PAPER

Remote Video Revisited: A Visual Technique for Conducting Long-term Monitoring of Reef Fishes on the Continental Shelf

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ABSTRACT

Fisheries observation data collected at similar times and frequencies as hydrographic data could contribute significantly to the development of models for predicting responses of fish assemblages to changing environmental conditions. Traditional collections of fishery observation data rarely occur with sufficient temporal replication for modeling; however, remotely collected underwater video data represents a promising remedy. In August 1999, an experimental underwater fish habitat and video data collection system were established on the middle continental shelf off the coast of Georgia. Short (10 s) video data files were collected hourly during daylight and transmitted 72 km to shore by microwave once daily. An extraordinarily large and valuable dataset was generated despite technical problems, which precluded data collection during more than half of the days within the 1999-2002 study period. Evaluation of 5,590 usable video files from 429 observation days resulted in documentation of presence, relative abundance and behavior for at least 50 species, including several highly migratory pelagic species for which little scientific data exists. Future efforts of this ongoing study will attempt to mitigate technical problems discovered during 1999-2002. Expansion of automated visual sampling to numerous index stations along the continental shelf has the potential of greatly complementing infrequent and expensive sampling cruises to collect ecological and behavioral data.

INTRODUCTION

Direct observation in the marine environment provides several sampling advantages with respect to sampling involving traditional sampling gears. During daylight, direct observation generally documents more species (and individuals) of management interest than other sampling gears (Grace et al., 2000; Cappo et al., 2004). Direct observations result in minimal damage to habitats and species loss, making this approach especially valuable in sensitive areas difficult or otherwise impossible to sample (Barnett and Pankhurst, 1996; Westera et al., 2003). Direct observation is one of the only methods that enables documentation of species interactions, which may subsequently affect catch composition due to changes in distributional habits or altered ability to collect species. Given these advantages, recording direct observations through photography has been pursued by both terrestrial (Sanderson and Trolle, 2005) and marine (Stryke) scientists for more than a century.

Underwater photography in the marine environment has largely been limited to point-in-time efforts. Through the use of SCUBA (Brock, 1954; Hobson, 1972; Parker et al., 1994), submersibles (Parker and Ross, 1986), or remotely operated camera systems (Powles and Barans, 1980; Baamstedt et al., 2003; Stevens, 2003), there are few physical limits, other than water clarity, to where photographic observations can be recorded. Unfortunately, none of these innovative visual techniques have provided long-term, continuous observations, which could be used in developing physical-biological models to predict relationships between fish abundance and environmental factors, such as those reported by Runge et al. (2004). Furthermore, moderate sea states are necessary to use such techniques; thus, sampling schedules and the temporal continuity of data can be greatly compromised by weather.

In contrast to point-in-time visual sampling, visual observations at fixed locations ("Eulerian" approach) using remote, semi-permanently deployed data collection systems enable sampling over extended periods (due to reduced weather-dependence) under more 'natural' conditions. Semi-permanently deployed systems become part of the landscape with time; thus, attraction to or avoidance of recently introduced remote controlled camera systems by many species (Parker et al., 1994) is reduced. Similarly, biased fish behavior due to SCUBA diver presence and "bubble curtains" (partially mitigated with re-breather systems, Lobel, 2001) is also not a factor with semi-permanent systems.

An early attempt to use a remote video data collection system occurred off of North Bimini Island in the early 1970's (Smith and Tyler, 1973). The camera system, located in 17 m of water with a 10 m field of view, was wired to and controlled from a shore-based laboratory 1.6 km away (Steinberg et al., 1965; Myrberg, 1972; Smith and Tyler, 1973). Technological advancements such as radio-signal control and improved data collection and storage abilities have made such studies more feasible; however, most efforts continue to be conducted close to shore and focus on general public (CWC; Collins) rather than scientific (Nelson) interests. To date, long-term efforts to apply this fixed station approach for conducting research at remote locations in the marine environment have not been reported.

In August 1999, an automated video system was established to monitor fish assemblages at a small artificial reef and, eventually, correlate fisheries video data with hydrographic information as part of the South Atlantic Bight Synoptic Offshore Observational Network (SABSOON). In this paper we describe the remote video system and discuss: the mechanics of data collection for this revisited, remote fisheries approach; problems encountered with the current configuration and potential remedies; and examples of the types of scientific data that can be collected and analyzed using temporally intensive video data. Expanded use of offshore video monitoring for long-term monitoring of areas where underwater visibility is fairly good can complement traditional fisheries data and provide behavioral information on temporal and spatial scales previously unattainable.

Methods

Research Site

In May 1999, a research site consisting of concrete fish habitats was established on the mid-continental shelf approximately 72 km off the Georgia coast in approximately 25 m of water to evaluate a small-scale no-take fishing area for stock enhancement purposes. To reduce the probability of fishing activity, the exact location of the site was not disclosed to the public. Similar to many artificial reefs created in this region, the research site was established on an otherwise sandy bottom separating low relief, "live bottom" sponge/coral or "hard-bottom" habitats, located sporadically throughout the continental shelf of the South Atlantic Bight (Struhsaker, 1965).

Fish habitats were arranged in a circular distribution to influence the frequency of positive fish observations by a centrally located camera system. Twelve large pyramid-shaped concrete fish habitats (Artificial Reefs Inc.), each measuring 2.5 m wide at the base by 1.5 m tall, were arranged in six clusters of two structures each and evenly spaced along the perimeter of a 'circle' approximately 15 m in diameter. Each of the three sides of each habitat had three triangular-shaped openings, each measuring about 0.1 m (b) x 0.2 m (h), which were penetrable by most reef fishes.

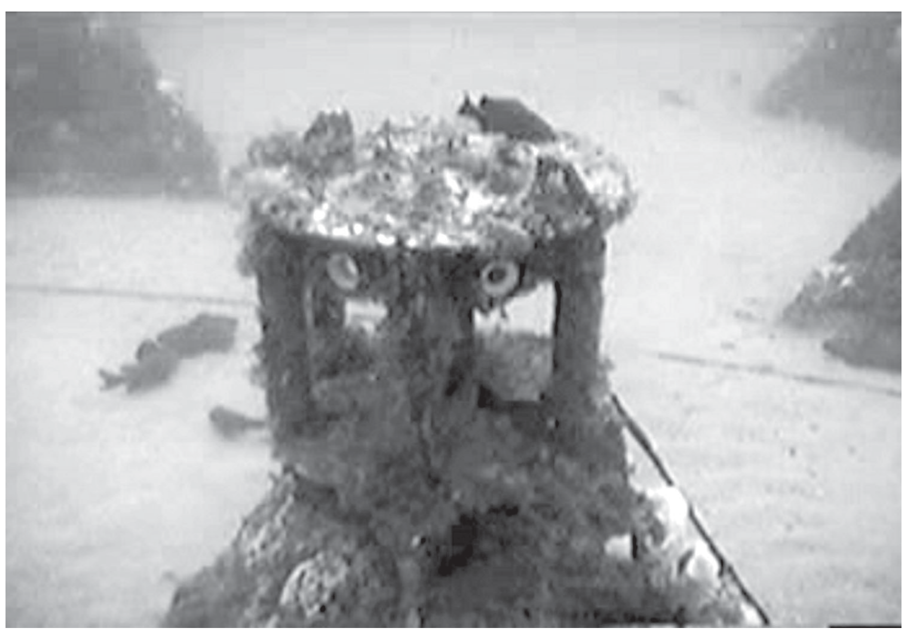
Data Collection and Standardization

Collection of visual observation data began in August 1999. Video data files were collected by six underwater cameras positioned on the top of one pyramid unit (Figure 1) at the center of the reef circle, roughly 7 m from the outer-edge of the reef-unit clusters. Small black and white security cameras (Supercircuts PC-23C) with low light capabilities (< 0.04 lux), wide-angle lenses (8 mm, 12° angle of view), and relatively low resolution (460 lines) collected short (10 s) video data files hourly during daylight.

The camera housing contained a microprocessor and several basic sensors. The Intel 8031 microprocessor with on-board SCSI and video controllers and PCI BUS frame grabber with JPEG compression (Sensoray Co.) provided the means to multiplex analog video signals (NTSC RS-170) from each camera to a single coaxial cable running between the pressure housing and the video capture computer. The capture computer operated Windows NT 4.0, with an Intel-Pentium II single board (Advantech Model SBC 8259) and was remotely located on an above-water platform. The microprocessor interfaced with a video titler and sensors, while the embedded computer acted as a web server; thus file transfer and system parameter updates were possible at anytime via "PC ANYWHERE" software. A console-controlled video frame grabber then converted analog video signals to digital images.

Data logging constraints and broad bandwidth transmission resulted in the selection of 10 s video data files (treated as independent point-counts) for this study. Ten-second video data files with 15-20 frames/s (full motion = 30 frames/s) resulted in compressed files of about 450 KB, which

FIGURE 1
In situ image of the camera housing, showing two of the six camera windows. Note the establishment of sessile invertebrates (sponges, bryozoans) on and fish near the camera housing support structure.



were a compromise between data storage space and minimum resolution needed for species identifications. Power limitations prohibited the use of strobes to monitor the research site at night, when species assemblages and behavior can be vastly different (Stark and Davis, 1966; Wenner, 1983).

Data Transmission

Digital image data from the bottom-mounted camera system was transmitted by an established microwave linkage (U.S. Navy, Tactical Air Combat Training System) to shore (Skidaway Institute of Oceanography, SkIO) in Savannah, GA, and finally via the Internet to the Marine Resources Research Institute (MRRI) of the South Carolina Department of Natural Resources (SCDNR) in Charleston, SC. The transmission system was essentially a transparent wireless local area network (LAN) using a 10/100-Base-T Ethernet topology running a TPC/IP protocol, with the offshore computer appearing as node on the SkIO network.

Video data files were transferred using FTP protocols. The LAN interface, both offshore and at SkIO, was an Ethernet port on a Remote LAN Bridge (RLB) line card installed in a Coastcom T1 Multiplexer. The RLB mapped the Ethernet data packets into a DS1 data stream, or frame. A DS1 frame comprised 24 Time Division Multiplexed (TDM) 8-bit data slots, or DS0's. Data were mapped to 23 DS0's, with one DS0 being reserved for control and monitoring functions. A DS1 frame was transmitted at a rate of 8000 frames per second, resulting in a bandwidth of 8000 x 23 x 8 bits, or 1.472 Mega bits per second (Mbps).

The DS1 frames from the T1 Mux were further multiplexed into the Navy's data stream and transmitted via a terrestrial microwave system to an onshore site at Shellman Bluff, GA. The data stream was subsequently transported via a series of microwave rely links to the Navy's facility at MCAS Beaufort. At one of these rely sites near Savannah, GA, the SABSOON DS1 was de-multiplexed from the Navy's data stream and interfaced to a T1 landline via a Spannet CSU. The T1 line was a copper based four wire dedicated data line leased from AT&T. After being routed through a myriad number of AT&T interconnections and devices, the leased line terminated at SkIO and into a Coastcom T1 Multiplexer where, in an identical (but reversed) process as on the offshore platform, the TDM data were converted back into Ethernet data packets.

Data Management and Analysis

Video data files were manually reviewed and a database of video metadata and annotated content data for each recorded file was created and stored in MS Access. A searchable database of video files was made accessible to the public on the Internet at: http://fishwatch.dnr.sc.gov/

Video metadata was used to document visibility and sample quality. "Good" visibility was defined as the ability to see (1) to and beyond the closest fish habitat and (2) the insides of the structure crevices, which corresponded to at least 10 m of horizontal visibility. "Fair" visibility was defined as the ability to see the extent of the closest habitat and corresponded to approximately 3-10 m of horizontal visibility. "Poor" visibility was defined as the inability to see the full extent of the closest habitat and an inability to differentiate details of the structure (i.e., crevices) and corresponded to approximately <3 m of horizontal visibility. Files that could not be opened or contained a solid-color image were classified as "corrupt".

Video content data consisted of the metadata collection number, species identification to the lowest possible taxon and qualitative codes denoting (1) confidence of proper identification, (2) species-specific relative abundance estimates and (3) species-specific behavioral observations.

Hourly meteorological and hydrographic observations collected within 20 km (Station 41008, "Gray's Reef") of the research site were obtained online from the National Data Buoy Center (NDBC). Using the relational database, video metadata were matched with wave heights (m) based on the day and hour of collection. Descriptive statistics and correlations (MS Excel) were used to compare relationships between the percent of video metadata files with respect to four visibility conditions and six wave height intervals: <0.5 m; 0.5-0.99 m; 1.0-1.49 m; 1.5-1.99 m; 2.0-2.49 m; and >2.5 m.

Detailed analyses of species behavioral and biological-physical relationships were beyond the scope of the present descriptions. Examinations of trends in temporal distribution are the subject of a companion paper; however, examples of some unique findings are included here to demonstrate the types of data available for analyses.

Results

Automated video monitoring resulted in collection of an enormous database of visual observations over an unprecedented amount of time (Table 1) despite some operational difficulties. At least one usable video file (*n*=5,590 total) was recorded daily on 429 of 1,216 d (35% of study) between 27 August 1999 and 24 December 2002. Furthermore, although video monitoring was only conducted for approximately 10 s (0.3%) of every hour, 77% (*n*=4,306) of these files contained at least one 'species' observation.

TABLE 1

Comparison of sampling efforts by this study and other remote camera investigations.

	This Study	Smith and Tyler 1973	Powles and Barans 1980	Capo et al. 2004	Grace et al. 2000
Water Mass	Temperate	Tropical	Temperate	Tropical	Tropical
Water Visibility (m)	1-15		7.5		
Water Depth (m)	25	17	16-32	18-38	30-38
Camera Method	Automated	Automated	Remote	Baited	Baited
Study Duration (d)	1216	487	6	6	1
N Sampling Days	429	34	6	6	1
Sampling Effort (h)	15.5	70	3.5	50	13.7
N species	35	60*	10	67^	57

*Seen with camera ^Day-time only

Video files represented 15.5 h of observations, which were disproportionately collected during 1999 (0.6 h), 2000 (8.5 h) and 2002 (6.4 h). Annual differences in sampling effort were attributed to variable numbers of cameras available for sampling. Electrical problems with computers resulting in file corruptions or incapacitated transmission ability were implicated in 23 incidences totaling 153 d (13% of study) in which no usable video files were available. Malfunction or maintenance of the microwave transmission system resulted in 634 d (52% of study) for which no data could be collected between 19 November 2000 and 14 August 2002.

Fifty-one unique animal 'species' (most identified to genus and species) were observed, of which 35 were positively identified (Table 2). Using the classifications of Smith and Tyler (1973), 12 species could be considered benthic residents, three as benthic cryptics, 15 as mid-water visitors, four as supra-benthic nomads, and one species, the common loon (*Gavia immer*) was unique enough to treat separately. Nearly half of all species with less certain identifications were mid-water visitors (Table 2).

The accumulated number of positively identified species observed over time increased little after the first few months. Forty-nine percent (n=17) of positively identified species were first observed during 0.6 h of sampling between August and December 1999. Substantially increased sampling effort (4.5 h) during the first six months of 2000 produced observations of 13 additional species, including several highly migratory species such as cobia (*Rachycentron canadum*), loggerhead sea turtle (*Caretta caretta*), common loon (*G. immer*) and the roughtail stingray (*Dasyatis centroura*). Monitoring during August-December 2000 (4.0 h) and August-December 2002 (6.4 h) only resulted in documentation of five additional species, all but one of which were not observed at the research site until 2002.

Wave heights were correlated with visibility categories (n=8,523 observations; Figure 2). A strong positive correlation (R^2=0.95) was observed for the relationship between "poor" visibility and wave height intervals (y=11.731x+8.6895). Similarly, a moderate negative correlation (R^2=0.80) was observed for the relationship between "fair" visibility and wave height intervals (y=-6.1776x+38.528). A strong negative correlation (R^2=0.87) was noted for "corrupt" files and wave height intervals (y=-5.1265x+49.905).

Although "poor" visibility and camera fouling (Figure 3) commonly reduced the field of view for recording observations, fish viewing was rarely completely lost. Ninety-seven percent of "good" visibility files (n=171) contained at least one species observation, similar to "fair" visibility files (90%; n=2,060) but quite different from "poor" visibility files (66%; n=2,075). A strong positive correlation existed between the percent of files with at least one 'species' observation among the three visibility categories (R^2=0.90; y=-15.443x + 115.44). Mean number of 'species' per file was slightly greater for "good" (1.82 species/file) visibility than "fair" (1.62 species/file) visibility,

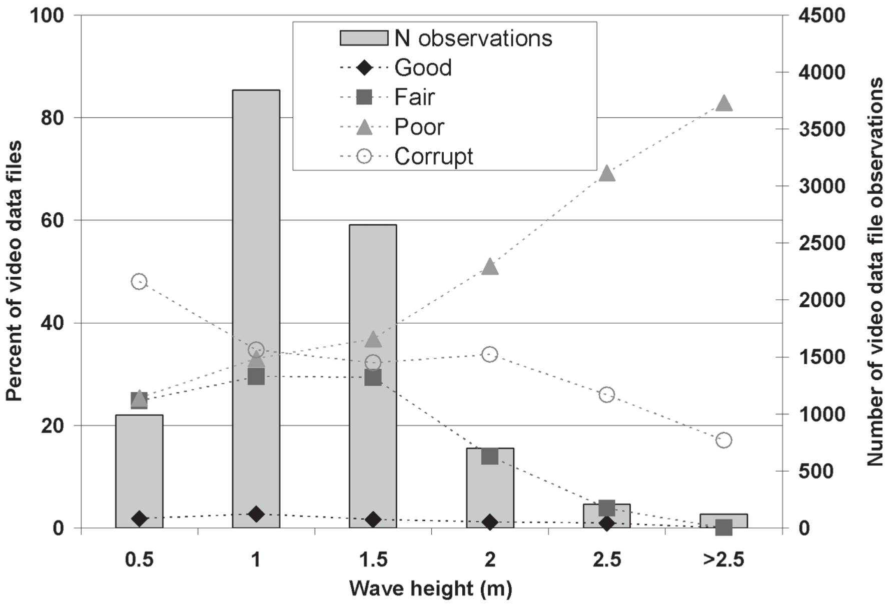
TABLE 2

List of species and species groups (Smith and Tyler, 1973) identified from remote video sampling at the research site between 1999 and 2002. B=Benthic resident; MV=Mid-water visitor; CB=Cryptic benthic; SN=Suprabenthic nomad.

Scientific Name	Common Name	S&T Class	Certainty of Identification
Gavia immer	Common loon	A	Positive
Alueterus schoepfi	Orange filefish	B	Positive
Archosargus probatocephalus	Sheepshead	B	Positive
Balistes capriscus	Gray triggerfish	B	Positive
Centropristis striata	Black seabass	B	Positive
Chaetodipterus faber	Atlantic spadefish	B	Positive
Haemulon aurolineatum	Tomtate	B	Positive
Holocanthus bermudensis	Blue angelfish	B	Positive
Lutjanidae	Snapper (non-specific)	B	Positive
Lutjanus campechanus	Red snapper	B	Positive
Mycteroperca microlepis	Gag grouper	B	Positive
Mycteroperca phenax	Scamp	B	Positive
Rhomboplites aurorubens	Vermilion snapper	B	Positive
Canthidermis sufflamen	Smooth puffer	B	Less certain
Stenotomous aculeatus	Longspine porgy	B	Less certain
Tautoga onitis	Tautog	B	Less certain
Caretta caretta	Loggerhead sea turtle	SN	Positive
Dasyatis centroura	Roughtail stingray	SN	Positive
Dasyatis sp.	Stingray (non-specific)	SN	Positive
Ginglymystoma cirratum	Nurse shark	SN	Positive
Carcharinus taurus	Sandbar shark	SN	Less certain
Gymnura micrura	Smooth butterfly ray	SN	Less certain
Rhinoptera bonasus	Cownose ray	SN	Less certain
Caranx crysos	Blue runner	MV	Positive
Caranx ruber	Bar jack	MV	Positive
Carcharinus limbatus	Blacktip shark	MV	Positive
Carcharinus plumbeus	Sandbar shark	MV	Positive
Ctenophora	Ctenophore	MV	Positive
Cyanea capillata	Lion's mane jellyfish	MV	Positive
Decapterus sp.	Scad	MV	Positive
Etrumeus teres	Round scad	MV	Positive
Euthynnus alletteratus	Little tunny	MV	Positive
Rachycentron canadum	Cobia	MV	Positive
Remora remora	Remora	MV	Positive
Selar crumenopthalmus	Bigeye scad	MV	Positive
Seriola dumerili	Greater amberjack	MV	Positive
Sphyraena barracuda	Great barracuda	MV	Positive
Mola mola	Ocean sunfish	MV	Positive
Anchoa sp.	Anchovy	MV	Less certain
Chloroscombrus chrysurus	Atlantic bumper	MV	Less certain
Sphyrna tiburo	Bonnethead shark	MV	Less certain
Stomolophus melagris	Cannonball jellyfish	MV	Less certain
Stronglyura marina	Atlantic needlefish	MV	Less certain
UnID Finfish		MV	Less certain
Unid Shark		MV	Less certain
Apogon pseudomaculatus	Two-spot cardinalfish	CB	Positive
Gobiesocidae	Gobie (non-specific)	CB	Positive
Pomacentrus sp.	Damselfish (non-specific)	CB	Positive
Portunidae	Portunid crab	CB	Less certain
Rypitcus maculatus	White-spotted soapfish	CB	Less certain
Unid Invert		CB	Less certain

FIGURE 2

Descriptive relationships between visibility and wave height.



but was nearly twice as great as the mean number of species observed for "poor" (0.98 species/file) visibility. Minimum (0) and maximum (5-6) numbers of 'species' per file were similar for all three visibilities.

Observations of interactions between and among species (i.e., feeding habits, co-occurrence, etc.), particularly during the late fall and winter were likely unattainable using any other means of data collection. As many as three individual ocean sunfish (*Mola mola*, Figure 4) were observed at a time in 23 video files, predominantly collected between January and March. Courtship displays and the presence of pre-spawning "gray-head" male black sea bass (*Centropristis striata*, Figure 5) were common during the late fall and early winter in all years. Although juvenile black sea bass were not observed, juveniles of what appeared to be vermilion snapper (*Rhomboplites aurorubens*) were exceedingly abundant in the late fall of all years. Eighty-five percent (n=18 of 21 files) of sandbar shark (*Carcharinus plumbeus*) observations were associated with large schools of predatory teleosts including blue runner (*Caranx crysos*), greater amberjack (*Seriola dumerili*) and/or little tunny (*Euthynnus alletteratus*, Figure 6), with all but two sandbar shark observations occurring between August and November in all years.

Discussion

Intensive temporal sampling, combined with the visual nature of the data, resulted in the creation of a large quantitative and qualitative dataset for detailed examination of species distributional patterns (examined in a companion paper), that probably could not have been collected without the use of a remote video camera system. Infrequent point-in-time methods, whether visual in nature (Gledhill et al., 1996) or involving removal of individuals can provide good estimates of differences in species relative abundance in space; however, they rarely provide adequate short-term temporal replication for assessing long-term trends given documented relationships between natural physical cycles, such as tides and photoperiod, on short-term distributional patterns of many fishes (Wirjoatmodjo and Pitcher, 1984; Klimley et al., 1988; Meyer et al., 2000; Arendt et al., 2001b; Hartill et al., 2003). Hourly sampling during daylight also afforded greater probability of observing cyclic or stochastic events under natural conditions than traditional point-in-time sampling, particularly during periods of high seas, when non-remote sampling is often not possible. The data collected in this study should enhance the ability of fisheries managers to make informed decisions, particularly once data are incorporated into ecosystem or biological-physical models. Although many benefits resulted from the use of the remotely operated video system, these benefits have not yet reached their full potential due to several disadvantages.

FIGURE 3

Temporal distribution of video files (%) with "poor" visibility and camera fouling between 1999 and 2002.

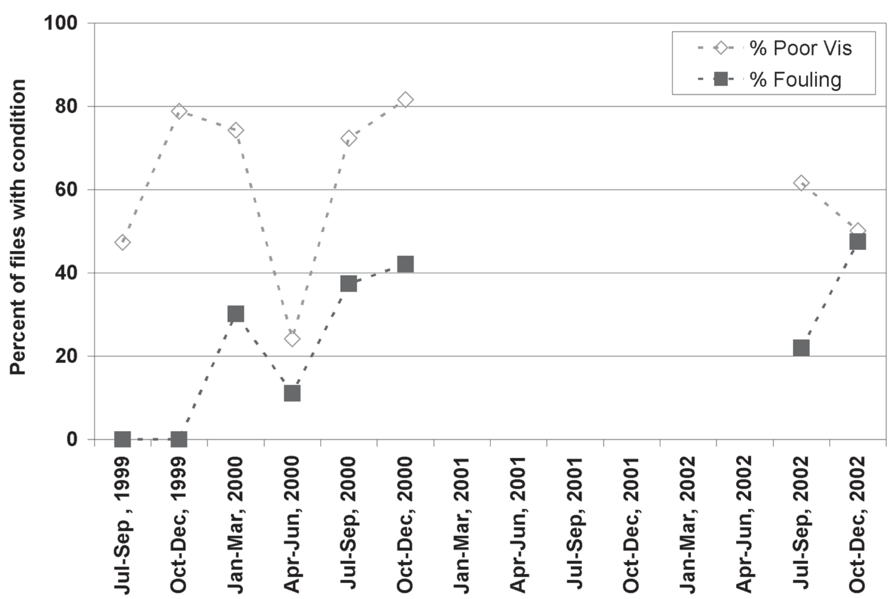
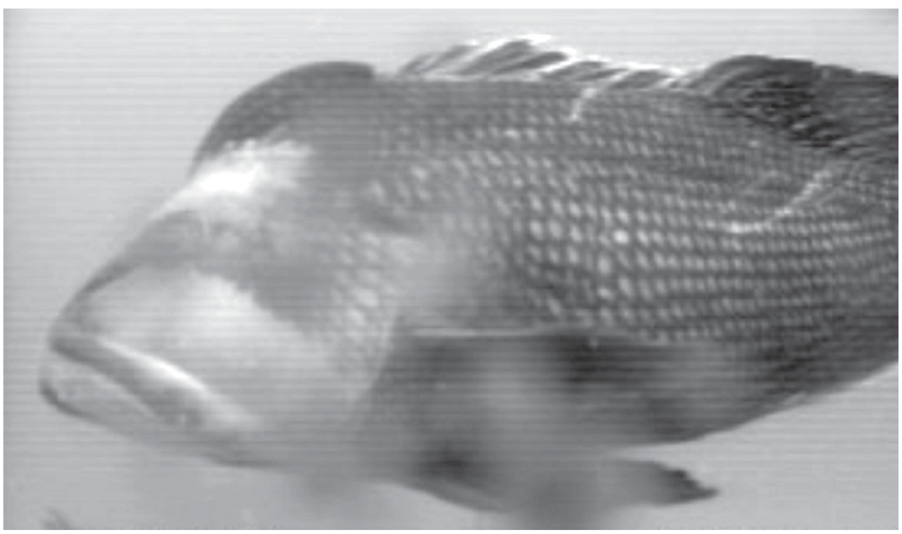


FIGURE 4

In situ image of the three individual ocean sunfish, *Mola mola*, at the research site.

FIGURE 5

In situ image of a pre-spawning "gray-head" male black sea bass (*C. striata*) near a camera.



The primary disadvantage of the present remote camera system was unreliability of the multi-faceted data collection and transmission system, which resulted in short- and long-term interruptions in sampling. Most disruptions to data collection were caused, primarily, by electronic (power source and transmission) problems. Furthermore, electrical problems could not be immediately addressed because of the remote, offshore location of the system; thus, maintenance and repair of the at-sea system was much more difficult and complicated than if the system were shore-based due to weather dependence, transportation requirements (i.e., vessels or helicopter support), opportunistic transportation availability, and expense. Although microwave transmission has the advantage of near real-time data transfer and substantial transmission distance, its technical complexity offshore, dependence on solar and wind power sources, associated battery storage cells, and sophisticated electronics often contributed to relatively long interruptions in data acquisition. This unfortunate reality should improve with the development of more reliable remote power sources and marine electronics, or other designs for remote collection of visual data offshore.

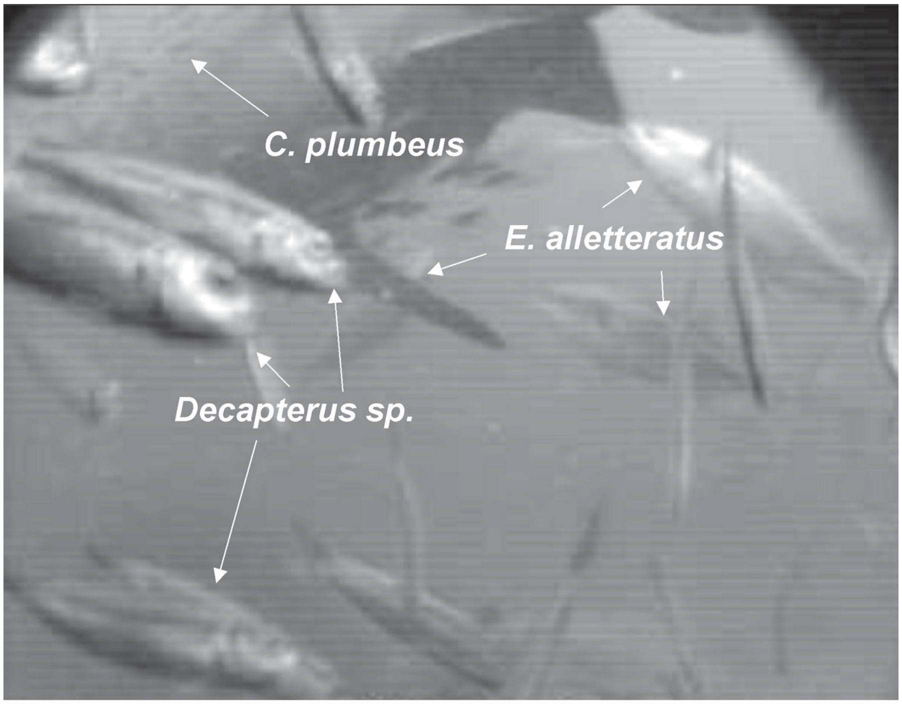
An alternative to the microwave video system used in this study may be to use autonomous video logging systems, which would require the same diver support for recovery and basic maintenance of camera windows as the present system, but without cable replacement and transmission problems. Data loggers could be recovered from shallow shelf depths by divers or by shipboard scientific crews during routine maintenance of oceanographic instruments associated with existing offshore mooring systems. A network of such video systems at regional index stations along latitudinal and depth gradients on the continental shelf would greatly expand spatial data coverage of reef fish assemblages in areas where real-time transmission to shore is unreliable or otherwise not feasible.

Deployment durations for data logger video systems are presently limited by window fouling, power supply and data storage. Data memory chips are rapidly increasing in capacity, while battery packs are becoming smaller and more powerful. Copper hoods shielding camera windows may help reduce settlement of fouling organisms. In collaboration with researchers in North Carolina, South Carolina, and Georgia, remote video data loggers will be evaluated at several locations in mid-shelf waters of the South Atlantic Bight beginning as early as summer 2005.

As electronic improvements enhance the ability to collect and store large video data files using either microwave-based or automated data logging systems, additional emphasis must be placed on increasing the efficiency of processing and managing volumes of video data, so that their near real-time value is not reduced or lost. Presently, annotation of video file content is labor-intensive, although data management in a rela-

FIGURE 6

In situ image depicting the predatory associations among sandbar sharks (*C. plumbeus*), little tunny (*E. alluterus*) and greater amberjack (*S. dumerili*, not visible) during a feeding event on forage species, predominantly scad (*Decapterus* sp.).



tional database format enables expeditious analyses. Automated annotation methods, using artificial intelligence attention selection algorithms, have been developed for use with video data files collected by remotely operated vehicle and submersible video projects (Edgington et al., 2003) at the Monterey Bay Aquarium Research Institute. Successful application of this technology to the short video data files collected in the current study could result in significant time savings and increased efficiency in conducting the critical process of annotating large quantities of fisheries video data; thus, automated annotation would increase the overall effectiveness of the video sampling methodology, including incorporation of data into future fisheries models.

The video camera system described in this paper documented a diversity of species over several years while only sampling 0.3% of every hour at best. Benthic reef fishes, the focus group for this study, were readily identifiable even under difficult viewing conditions due to characteristic swimming patterns and other behavioral cues. Mid-water visitors were common throughout the study, yet many of these species do not appear, or appear in greatly reduced numbers, in collections made using trawls, traps and longline sets on the mid-continental shelf in the Southeastern U.S. (Powles and Barans, 1980; Wenner, 1983; Collins, 1990) and elsewhere (Grace et al., 2000; Cappo et al., 2004). Many mid-water visitors were large teleosts or elasmobranches of management interest, supporting the assertion of Cappo et al. (2004) that intense video monitoring can play an important role in the study of these species, as well as large suprabenthic nomads such as sea turtles and stingrays. Similar to Smith and Tyler (1973), our camera system was not ideal for studying small cryptic species; however, remote camera systems with a modified field of view have been used for this purpose (Nelson).

Failure to observe a species did not necessarily imply species absence. Inability to observe species, particularly benthic reef species that remained at the research site but were not seen, could have resulted from (1) poor visibility, (2) high concentrations of mid-water visitors restricting the field of view and/or (3) shifts in horizontal and vertical positions within the visible habitat. While researchers cannot control environmental conditions or species dynamics, the probability of observing resident reef fishes at least once per day was greatly increased with multiple cameras and sampling events. Determination of more detailed temporal distribution and habitat utilization patterns for individual fishes, and insight into whether non-observation resulted from absence or some other factor, could be accomplished using automated acoustic telemetry systems (Arendt et al., 2001a; Hartill et al., 2003; Egli and Babcock, 2004). Joint use of automated telemetry and video monitoring might assist in developing video data 'correction factors' for estimates of species relative abundance; similar correction factors have been developed for aerial surveys using telemetry data for bluefin tuna (Brill et al., 2002) and loggerhead sea turtles (Keinath et al., 1996). The combination of visual and acoustic methods could also provide further data on species interactions, which influence habitat carrying capacity, and therefore the effectiveness of small "no fishing" areas.

Visual data represent some of the highest quality fisheries information available because they allow for positive species identifications, particularly for species which might not otherwise be collected using traditional sampling gears. Visual data also contribute to understanding behavioral responses to hydrographic conditions and complement other remote data collection methods such as passive and active acoustics. Pending mitigation of technical problems, remote visual sampling will provide a means for collecting data at rates comparable with oceanographic measurements, a requirement for correlating visual/biological and physical data sets. Technological advances since the work of Smith and Tyler (1973) suggest continued improvements in system reliability, making their widespread use more likely in the near future. Given the merits of remote collection of fisheries video data, this approach should be expanded spatially to include a wider range of sampling in both depth and latitude.

Acknowledgements

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References

Arendt, M.D., J.A. Lucy and T.A. Munroe. 2001a. Seasonal occurrence and site utilization patterns of adult tautog, *Tautoga onitis* (Labridae) at manmade and natural structures in lower Chesapeake Bay. Fish Bull. 99(4):519-527.

Arendt, M.D., J.A. Lucy and D.A. Evans. 2001b. Diel and seasonal activity patterns of adult tautog, *Tautoga onitis*, in lower Chesapeake Bay, inferred from ultrasonic telemetry. Environ Biol Fishes. 62:379-391.

Baamstedt, U., S. Kaartvedt and M. Youngbluth. 2003. An evaluation of acoustic and video methods to estimate the abundance and vertical distribution of jellyfish. J Plankton Res. 25(11):1307-1318.

Barnett, C.W. and N.W. Pankhurst. 1996. Effect of density on the reproductive behavior of the territorial male demoiselle *Chromis dispilus* (Pisces: Pomacentriade). Environ Biol Fishes. 46:343-349.

Brill, R., M. Lutcavage, G. Metzger, J. Stallings, P. Bushnell, M. Arendt, J. Lucy, C. Watson, and D. Foley. 2002. Horizontal and vertical movements of juvenile bluefin tuna (*Thunnus thynnus*) in the western North Atlantic, determined using ultrasonic telemetry. Fish Bull. 100(2):155-167.

Brock, V.F. 1954. A preliminary report on a method of estimating reef fish propulations. J Wildl Manage. 18:299-308.

Cappo, M., P. Speare and G. De'ath. 2004. Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessment of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. J Exp Mar Biol Ecol. 302:123-152.

Caribbean Web Cam (CWC), LLC. "Bonaire Web Cams." Available at: http://www.bonairewebcams.com/BonaireReefCam.php? Accessed 22 Mar 2005.

Collins, M.R. 1990. A comparison of three fish trap designs. Fish Res. 9:325-332.

Collins, S. "Cams and Reports". Available at http://www.surfline.com/home/index.cfm Accessed 22 March 2005.

Edgington, D.R., D. Walther, K.A. Salamy, M. Risi, R.E. Sherlock and C. Koch. 2003. Detection of visual events in underwater video using a neuromorphic saliency-based attention system. EOS Transactions, AGU 84(46), Fall Meet. Suppl., Abstract H11F-0912.

Egli, D.P. and R.C. Babcock. 2004. Ultrasonic tracking reveals multiple behavioural modes of snapper (*Pagrus auratus*) in a temperate no-take marine reserve. ICES Journal of Marine Science. 61:1137-1143.

Gledhill, C.T., J. Lyczkowski-Shultz, K. Rademacher, E. Kargard, G. Crist and M.A. Grace.1996. Evaluation of video and acoustic index methods for assessing reef-fish populations. ICES Journal of Marine Science. 53:483-485

Grace, M., M. Bahnick and L. Jones. 2000. A preliminary study of the marine biota at Navassa Island, Caribbean Sea. Mar Fish Rev. 62(2):43-48.

Hartill, B.W., M.A. Morrison, M.D. Smith, J. Boubée and D.M. Parsons. 2003. Diurnal and tidal movements of snapper (*Pagrus auratus*, Sparidae) in an estuarine environment. Mar Freshwater Res. 54:931-940.

Hobson, E.S. 1972. Activity of Hawaiian reef fishes during the evening and morning transitions between daylight and darkness. Fish Bull. 70:715-740.

Keinath, J.A., J.A. Musick and D.E. Barnard. 1996. Abundance and distribution of sea turtles off North Carolina. Final report for the Minerals Management Service (Contract 14-35-0001-30590) Atlantic OCS Region. OCS Study MMS 95-0024. Prepared by the Virginia Institute of Marine Science, College of William and Mary. Gloucester Point, VA, 156 p.

Klimley, A.P., S.B. Butler, D.R. Nelson and A.T. Stull. 1988. Diel movements of scalloped hammerhead sharks, *Sphyrna lewini* Griffith and Smith, to and from a seamount in the Gulf of California. J Fish Biol. 33:751-761.

Lobel, P.S. 2001. Fish bioacoustics and behavior: Passive acoustic detection and the application of a closed-circuit rebreather for field study. Mar Technol Soc J. 35(2):19-28.

Meyer, C.G., K.H. Holland, B.M. Wetherbee and C.G. Lowe. 2000. Movement patterns, habitat utilization, home range size and site fidelity of whitesaddle goatfish, *Parupeneus porhyreus*, in a marine reserve. Environ Biol Fishes. 59:235-242.

Myrberg, A.A. 1972. Using sound to influence behavior of free-ranging marine animals. Pp. 435-468 In: Winn, H.E. and B.L. Olla (eds.). Behavior of Marine Animals: Current Perspectives in Research, Vol. 2, Vertebrates. New York: Plenum Press.

National Data Buoy Center (NDBC), National Weather Service (NWS), National Oceanograhic and Atmospheric Administration (NOAA). "Historical Data and Climate Summaries." Available at: http://www.ndbc.noaa.gov/station_page.php?station=41008 Accessed 08 April 2005.

Nelson, R. "Usage of unique video surveillance techniques to study Hawaiian shrimp gobies and their snapping shrimp partners." Available at: http://www2.hawaii.edu/~robertne/research.htm. Accessed 22 March 2005.

Parker, R.O., Jr. and S.W. Ross. 1986. Observing reef fishes from submersibles off North Carolina. Northeast Gulf Science. 8:31-49.

Parker, R.O., Jr., A.J. Chester and R.S. Nelson. 1994. A video transect method for estimating reef fish abundance, composition, and habitat utilization at Gray's Reef National Marine Sanctuary, Georgia. Fish Bull. 92:787-799.

Powles, H. and Barans, C.A. 1980. Groundfish monitoring in sponge-coral areas off the Southeastern United States. Mar Fish Rev. 42(5):21-35.

Runge, J.A., P.J.S. Franks, W.C. Gentleman, B.A. Megrey, K.A. Rose, F.E. Werner and B. Zakardjian. 2004. Chapter 13: Diagnosis and prediction of variability in secondary production and fish recruitment processes: development in physical-biological modeling. In: The Sea, Vol. 13, eds. A.R. Robinson and K.H. Brink. pp. 413-473. New York: John Wiley & Sons.

Sanderson, J.G., and M. Trolle, 2005. Monitoring elusive mammals: unattended cameras reveal some of the world's wildest places. Am Sci. 93:148-155.

Smith, C.L. and J.C. Tyler. 1973. Population ecology of a Bahamian suprrabenthic shore fish assemblage. Am Mus Novit. 2528:1-37.

Stark, W.A., II and W.P. Davis. 1966. Night habits of fishes of Alligator Reef, Florida. Ichthyological Aquarium Journal, 38:313-356.

Steinberg, J.C., W.C. Cummings, B.D.Bray and J.Y. MacBain (Spires). 1965. Further bio-acoustic studies off the west coast of North Bimini, Bahamas. Bull Mar Sci. 15(4):942-963.

Stevens, B.G. 2003. Timing of aggregation and larval release by Tanner crabs, *Chionoedi bairdi*, in relation to tidal current patterns. Fish Res. 65(1-3): 201-216.

Stryke, D. "Diving History: Picture This!" Available at: http://www.enekton.com/divehistory3.html. Accessed 22 March 2005.

Struhsaker, P. 1969. Demersal fish resources: Composition, distribution and commercial potential of the continental shelf stocks off southeastern United States. U.S. Fish and Wildlife Service, Fisheries Industrial Research, 4:261-300.

Wenner, C.A. 1983. Species associations and day-night variability of trawl-caught fishes from the inshore sponge-coral habitat, South Atlantic Bight. Fish Bull. 81(3):537-552.

Westera, M., P. Lavery and G. Hyndes. 2003. Differences in recreationally targested fishes between protected and fished areas of a coral marine park. Journal of Experimental Biology and Marine Ecology, 294:145-168.

Wirjoatmodjo, S. and T.J. Pitcher. 1984. Flounders follow the tides to feed: evidence from ultrasonic tracking in an estuary. Estuar Coast Shelf S. 19:231-241.