is likely no one "best" method for all conditions. Depending on the specific questions being asked, a variety of methods may be needed.

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## APPENDIX

### *Names and addresses of panel members*

Dr. Robert Carpenter  
Department of Biology  
California State University  
Northridge, CA 91330-8303

Dr. Stephen Gittings  
NOAA  
Flower Garden Banks Natl Mar Sanctuary  
1716 Briarcrest Drive, Suite 702  
Bryan, Texas 77802

Dr. Betsy Gladfelter  
5006 North Grapetree  
St. Croix, USVI 00820

Mr. Bill Goodwin  
Florida Keys National Marine Sanctuary  
Upper Keys Region  
Key Largo, FL 33037

Dr. Roger Green  
Department of Zoology  
University of Western Ontario  
London, Ontario, Canada N6A5B

Dr. Mark Hay  
University of North Carolina  
Institute of Marine Science  
Morehead City, NC 28557

Mr. Harold Hudson  
Florida Keys National Marine Sanctuary  
Upper Keys Regions  
Key Largo, Florida 33037

Dr. Alan Hulbert  
National Undersea Research Center  
University of North Carolina at Wilmington  
7205 Wrightsville Avenue  
Wilmington, NC 28403

Dr. Steven Miller  
National Undersea Research Center  
University of North Carolina at Wilmington  
Florida Program  
514 Caribbean Drive  
Key Largo, Florida 33037

Dr. Peter Sale  
University of Windsor  
Biology Department  
401 Sunset Ave.  
Ontario, Canada N9B3P4