

Abstract—Red hind (*Epinephelus guttatus*) have been overfished in the Caribbean and were included with seven other regional grouper species deemed vulnerable to risk of extinction. The Puerto Rico Department of Natural and Environmental Resources desired to map spawning red hind aggregations within commonwealth waters as part of their resource management program for the species. Mobile hydroacoustic surveys were conducted over 3-day periods in 2002 and 2003, indexed to the full moon phase in February or March when red hind were known to aggregate. Four vessels concurrently sampled the southwest, south, and southeast coasts of Puerto Rico in 2002. In 2003, three vessels conducted complementary surveys of the northwest, north, and northeast coasts of the island, completing a circuit of the coastal shelf-spawning habitat. These surveys indicated that red hind spawning aggregations were prevalent along the south and west coasts, and sparse along the north coast during the survey periods. Highest spawning red hind concentrations were observed in three areas offshore of the west coast of Puerto Rico, around Mona and Desecheo islands (20,443 and 10,559 fish/km², respectively) and in the Bajo de Cico seasonal closed area (4,544 fish/km²). Following both 2002 and 2003 surveys, a series of controlled acoustic measurements of known local fish species in net pens were conducted to assess the mean target strength (acoustic backscatter) of each group. Ten species of fish were measured, including red hind (*E. guttatus*), coney (*E. fulvus*), white grunt (*Haemulon plumieri*), pluma (*Calamus pennatula*), blue tang (*Acanthurus coeruleus*), squirrel fish (*Holocentrus* spp.), black durgelon (*Melichthys niger*), ocean file fish (*Canthidermis sufflamen*), ocean surgeon fish (*Acanthurus bahianus*), and butter grouper (*Mycteroperca* spp.). In general, the mean target strength results from the caged fish experiments were in agreement with published target strength length relationships, with the exception of white grunt and pluma.

Hydroacoustic evaluation of spawning red hind (*Epinephelus guttatus*) aggregations along the coast of Puerto Rico in 2002 and 2003

Samuel V. Johnston

Hydroacoustic Technology, Inc.
715 NE Northlake Way
Seattle, WA 98105-6429
E-mail: sjohnston@htisonar.com

José A. Rivera

Under contract to:
Biodiversity and Protected Resources Division
Miami Laboratory
National Marine Fisheries Service, NOAA
Box 1736
Boquerón, PR 00622-9704

Aida Rosario

Department of Natural and
Environmental Resources
Commonwealth of Puerto Rico
P.O. Box 9066600
Pta. De Tierra Station
San Juan, PR 00906

Mark A. Timko

Patrick A. Nealson

Kevin K. Kumagai

Hydroacoustic Technology, Inc.
715 NE Northlake Way
Seattle, WA 98105-6429

Introduction

Tropical marine fish species, such as groupers, are generally considered to be overfished across most of their worldwide distribution (Sadovy, 1994; Gascoigne¹). Over fishing has driven many grouper stocks below sustainable levels and eliminated them from much of their historic range (Sadovy, 1997). Effective management of these fisheries requires innovative approaches, including harvest restrictions, community management systems, and networks of marine protected areas (MPA's). Selection of the most effective management approach requires reliable information as to the distribution, abundance, biology, and harvest of these populations.

Caribbean groupers include a variety of species of the family Serranidae (order Perciformes), belonging to either the genera *Epinephelus* or *Mycteroperca*. Common representatives of these genera that are found in Puerto Rican waters include the speckled hind (*E. drummondhayi*), rock hind (*E. adscensionis*) and red hind (*E. guttatus*). The red hind is the most commercially important of the Puerto Rican hinds and has historically supported significant regional fisheries

along the west and south coasts of the island (Matos-Caraballo, 2004). However, available information shows that overall grouper landings in the U.S. Caribbean have declined 45% between 1977 and 1985, with an even greater rate of decrease between 1987 and 1989 (Appeldoorn et al., 1992; Sadovy, 1994).

From fishermen it is known that red hind spawn within a specific time period surrounding the full moon in late winter, typically in January, February, or March (Sadovy et al., 1994). They aggregate only at specific locations, where they are present in large numbers (Shapiro, 1993; Sadovy et al., 1994). This stage in the life cycle of the red hind is particularly important since the entire annual reproduction for a region may be concentrated at a few particular locations where aggregations occur for only a few days each year (Nemeth, 2005). In many instances, entire regional stocks have

¹ Gascoigne, J. 2002. Nassau grouper and queen conch in the Bahamas: Status and management options. Report by MacAlistair Elliot and Partners, Ltd.. (MEP) to the Bahamas Reef Environment Educational Foundation (B.R.E.E.F.). <http://www.macalisterelliott.com/media/reports/1651R02C.pdf> [Accessed 25 Sept. 2006.]

been wiped out due to intense fishing pressure on spawning aggregations (Bohnsack²).

While the spatial and temporal aggregating behavior of spawning grouper makes them subject to high exploitation, it also provides an annual opportunity to assess population density and distribution. The objective of this paper was to use this localized spawning behavior to identify, map, and quantify red hind aggregations along the entire Puerto Rican shelf using mobile hydroacoustics. The study quantified school aggregations with the characteristic vertical stacking behavior consistent with spawning behavior in red hind and similar grouper species along the continental shelf surrounding Puerto Rico. Due to the limited effort available and the narrow time window for the aggregations, the study objectives were exploratory in nature. Specific project objectives included the following:

- 1) Employ mobile hydroacoustics to estimate the density and map the location and distribution of red hind/grouper schools across the surveyed coastline.
- 2) Characterize fish school metrics including school location and mean target strength values.
- 3) Estimate mean target strength values from caged fish of known species and size to aid in interpretation of the field data and accurate scaling of echo integration density results.
- 4) Compare the distribution of observed fish aggregations with fishing activity indicated by the distribution of fishing vessels.

Methods

Burczynski (1979) and MacLennan and Simmonds (1992) discuss the principles of mobile hydroacoustic fisheries assessment. Over 1300 km of transects were surveyed during the 2002–2003 Puerto Rico red hind surveys, encompassing the entire 500 km coastline of the island, with the exception of the area between Culebra and Vieques islands.

The areas surveyed during the 2002 hydroacoustic red hind assessment (Johnston et al.³) were located along the edge of the continental shelf surrounding

the south, southwest, and southeast coasts of Puerto Rico. Four individual geographic survey areas were designated within the overall region of interest, based on the length of transects that could be monitored within a 3-day period of time surrounding the full phase of the moon in February (Fig. 1). The areas were adjacent to one another, providing a coherent sampling record along the southern half of the Island of Puerto Rico. A total of approximately 957 kilometers (517 nautical miles) of transects were surveyed by the four survey vessels between 27 February and 2 March 2002, gathering data for approximately 12 h/d.

- 1) Area 2002-A: the southern half of the west coast centered around Mayaguez between approximately Rincon and Cabo Rojo. A total of 92 km of transects were surveyed.
- 2) Area 2002-B: the southern half of the eastern Puerto Rican coast between Arroyo and the eastern end of the Island of Vieques. A total of 182 km of transects were surveyed.
- 3) Area 2002-C: the southern coast between approximately Cabo Rojo and Ponce, centered around La Perguera. A total of 111 km of transects were surveyed.
- 4) Area 2002-D: the south central coast of Puerto Rico between approximately Ponce and Arroyo, based out of Salinas. A total of 143 km of transects were surveyed.

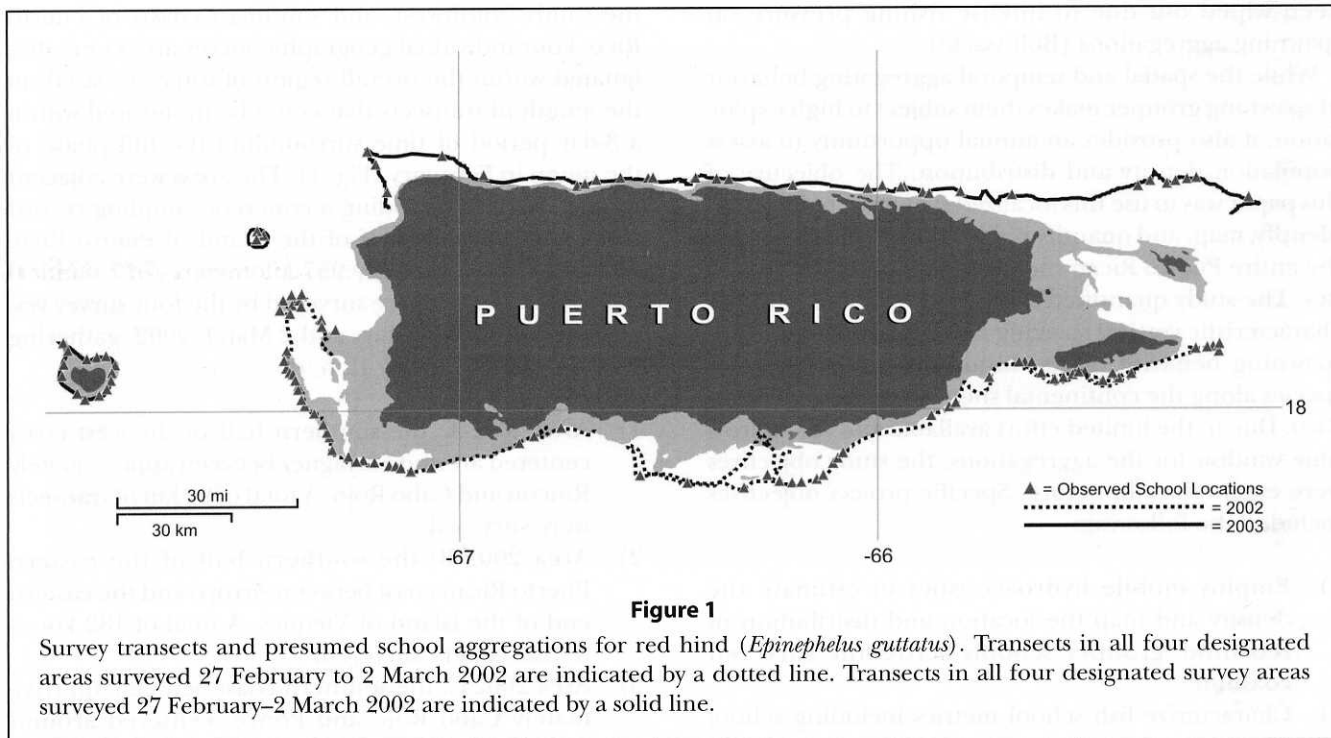
The areas surveyed during the 2003 hydroacoustic red hind assessment were located along the edge of the continental shelf surrounding the north, northwest, and western offshore islands of Puerto Rico (Nealson et al.⁴). Three individual geographic survey areas were designated within the overall region of interest, based on the length of transects that could be monitored within a 3-day period of time surrounding the full phase of the moon in March (Fig. 1). The areas were adjacent to one another, providing a coherent sampling record along the northern half of Puerto Rico. A total of approximately 395 kilometers (213 nautical miles) of trackline were surveyed by the three survey vessels between March 18 and March 21, 2003, gathering data for approximately 12 h/d.

- 1) Area 2003-A: the northeast Puerto Rican coast, from Culebra Island to San Juan. A total of 128 km of transects were surveyed.

² Bohnsack, J. A. 1989. Protection of grouper spawning aggregations. Coastal Resource Division Contribution CRD-88/89-06. Southeast Fisheries Science Center, NMFS, 75 Virginia Beach Dr., Miami, FL 33149. 8 p.

³ Johnston, S. V., P. A. Nealson, K. K. Kumagai, M. A. Timko, and G. W. Tritt. 2002. Hydroacoustic evaluation of spawning red hind (*Epinephelus guttatus*) aggregations along the coast of Puerto Rico in February 2002. Report by Hydroacoustic Technology, Inc. (715 NE Northlake Way, Seattle, WA 98105-6429) to Puerto Rico Dept. of Natural Resources, San Juan, PR.

⁴ Nealson, P. A., G. W. Tritt, M. A. Timko, K. K. Kumagai, and S. V. Johnston. 2003. Hydroacoustic evaluation of spawning red hind (*Epinephelus guttatus*) aggregations along the coast of Puerto Rico in March 2003. Report by Hydroacoustic Technology, Inc. (715 NE Northlake Way, Seattle, WA 98105-6429) to Puerto Rico Dept. of Natural Resources, San Juan, PR.



- 2) Area 2003-B: the northwest coast of Puerto Rico, from San Juan to Aguadilla. A total of 153 km of transects were surveyed.
- 3) Area 2003-C: the western coast from Aguadilla to Rincon, Mona, Monita, and Desecheo Islands, and Baja de Cico. A total of 114 km of transects were surveyed.

Six-second echo integration sampling intervals were used to define the minimum spatial areas of resolution over which to estimate school biomass during field data collection. During data analysis, individual school events were identified and processed from the digital samples (DAT tape) data set, to provide finer-scale resolution and editing of these events. GPS data were collected simultaneously, permitting individual schools to be precisely located along the survey transects.

Fishing boat locations were obtained from aerial surveys conducted in 2002 and 2003 by the Puerto Rico Department of Natural and Environmental Resources (DRNA).

Hydroacoustic equipment

Split-beam hydroacoustic systems (Model 243, Hydroacoustic Technology Inc., Seattle, WA) operating at 200 kHz were used for the 2002–2003 Puerto Rico red hind population assessments. Data were recorded to computer and DAT tape during field collection, and

later analyzed using EchoScape, an HTI data entry and analysis program.

In 2002, the echo sounders on each survey vessel sampled both 6° and 15° transducers in a fast-multiplexed (simultaneous) mode. The 15° beam width transducers were incorporated to ensure adequate sampling volumes in shallow water. Based on exploratory transects surveyed in shallow waters in 2002, the characteristic red hind spawning aggregations were not observed in shallow water, and it was determined that a single 6° transducer was sufficient for monitoring the relatively deeper areas along the shelf breaks where these schools were observed. This single 6° configuration was used for sampling in 2003. Both transducers were oriented straight down in the water column and mounted on a 1-m long aluminum dead-weight towing vehicle. The maximum sample depth for the hydroacoustic systems was approximately 200 m for the sizes of red hind encountered during the 2002 and 2003 surveys.

Each survey system collected the hydroacoustic data files directly to a laptop computer. All data were also concurrently recorded to DAT tape, providing an ultimate data backup of the unfiltered digital samples for later reprocessing as digital samples. Differential or WAAS-enabled (Wide Area Augmentation System) Global Positioning System (GPS) receivers were interfaced with all hydroacoustic systems to provide position to within approximately 3 m.

Prior to the survey period, the hydroacoustic systems used in this study were calibrated relative to a U.S.

Naval standard transducer of known sensitivity. The 2002–2003 Puerto Rico red hind surveys employed a minimum on-axis target detection threshold of -50 dB. This threshold corresponded to a minimum fish detection length across the full nominal transducer beam width of approximately 55 mm based on Love (1971). To verify the laboratory calibration of the hydroacoustic system, in situ field measurements were made using a 38.1 mm tungsten carbide standard target (MacLennan and Simmonds, 1992) during each individual survey cruise.

Data collection

The 2002 red hind hydroacoustic surveys were conducted between 27 February and 2 March 2002. All school density data were successfully collected within 2 days following the full moon (27 February). The 2003 red hind hydroacoustic surveys were conducted 18–21 March 2003 (the full moon occurred on 18 March). Surveys consisted of a series of predetermined transects following the continental shelf area and the region just inshore of this break. Survey transects generally zigzagged along the edge of the continental shelf approximately 55 m (180 ft) deep. Transects were traversed at a boat speed of approximately 4–5 knots. The overall acoustic repetition (ping) rate of the hydroacoustic system was 2 pings/sec per transducer.

Data analysis

Data were analyzed to provide estimates of fish population and biomass in the survey areas, estimates of fish target strength (related to fish length), and spatial school metrics. Data visualization and editing was performed using the program EchoScape (Version 2.52, Hydroacoustic Technology, Inc., Seattle, WA) to visually identify aggregations from the field computer data file records and mark all single echoes within identified school aggregations as tracked fish. The EchoScape program linked all of the field data records such that, within the tracked fish table, each aggregation was identified with mean target strength, detection time, and a latitude/longitude location.

Raw digital sample files that were collected on the DAT were reintegrated at fine integration intervals of 6 sec in duration and 1 m deep. This provided the ability to isolate the red hind schools from surrounding structure and other targets. These reintegrated files were then read back into EchoScape for final editing. EchoScape was used to manually select the cells that contain aggregations for subsequent estimation of school densities.

In situ target strengths of ten species of coral reef-dwelling fish were measured by using the same split-

Table 1

Fish species used in the 2002 and 2003 caged fish measurements, and the average length of each individual.

Fish name	Fish species	Length (cm)
2002		
Red hind	<i>Epinephelus guttatus</i>	20.2
Coney	<i>Epinephelus fuscus</i>	21.3
White grunt	<i>Haemulon plumieri</i>	16.0
Pluma	<i>Calamus pennatula</i>	17.9
Blue tang	<i>Acanthurus coeruleus</i>	18.0
2003		
Squirrel fish	<i>Holocentrus</i> spp.	22.9
Black durgon	<i>Melichthys niger</i>	27.9
Ocean file fish	<i>Canthidermis sufflamen</i>	45.7
Ocean surgeon fish	<i>Acanthurus bahianus</i>	41.9
Butter grouper	<i>Mycteroperca</i> spp.	25.4

beam hydroacoustic system described above (Table 1). Measurements were made at La Perguera on 2 March 2002, and Escollo Negro, near Cabo Rojo, on 21 March 2003. Individual fish were placed in a cylindrical, steel-framed cage that was 3 m in diameter, 0.9 m in height, covered with fine mesh monofilament netting. The cage was suspended 7 m below the surface, and fish were placed in the cage individually by divers. One fish of each species was measured at a time. All fish were alive when placed in the cage. The squirrel fish was dead upon retrieval, but all others were alive. The transducer was suspended 5.7 m above the cage, and aimed downward through the fine mesh netting. The ping rate was 10 pings per second. EchoScape was used to summarize the target strength values of red hind and other commonly occurring species measured during the caged fish experiments. These mean backscatter (σ) values were compared to the in situ measures of observed fish target strength collected during the mobile surveys, which were used to scale the integrated relative biomass values to estimates of absolute red hind spawning fish density (fish/m³).

Results

Geographic distribution of spawning aggregations

The distribution of the red hind spawning aggregations during the 2002 and 2003 survey periods are presented by regional subarea in Fig. 1. The geographic (latitude/longitude) locations, time of observation, and estimated

Table 2

Mean observed spawning red hind (*Epinephelus guttatus*) density (presumed) in 2002 for each designated survey area. Sequences are defined as the 1-min field echo integration intervals (approximately 150 m long at 5 knots).

Area	Location	Fish/km ²	Sequences surveyed	Sequences w/schools	Percent w/schools	Transect length (km)
A	Cabo Rojo and Mayaguez	1,286	777	67	8.62%	91.5
B	Arroyo and Vieques	1,357	1144	74	6.47%	110.6
C	Cabo Rojo to Cayo Parguera	395	834	85	10.19%	143.1
D	Ponce to Arroyo	962	1073	102	9.51%	182.0

Table 3

Mean observed red hind (*Epinephelus guttatus*) density (presumed) in 2003 for each designated survey area. Sequences are defined as the 1-min field echo integration intervals (approximately 150 m long at 5 knots).

Area	Location	Fish/km ²	Sequences surveyed	Sequences w/schools	Percent w/schools	Transect length (km)
C	Mona	20,443	412	154	37.4%	63.7
C	Desecheo	10,559	82	26	31.7%	9.9
C	Bajo de Cico	4,544	148	82	55.4%	19.9
C	West coast	686	151	3	2.0%	20.3
B	Northwest coast	629	897	47	5.2%	153.3
A	Northeast coast	32	822	24	2.9%	128.2

mean aggregation density (in fish/m²) are presented for each designated survey area in Table 2 for 2002 and Table 3 for 2003. The acoustic data sets were carefully scrutinized during the analysis process and only coherent, vertically-stacked aggregations of fish were included in the red hind spawning density estimates (Fig. 2). Based on prior knowledge of red hind spawning behavior and the targeted nature of the hydroacoustic surveys, the stacked aggregations were presumed to consist solely of red hind.

Comparison of estimated overall spawning red hind densities in 2002 and 2003

Highest densities were observed associated with either islands or reef areas off of the west coast of the island (Fig. 3). The area surrounding Mona Island had the highest estimated spawning densities (20,443 fish/km²). Desecheo, in the same general area, had approximately half the spawning density (10,559 fish/km²) of Mona Island. The Bajo de Cico rise area had estimated spawning densities of 4,544 fish/km². The area between Arroyo and Vieques Island had the fourth highest estimated spawning densities (1,357 fish/km²). Estimated spawning densities along the north and south coasts of Puerto Rico were consistently low, and were lowest off of the northeast coast (32 fish/km²).

Comparison of acoustic spawning estimates and fishing vessel distribution in 2002

The location of fishing boats targeting red hind, based on Puerto Rico Dept. of Natural and Environmental Resources overflights conducted on 14 February 2002 and 23 January 2003, are shown in Fig. 4, along with the distribution of spawning aggregations observed by the hydroacoustic surveys. The location of fishing vessels was closely associated with the occurrence of schools of red hind, as observed by the hydroacoustic surveys conducted later.

Caged fish target strength experiments

Table 4 presents the mean dorsal aspect target strength and surrounding standard deviation for red hind and nine other species measured during the caged fish target strength experiments. The 2002 experiments revealed mean target strength values of approximately -37 dB for red hind (20 cm in length) and for coney (21 cm in length). White grunt, although physically smaller (16 cm) than the red hind, returned higher target strength values (-32 dB), perhaps due to differing morphology or swim bladder size. The single example of blue tang measured was 18 cm in length and returned a target strength value of -33 dB, also larger than the mea-

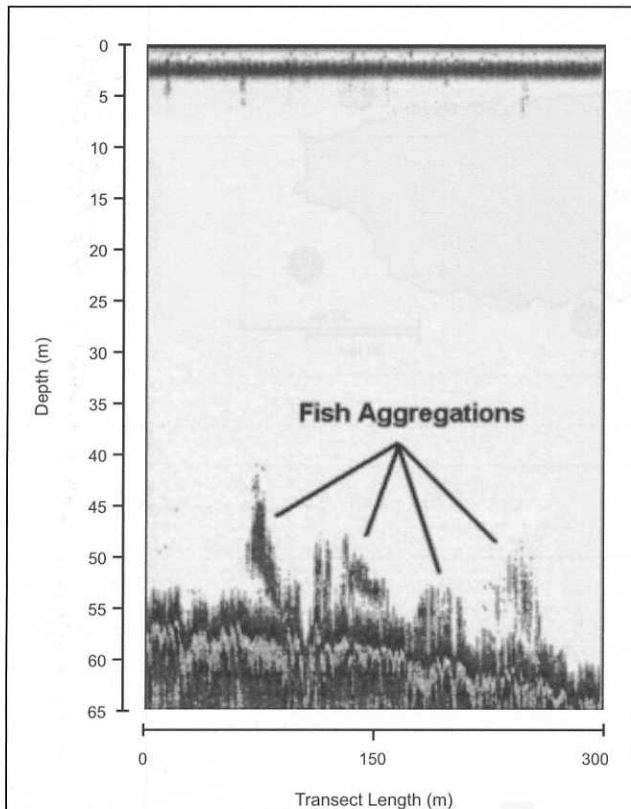


Figure 2

Example hydroacoustic echogram showing identified aggregations near the bottom of the shelf edge. Horizontal scale represents distance (m) along transect line. Vertical axis represents depth (m).

sured grouper species. Eight pluma were acoustically measured during the caged fish experiments, varying in length from 16–24 cm. Pluma returned the smallest mean target strength values, averaging -43 dB, indicating that they reflect less energy from the acoustic signal than the other evaluated species.

The 2003 experiments produced similar target strengths for 23 cm squirrel fish (-35 dB), 28 cm black durgelon (-36 dB), 46 cm ocean file fish (-32 dB), 42 cm ocean surgeon fish (-32 dB), and 25 cm butter grouper (-33 dB).

Discussion

The Puerto Rico 2002–2003 spawning red hind population surveys demonstrated the feasibility of hydroacoustic survey techniques for quantification of schooled spawning aggregations along the continental shelf during the brief full moon spawning period in early spring. The use of fish behavior, specifically the known site fidelity and timing of red hind spawning aggregations,

Table 4

Summary of the observed acoustic target strength values of 10 species of caged fish during 2002 and 2003.

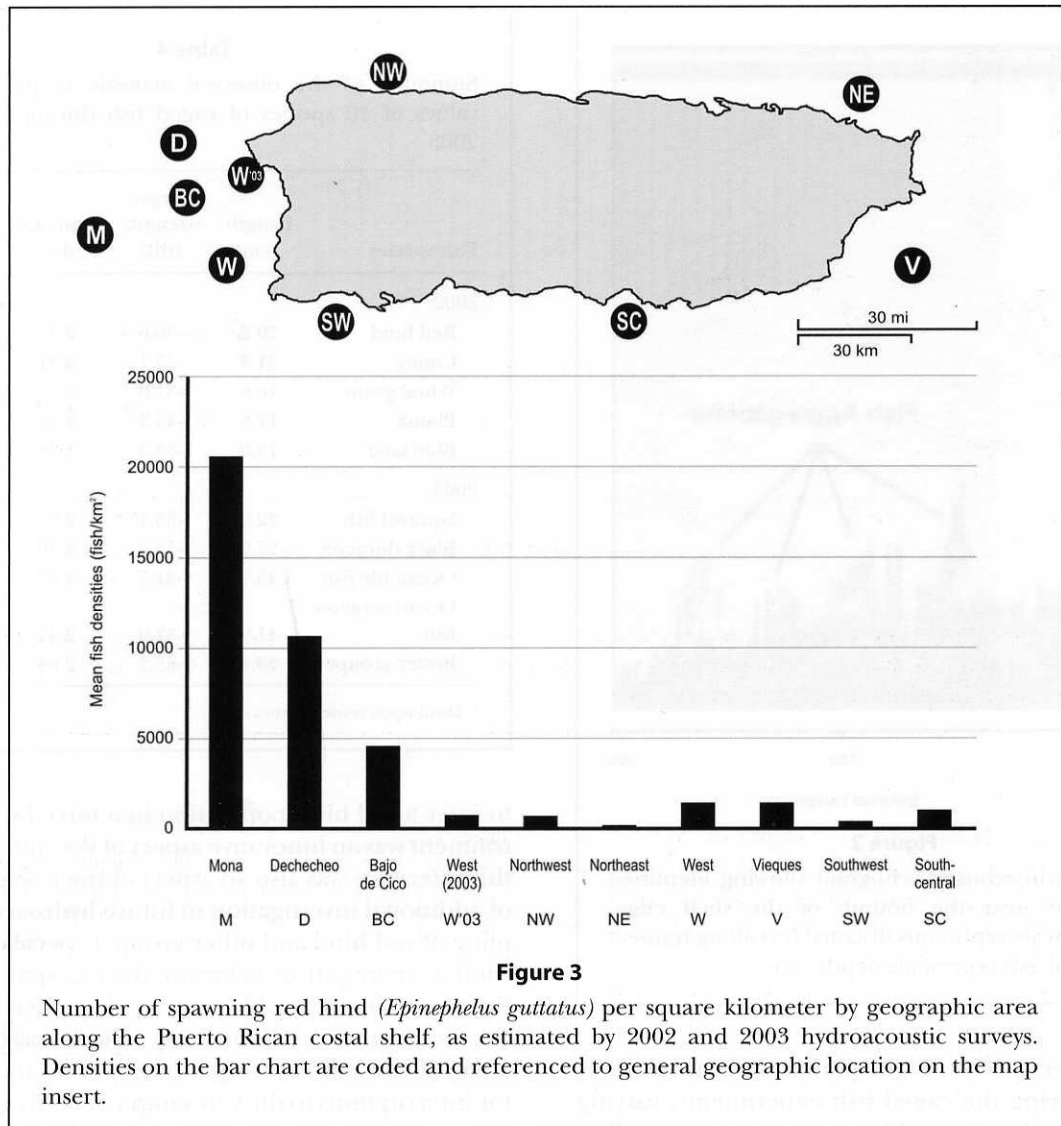
Fish species	Length (cm)	Target strength (dB)	Standard dev.	Number echoes
2002				
Red hind	20.2	-36.6	2.95	73
Coney	21.3	-37.1	3.31	440
White grunt	16.0	-31.9	0.59	48
Pluma	17.9	-43.2	2.58	124
Blue tang	18.0	-33.4	1.38	16
2003				
Squirrel fish ¹	22.9	-35.1	2.07	21
Black durgelon	27.9	-35.8	4.39	696
Ocean file fish	45.7	-31.7	4.87	475
Ocean surgeon fish	41.9	-32.0	2.42	549
Butter grouper	25.4	-33.2	2.64	225

¹ Dead upon retrieval from cage.

to infer a red hind population in a mixed-species environment was an innovative aspect of the study. However, this inference was also an aspect of the research worthy of additional investigation in future hydroacoustic sampling of red hind and other grouper species exhibiting similar aggregating behavior during spawning. The tight sampling timetable mandated by the requirement to cover large areas of the Puerto Rican coastline within a day of the full moon spawning period did not allow for interruptions to directly sample school aggregations for species identification. The vertically-stacked coherent schools were unique and readily identified from the more frequently observed diffuse and horizontally spread fish aggregations. However, the density estimates obtained may include species other than red hind (Whaylen et al., 2004; Luckhurst⁵). Species-inference of the resulting density estimates based on the vertical schools was solely based on their shape, near-shelf distribution, and timing (proximity to the full-moon). These characteristics, along with the occurrence of fishing vessels targeting red hind, were assumed to uniquely identify spawning red hind schools.

Recommendations for future quantitative population surveys of this resource include incorporation of additional species identification sampling. Options include

⁵ Luckhurst, B. 2001. Policies, legislation and management options. Workshop report, Towards sustainable Management of Nassau groupers in Belize, Belize City, 30 July 2001. Marine Resources Division, Bermuda Dep. of Env. Prot., P.O. Box CRS2, Crawl CRBX, Bermuda.



video, divers, or hook and line sampling. These efforts should be supported by an independent vessel in contact with the hydroacoustic survey boat, which could identify observed school aggregations for investigation.

It would also be worthwhile to investigate spawning aggregation persistence, that is, whether red hind spawn in the same general areas over time. Spawning aggregation persistence could be readily measured within a designated area by a single vessel conducting repetitive survey transects. These longer-term acoustic surveys could also be used to investigate the patchiness of red hind spawning in time over the months of January-March. The fidelity of spawning relative to the full moon phase (number of days over which significant spawning activity occurs) should also be investigated by repetitive acoustic surveys. If spawning activity occurs over a longer time frame than targeted by these acoustic

surveys, the overall estimates of spawning biomass could be affected.

Adding hydroacoustic survey transects inshore of the shelf break areas would aid in defining the overall red hind spawning habitat area surrounding Puerto Rico (J. Rivera, pers. observ.). Defining spawning habitat would allow for better identification and delineation of spawning habitats for red hind and potentially other aggregating grouper species around Puerto Rico. In addition, side scan or multi-beam bottom profiling acoustic systems (or geo-referenced data acquired by these systems at an earlier time) could be employed to correlate benthic habitat types with the observed red hind densities. These data may also help to better define spawning habitat for the species.

In general, the mean target strength results of the caged fish experiments for red hind and nine other

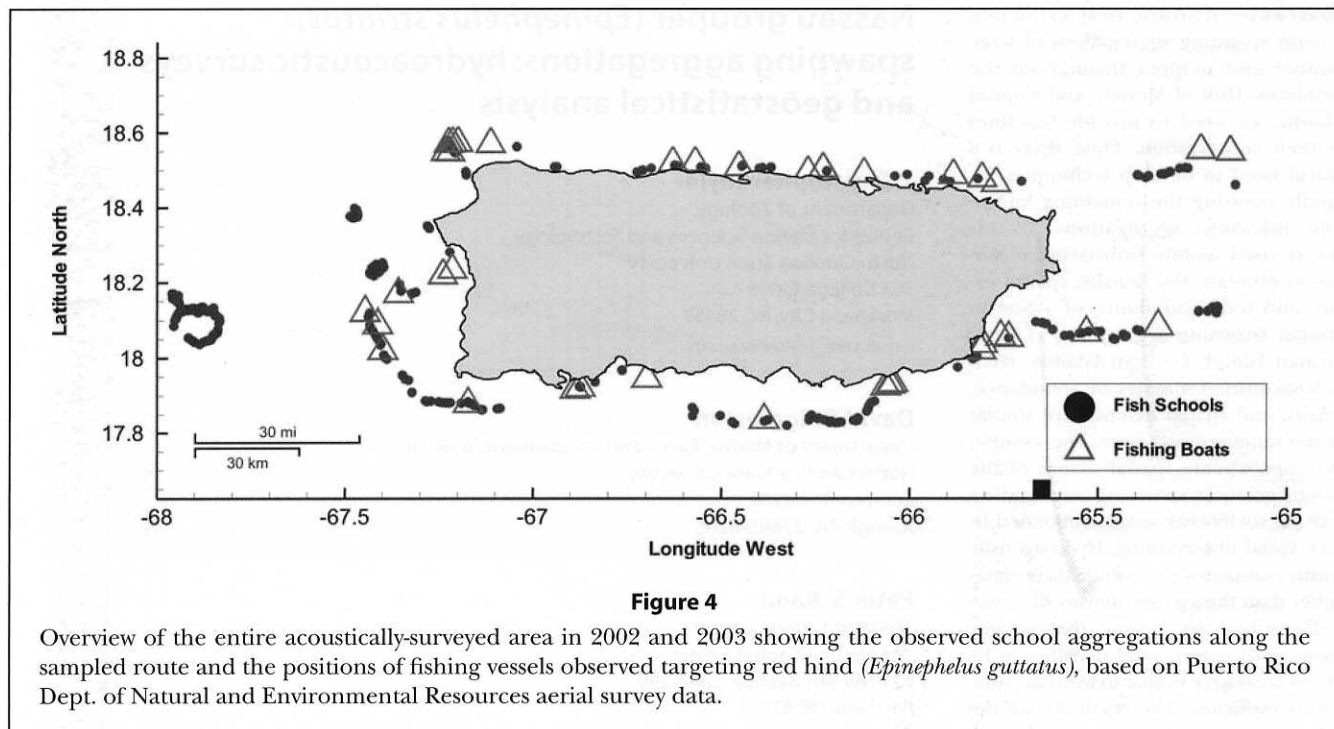


Figure 4

Overview of the entire acoustically-surveyed area in 2002 and 2003 showing the observed school aggregations along the sampled route and the positions of fishing vessels observed targeting red hind (*Epinephelus guttatus*), based on Puerto Rico Dept. of Natural and Environmental Resources aerial survey data.

species were in agreement with the expected length-to-target strength relationship of Love (1971), with the exception of white grunt and pluma. These two species appeared to have higher backscatter values than would be predicted using this relationship. The observed mean in situ target strength values for the observed vertically-stacked fish aggregations enumerated in 2002–2003 were consistent with the controlled measurements of known red hind, varying between approximately -37 and -42 dB. It would be advisable to conduct additional caged fish target strength experiments on individual red hind specimens over the entire expected length distribution of the species (approximately 10–80 cm). Using these data, a target strength-to-length relationship for the species could be developed. These data would also aid in scaling density estimates and permit examination if unique acoustic descriptors exist that could aid in resolving red hind from other species.

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