A Protocol and Database for Monitoring Transient Multi-species Reef Fish Spawning Aggregations in the Meso-American Reef

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ABSTRACT

Most commercially important Caribbean reef fish species reproduce within transient spawning aggregations in specific times and places. Fishers have long recognized and capitalized on this behavior, and heavy fishing pressure on spawning aggregations has led to declines and extirpations around the Caribbean, particularly for Nassau grouper. For the same reason that spawning aggregations are attractive to fishers, they are also an opportunity for managers to monitor the populations. To maximize this opportunity, we developed, tested, and produced a standardized protocol and accompanying database for monitoring transient reef fish spawning aggregations. The protocol includes both fisheries dependent and independent techniques for data collection as well as physical oceanographic measures. The accompanying database and user manual are designed intimately with the monitoring protocol, providing easy data entry and data retrieval via generation of reports. The system design allows upgrading to a web-based, SQL-server platform that can handle data from around the world. The protocol has been adopted by the World Bank's Meso-American Barrier Reef Systems Project (MBRS) for Belize, Mexico, Honduras and Guatemala.

KEY WORDS: Database, monitoring, spawning aggregations

Protocolo y Base de Datos para el Monitoreo de Agregaciones Reproductivas Transitorias de Múltiples Especies de Peces Arrecifales en el Arrecife Mesoamericano

La mayor parte de las especies de peces arrecifales del Caribe con valor comercial se reproducen en períodos y lugares específicos dentro de las agregaciones reproductivas transitorias. Toda la producción reproductiva de los peces que utilizan esta estrategia ocurre dentro de estas agregaciones. El monitoreo de estas agregaciones puede servir como una manera eficiente de monitorear estas poblaciones cuando pasan a través de cuellos de botella físicos y temporales de gran importancia para sus ciclos de vida. No obstante, hasta ahora no hay un protocolo de monitoreo sistemático generalmente aceptado de estas agregaciones. Nosotros desarrollamos, probamos y produjimos un protocolo estandarizado y una base de datos que lo acompaña para el monitoreo de agregaciones reproductivas transitorias de peces arrecifales. El sistema de monitoreo ha sido adoptado como estándar por los cuatro países del arrecife mesoamericano, Belice, México, Honduras y Guatemala, a través del Proyecto de Sistemas de Arrecifes de Barrera Mesoamericanos del Banco Mundial.

El protocolo y la base de datos fueron desarrollados en colaboración bajo el liderazgo del Comité Nacional de Trabajo sobre Agregaciones Reproductivas de Belice y bajo los auspicios de The Nature Conservancy. El sistema se encuentra en desarrollo y uso en Belice desde el año 2000 y se usa para el monitoreo de 17 sitios de agregaciones reproductivas de múltiples especies realizado por equipos de 8 organizaciones, gubernamentales y no gubernamentales, de Belice e internacionales.

El protocolo detalla métodos dependientes e independientes de pesquerías así como técnicas de oceanografía física cuyo fin es monitorear las agregaciones reproductivas. La base de datos en Access que lo acompaña y el manual del usuario fueron diseñados en estrecha relación con el protocolo de monitoreo, para proveer un sistema sencillo de ingreso y recuperación de datos mediante la generación de informes. El sistema está diseñado para ofrecer en el futuro una aplicación adaptable con base en la red que utiliza una plataforma de servidor SQL para manejar datos de todo el mundo.

PALABRAS CLAVES: Agregaciones reproductivas, base de datos, monitoreo

INTRODUCTION

Tropical marine fisheries have sustained the livelihoods of coastal communities throughout the Meso-American Reef and the wider Caribbean for generations, but these resources are collapsing at an alarming rate throughout the region (Safina 1995, NRC 1999, Jackson et al. 2001). Fisheries in the Caribbean are diverse, generally targeting a variety of species simultaneously. These multi-species fisheries are particularly difficult to monitor and manage using traditional means. Of particular interest to the managers are the large predatory reef fishes such as snappers and groupers because of their value both as fishery products–prized by diners worldwide–and as a “draw” in the tourism industry–divers enjoy seeing large predators while diving and sport fishing. These larger reef fishes generally reproduce in transient spawning aggregations that occur at specific times and places (Munro et al. 1973, Thompson and Munro 1978, Johannes 1978, Thresher 1984, Domeier and Colin 1997, Colin et al. 2003). Fishers have capitalized on this behavior by fishing intensively at spawning aggregations (e.g., Craig 1969, Auil-Marshellek 1994). Early work described the Nassau grouper fishery at Caye Glory, Belize, where as many as 300 boats captured over 2,000 kg of gravid groupers per day (Craig 1969). More recent studies have further documented aggregations of other species and at other times (e.g., Carter et al. 1994, Auil-Marshellek 1994, Heyman 1996, Paz and Grimshaw 2001, Sala et al. 2001). Intensive fishing pressure on these aggregations has led to declines and, in several cases, extirpations (Fine 1990, Sadovy 1994, Paz and Grimshaw 2001, Sala et al. 2001, Luckhurst 2004).

Confounding the problems associated with declining fisheries resources are the limited resources for the study, monitoring, and regulatory enforcement of reef fisheries throughout the tropics. Though scientists have been aware of spawning aggregations for many years, funding and resource constraints have limited most studies to few locations, few techniques, short durations, and focus on a single species at a time–generally groupers (e.g. Smith 1972, Colin 1992, Aguilar-Perera 1994, Carter et al. 1994, Aguilar-Perera and Aguilar-Dávila 1996). These studies have provided excellent information about the sites, species, and temporal aspect studied; however, the lack of consistency among studies has resulted in insufficient data for broad-scale understanding of spawning aggregation dynamics, or as a basis for management decisions. An exception is the relatively well studied reef fish spawning aggregations in Belize.

Anecdotal information from fishers and managers and the overall insufficiency of data and management pertaining to spawning aggregations was cause for concern. Individuals and organizations realized the still present threat to Nassau grouper and the value of multi-species reef fish spawning aggregations, and formed the Belize Spawning Aggregations Working Committee (BSAWC) to foster good management. Given the large geographic spread and simultaneous occurrences of the many aggregations in Belize this effort was challenging. The BSAWC sponsored various nation-wide assessments, starting in 2001 and data from 17 sites in Belize were synthesized into an understanding of transient multi-species reef fish spawning aggregations at reef promontories (Heyman and Requena 2002). Based in part on these data, a country-wide collaborative effort of data collection, education, and consensus building culminated in legislation that was enacted to conserve 11 of these sites within marine reserves in Belize (GoB 2003a, Heyman 2004). The Belize example shows the positive result of shared data collection and synthesis utilized for management.

Though fishers supported the legislation, they were particularly concerned about the efficacy of the new laws. The BSAWC understood that a system to monitor the populations status and to measure the success of management programs was needed. The authors, working under the auspices of The Nature Conservancy, and with the input, testing, review, and support of the BSAWC, worked collaboratively to develop a monitoring protocol, database, and data sharing agreement that would serve the needs of Belize fishers and managers alike. The BSAWC knew that Caribbean fisheries were facing similar issues, and decided to expand the project scope to the Meso-American Reef (with partial support provided by the Meso-American Barrier Reef Systems (MBRS) project).

The system's broad design criteria were to provide reliable data for monitoring and management decision-making on a large number of multi-species spawning aggregation sites, each having seasonal and annual monitoring needs. The system also needed a tool to facilitate the exchange of information and learning across sites and long time periods, and thus, the system required the storage, retrieval, filtering, and output of various data sets. To be truly useful, the system had to rely on existing technical, financial, and human resources and be operated by local technicians of the four countries of the

Meso-American Reef–Mexico, Belize, Guatemala, and Honduras.

After the initial development was completed, it was shared at the 55th Annual Meeting of the Gulf and Caribbean Fisheries Institute in Tulúm, Mexico, November 2002. An open invitation was extended at that time for user contributions to what has become this final (2004) product. This paper describes the development, application, and use of the "Reef Fish Spawning Aggregation Monitoring Protocol for the Meso-American Reef and the Wider Caribbean" (Heyman et al. 2004) (hereafter referred to as the "Protocol") and the corresponding "Spawning Aggregation Database," hereafter referred to as the "Database."

MATERIALS AND METHODS

The BSAWC sought involvement of all available institutional, financial, and human resources to complete this project, including the Belize National Government, local and international NGOs, fishing cooperatives, small-scale commercial fishers, local marine reserves, international foundations, community groups, government technicians, marine reserve staff, fishers, dive guides, students, oceanographers, marine scientists, marine biologists, map makers, computer programmers, and computer operators. A complete list of supporting institutions (14) and the names of contributing persons (over 100) are found within the acknowledgements of the Protocol.

The BSAWC recognized the existence of standardized fishery dependent and independent monitoring techniques that had been or could be adapted for spawning aggregation monitoring (e.g. Samoilys 1997a, Zeller 1998, Colin et al. 2003, The Nature Conservancy 2003a,b). Techniques in the Protocol are largely derived from these and other published techniques (see Table 1), but with some modifications to account for the institutional, human, and financial resource constraints of the implementers.

Various software packages and computer hardware platforms were evaluated for their suitability to store, retrieve, and share spawning aggregation monitoring data. Every effort was made to build a system that relies on commonly available hardware and software within the region. Further, while the system was designed to be operated initially by a network of individual users on individual PCs, we recognized the need for eventual upgrading to a web-based system to foster regional collaboration.

RESULTS AND DISCUSSION

Protocol Methodologies and Sample Results

Standardized metrics measured over time and compared among sites provide managers with information on the health of various stocks and thus a basis for management decisions (Lindeman et al. 2001).

Fishery-dependent monitoring — techniques evaluate catch/effort, length frequency distribution, and gonosomatic indices based on measurements of fish caught within an aggregation. Changes in population size structure can be illustrated with these techniques, and provide an early indication of depletion. Size frequency changes can appear before changes in numbers become apparent. Studies of age and growth, genetics, and histology require morphometric measures (e.g., length and weight of individuals and gonads) and simultaneous sampling of various tissue or organ types for subsequent laboratory analysis. Methods for extraction of otoliths for age determination; gill, heart, or fin tissue for genetics; and gonads for histology or gonosomatic indices are provided in the Protocol and other references (Table 1). These metrics have been developed and standardized by many authors previously (Table 1.). Fishery-dependent studies help provide an accurate assessment of spawning times and strategies and assessments of population structure.

Fishery-independent techniques — are available for monitoring spawning aggregations that are not being fished and to document behavior. Techniques to evaluate physical and environmental factors that may affect spawning time, or location, or egg dispersal are included.

Perhaps the simplest and most valuable techniques involve the documentation of spawning aggregations using photography and video (Domeier and Colin 1997, Colin et al. 2003). Photography and video have shown spawning colorations, behaviors, and actual spawning events (e.g. Figure 1).

Underwater Visual Survey (UVS) techniques document reproductive seasonality, abundance, and variability in the reef fish spawning aggregation populations. The techniques described within the Protocol are similar to other studies (e.g. Samoilys 1997b, Beets and Friedlander 1999, Sala et al. 2001, Whaylen et al. 2004, Table 1) in which SCUBA divers collect data on the abundance and sizes of fishes within aggregations. Through subsampling or direct counts, observers can provide relatively accurate estimates of the number of fish within particular aggregations. For example, pair-wise comparisons (n = 14) of Cubera snapper counts by two independent teams of observers, diving at the same time within the same aggregation in Belize, April-May 2004, were not significantly different. Sample data from Belize collected using these techniques are provided in Figure 2. These data on two commercially important reef fish species at a single spawning site show the daily abundance and the year-round importance of the site as a spawning ground, and have helped managers and fishers alike to agree on year-round closures for several reef promontory spawning aggregation sites in Belize. Using UVS, Beets and Friedlander (1999) showed significant increases in abundance and sizes of red hind during six years following the closure of an aggregation site. The BSAWC considers UVS techniques as described in the Protocol to be sufficiently accurate for monitoring and for the basis of management decisions.

There are a few caveats when using UVS, however. The objectives of the monitoring program must be clear, particularly in a multi-species spawning aggregation. By timing observations to coincide with specific seasonal, lunar, and diel cycles, observers can dramatically increase their chances of documenting the aggregations accurately. Further, some species aggregate near the bottom and toward the shelf edge (e.g., groupers), while other species, (e.g. jacks) aggregate higher in the water column. Observers must define sampling strategies and divide efforts to get accurate and repeatable counts on target species. Natural variations in populations can also confound UVS results. Six years of monitoring a Cubera snapper aggregation at Gladden Spit, using UVS revealed significant seasonal and annual variations in the numbers of fish at this aggregation site (Heyman et al. In review). Therefore, drawing conclusions about population trends using census data will require at least eight to ten years for slower growing species such as large groupers, and we recommend the precautionary principle.

Table 1. Techniques used in the Protocol with references to studies that describe and use each.

Fishery Independent Techniques	References and Examples
Photography and Videography	Olsen & LaPlace 1979; Colin 1992; Shapiro et al. 1993; Tucker et al. 1993; Samoilys 1997a,b; Beets & Friedlander 1999; Sala et al. 2001; The Nature Conservancy 2003a, b; Whaylen et al. 2004; Heyman et al. in rev.
Underwater Visual Survey	Colin et al. 1987; Colin 1992; Tucker et al. 1993; Carter et al. 1994; Domeier & Colin 1997; Samoilys 1997a,b; Beets & Friedlander 1999; Sala et al. 2001; Colin et al. 2003; The Nature Conservancy 2003b; Medina-Quej et al. 2004; Heyman et al. in rev.
Fish Tagging Studies	Carter et al. 1994; Sadovy et al. 1994; Luckhurst 1998; Zeller 1998; Bolden 2000
Bathymetric and Site Mapping and Site Descriptions	Colin et al. 1987; Colin 1992; Shapiro et al. 1993; Sadovy et al. 1994; Aguilar-Perera & Aguilar-Dávila 1996; Samoilys 1997a,b; Beets & Friedlander 1999; Sala et al. 2001; Colin et al. 2003; Ecochard et al. 2003
Current Drogue Studies	Colin 1992
Physical Oceanographic Monitoring	Colin 1992; Carter et al 1994; Heyman et al. in rev.
Fishery Dependent Techniques	
Length:Frequency Distribution	Olsen & LaPlace 1979; Colin et al. 1987; Claro 1981; Crabtree & Bullock 1998; Colin 1992; Tucker et al. 1993; Aguilar-Perera 1994; Carter et al. 1994; Sadovy et al. 1994; Aguilar-Perera & Aguilar-Dávila 1996; Domeier et al. 1996; Sosa-Cordero & Cárdenas-Vidal 1996; Beets & Friedlander 1999; García-Cagide et al. 2001; Burton 2002; Medina-Quej et al. 2004
Catch per Unit Effort	Olsen & LaPlace 1979; Carter et al. 1994; Sadovy & Ecklund 1999; Sosa-Cordero & Cárdenas-Vidal 1996; Beets & Friedlander 1999; Sala et al. 2001
Gonosomatic Index	Munro et al. 1973; Olsen & LaPlace 1979; Claro 1981; Thresher 1984; Tucker et al. 1993; Carter et al. 1994; Sadovy & Ecklund 1999; Sadovy et al. 1994; Domeier et al. 1996; García-Cagide & García 1996; Beets & Friedlander 1999; García-Cagide et al. 1999; García-Cagide et al. 2001; Burton 2002; The Nature Conservancy 2003b

A.

B.

Figure 1. Photographs of spawning aggregations illustrating A. spawning coloration in Nassau grouper, and B. Dog snapper spawning event (photo by Douglas David Seifert).

Tagging studies — described in the Protocol use either simple identification tags, and/or sonic tags and stationary sonic receivers. While somewhat expensive, tagging studies can be very valuable, detailing both migration patterns and patterns of seasonality and site fidelity. Carter et al. (1994) found a Nassau grouper swam 150 km from Belize to Mexico; Bolden (2000) recorded one that swam 220 km to a spawning aggregation. Zeller (1998) provides an excellent example of the utility of sonic tags in studies of site fidelity, arrival and departure times of fish at an aggregation site, without having to dive. Managers are urged to use identification tags before investing in much more expensive sonic tags, and are urged to consider tags where diving would be too difficult.

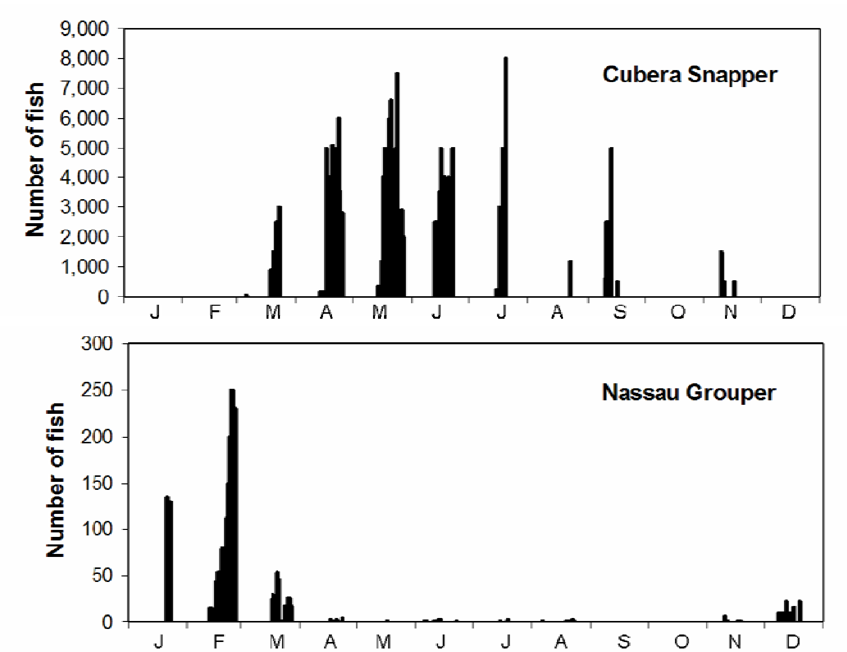

Figure 2. The timing and abundance of spawning aggregations from daily underwater visual surveys for A. Cubera Snapper and B. Nassau Grouper during 2003 at Gladden Spit in Belize. (Data kindly provided by Friends of Nature, Placencia, Belize).

Site maps and descriptions — are valuable for monitoring and assessment of spawning aggregations. A good base map is an essential tool if underwater visual assessments will be conducted regularly at a particular site. Maps of the spawning aggregation sites can also be helpful in the design and zoning of marine protected areas. Detailed methods for creating bathymetric maps that include spawning aggregation sites are described in Ecochard et al. (2003). Additional examples of maps and techniques are referenced in Table 1.

Database Design and Structure

Software was evaluated as a platform for the aggregation monitoring data. The software had to be scalable and flexible to handle the variety of data types and relationships. An automated database governed by a set of predefined rules and standards for the capture, update, and retrieval of data was needed. Microsoft Access 2000®, as a standalone application, offers all the basic features needed to manage the Database, and also has features that will allow for efficient data sharing and cost-effective upgrades. Access® is widely available and offers additional features that other platforms do not and was selected as the platform for the Database.

Access® has a built-in replication tool that can be used to distribute the Database to all participating organizations (see Data Sharing, below). Further, Access® can be used to create an easy-to-use interface to a more scalable and robust back-end database such as Microsoft SQL Server. Alternately, the entire Database can be upgraded to SQL Server.

Minimum hardware requirements for operating the database are:

i) Pentium II personal computer (PC),
ii) 233 Mhz processing speed,
iii) 128Mb of RAM,
iv) 200 Mb of hard disk space available,
v) VGA monitor,
vi) CD writer, and
vii) Internet connection and a reliable e-mail system

The Database stores data in a collection of related and linked tables. Data is entered into these tables through pre-made, automated, digital forms (e.g., Figure 3, the Underwater Visual Survey Data entry form). The four database entities are sites, survey types, organizations, and survey participants. Figure 4 shows the relationships among entities for the Visual Survey in an entity-relationship (ER) diagram. ER diagrams are popular high-level conceptual data models used in the design of database applications. In many cases, data entered for each entity is channeled into a data table for storage and retrieval. In some cases, however, complex entities are broken down into smaller, more stable tables for storage. Each table represents a group of relevant information captured and maintained together.

User Interface

The Database has been designed to be simple and easy to use, with heavy emphasis placed on the design of the user interface. The data entry screens (Figure 3) resemble the data sheets of the Protocol (Adrien 2003a). Whenever possible, data entry has been automated using look-up tables to minimize user entries of new species, new sites, or misspellings of existing entries.

Generating reports with the Database has also been designed to be simple (Figure 5) yet not compromise the functionality and flexibility for the user. The report section offers powerful ways to display survey data. Users can specify parameters of interest for specific comparisons. For example, within a single query, users can select to report either the count or the average of one or many species at one or many sites during any specific year or years (Figure 5).

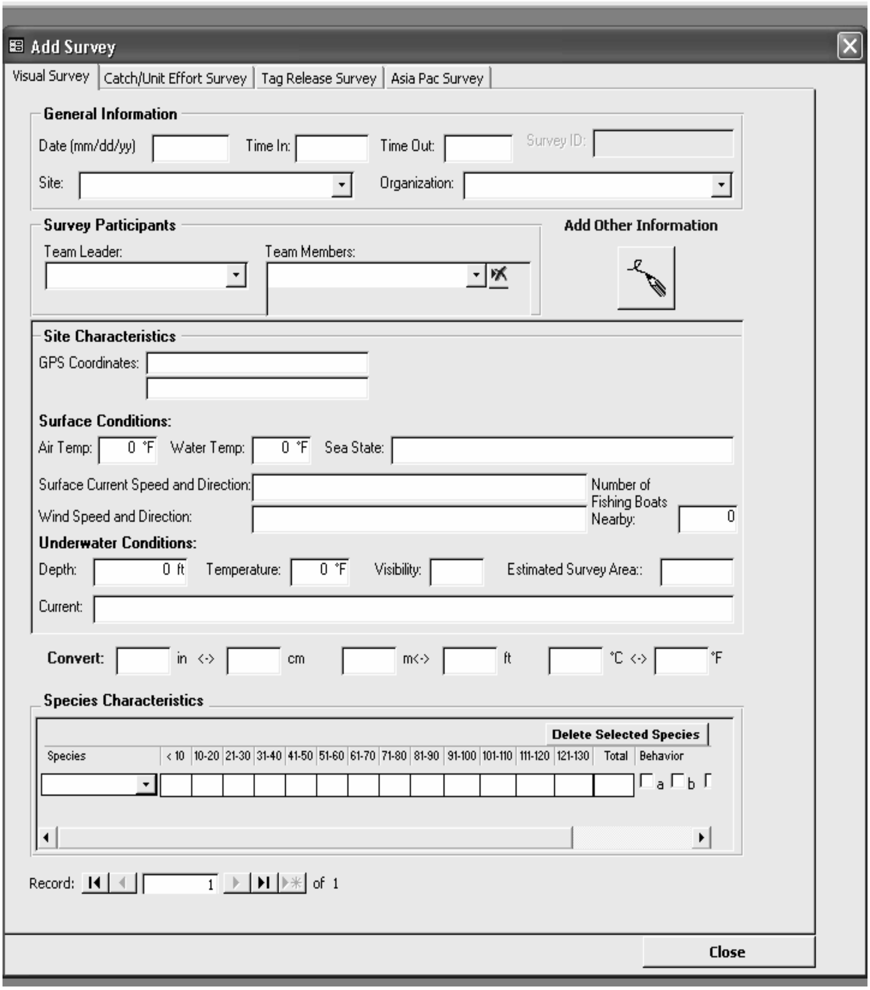

Figure 3. Spawning aggregation database digital entry form for visual underwater survey data.

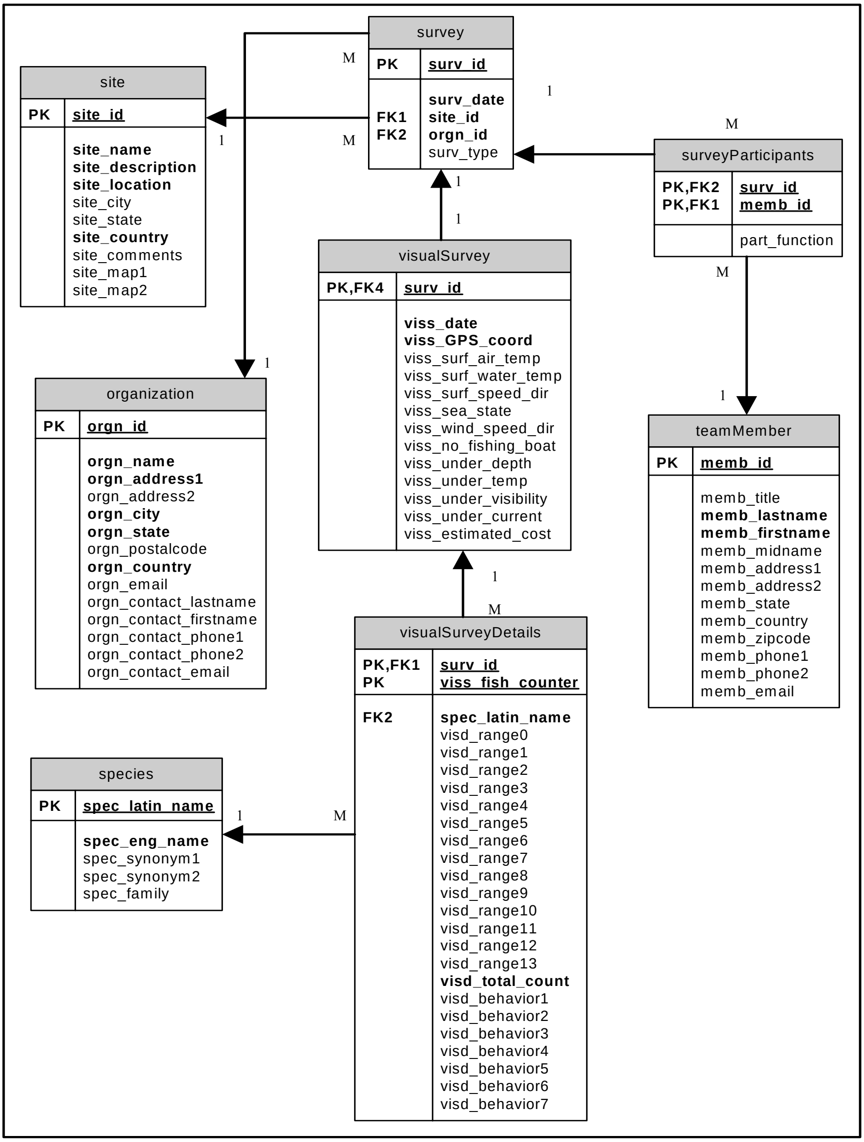

Figure 4. Entity-Relationship (ER) diagram for Visual Survey data from the Database illustrating the relationships between entities. Arrows indicate the type of relationship between entities with “1” (one) and “M” (many) at the end of each arrow.

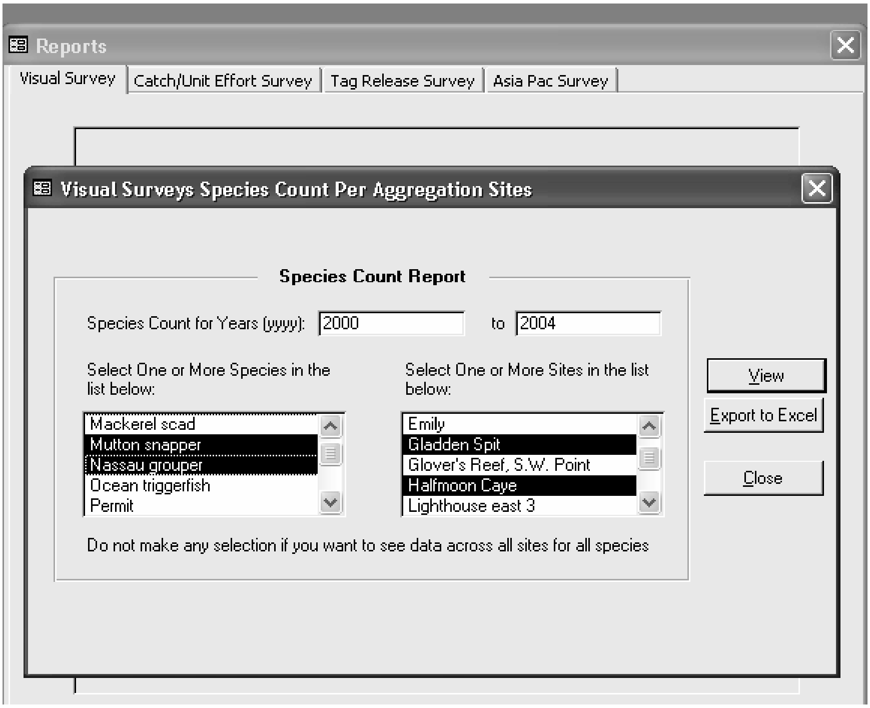

Figure 5. Visual survey report form from the Database illustrating an example of a user-defined query. In this case, a query is requested that will illustrate all entries of visual survey counts for two species (mutton snapper and Nassau grouper) at two sites (Gladden Spit and Halfmoon Caye) over a four-year period, 2000-2004. Users can also choose to see the data within Access, or have the data directly exported to an Excel spreadsheet, or choose another tab for queries using other data sets.

Data Sharing and Distribution

The database was designed with the understanding that many users, in different areas could use the system on a stand-alone PC, but that these data could be combined and shared. The eventual goal is to have the system operational on an SQL server that is accessible to all users over the Internet on a secure site. Web-based systems are more complex and costly to maintain and update, so in the interim, the system relies on desktop systems for individual organizations, each with a full copy of the database and all data. Data are shared and updated by manual replication and synchronization of the various databases (Figure 6). A detailed guide to Access® replication is freely available (Adrien 2003b). The drawback to the stand-alone system is synchronization. If synchronization does not occur regularly some organizations may end up with outdated data, leading to misinterpretation and incorrect reports.

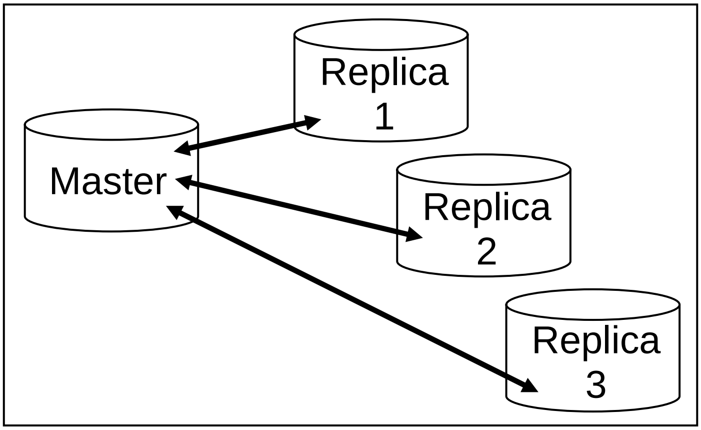

Figure 6. Database structure and replication: the database is designed to be able to be shared among multiple users. Using replication techniques, both the main database (master) and the copies (replicas) can update each other simultaneously.

CONCLUSIONS

As stated in the introduction to the Protocol:

> *"The purpose of the Protocol is to provide a standardized methodology for the evaluation and routine monitoring and conservation of transient multi-species spawning aggregations along the Meso-American Reef and the wider Caribbean. This document is intended for use by resource managers, conservationists, biologists, fishers, students and trained recreational divers." (Heyman et al. 2004).*

The Database is an automated tool for data generated using the Protocol from anywhere in the Caribbean, and it should be noted that it also can serve the same purpose for the Asia-Pacific region. Despite the acceptance of the Protocol and Database by users, we consider both as works in progress. Users are encouraged to evaluate the systems critically, and to provide feedback to the authors such that later releases can benefit.

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