Evaluation of seasonal closures of red hind, *Epinephelus guttatus* (Pisces: Serranidae), spawning aggregations to fishing off the west coast of Puerto Rico, using fishery-dependent and independent time series data

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By

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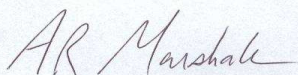Chairperson of the Department

ABSTRACT

The red hind (*Epinephelus guttatus*) is one of Puerto Rico's most important commercial and recreational fishes. Following stock decline, an annual spawning season fishing closure was enacted in 1996 for three aggregation sites off the west coast. Although presently continuing, its effectiveness toward population recovery has not been fully assessed. SEAMAP-C fishery-independent red hind data, and fishery-dependent reported landings and port-sampled biostatistical data, from the western platform of Puerto Rico were analyzed to infer recovery. An initial post-enactment increase of fishery-independent Catch-per-Unit-Effort (CPUE; kg/trip) was observed throughout the platform, and within spawning aggregations. Increased fishing effort within previously under-targeted platform regions led to increases in nominal CPUE within later years, but resulted in subsequent decreases in fishery-independent CPUE. Increased average length of red hind was observed in both data types, but was found to result from limited recruitment and proportional contributions of few remaining larger females. Although the closure was initially effective in stemming further stock decline, shifts in fishing strategy overrode potential recovery of red hind. However, recently enacted additional restrictions upon red hind fishing pressure may potentially aid in stock rebuilding.

RESUMEN

El mero cabrilla (*Epinephelus guttatus*) es uno de los peces comerciales y recreativos más importantes de Puerto Rico. En 1996 se decretó un cierre anual de su pesca dentro de tres áreas de agregación durante el periodo reproductivo como resultado de la reducción en las poblaciones de cabrilla en la plataforma insular al oeste de Puerto Rico. Aun cuando la pesca continúa vedada durante este periodo, la efectividad en la recuperación de la población no ha sido medida totalmente. Se analizaron datos de cabrilla independientes de la pesca comercial procedentes del programa SEAMAP-C; capturas reportadas, dependientes de la pesquería comercial, y datos bio-estadísticos colectados en los puertos de la plataforma oeste de Puerto Rico. Después de establecerse el cierre, se observó un aumento inicial en la captura por unidad de esfuerzo (CPUE, kg/viaje de pesca) en los datos de SEAMAP-C a través de la plataforma y dentro de las agregaciones reproductivas. Un aumento en el esfuerzo pesquero en áreas de pesca dentro de regiones previamente poco explotadas resultó en el incremento de la CPUE comercial de años posteriores. Este incremento del esfuerzo comercial se refleja en las capturas independientes, donde se observaron subsecuentes reducciones en la CPUE. En ambos grupos de datos, se observaron aumentos en las longitudes promedios de las cabrillas, como resultado de las limitaciones en el reclutamiento y por las contribuciones proporcionales de las pocas hembras de gran tamaño restantes. Aunque el cierre fue inicialmente efectivo en contener futuras reducciónes de la población, cambios en la estrategia de pesca anularon la recuperación potencial de la cabrilla. Pero, restricciones adicionales recientes a la presión pesquera de la cabrilla podrían permitir que los abastos se recuperen.

Dedicated to the makers of assorted Puerto Rican rums:

For the muse that remained upon me throughout this entire period of study, would not have come to fruition were it not for your constant efforts.

…Oh yeah, you'll have to share this with my parents, Bruce and Helen Marshak, since they greatly supported me through all of this too.

ACKNOWLEDGEMENTS

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INTRODUCTION

The groupers (Serranidae) of the western Atlantic have historically been a large component of Caribbean shallow reef fisheries. However, due to the decline and eventual commercial extinction of larger serranids, such as Nassau (*Epinephelus striatus*) and Goliath grouper (*Epinephelus itajara*) from overfishing within the Caribbean (Olsen and LaPlace, 1979; Beets and Friedlander, 1998), fishing pressure upon smaller groupers in Puerto Rico such as the red hind (*Epinephelus guttatus*) has intensified (Matos-Caraballo, 1997). The red hind is one of Puerto Rico's most important commercial and recreational fishes (Matos-Caraballo, 1997; Matos-Caraballo *et al.*, 2006). Individuals are primarily fished using hook-and-line, fish trap, and speargun throughout the insular platform to a depth of approximately 80 m (Sadovy *et al*., 1992). Like most groupers, red hind are characterized by a long lifespan (Manooch, 1987), slow growth (Sadovy *et al*., 1992), a protogynous sexual strategy, and short-term annual spawning aggregations (Colin *et al.*, 1987; Shapiro, 1987), which make them highly vulnerable to overexploitation (Bohnsack, 1989; Huntsman and Schaaf, 1994; Sadovy, 2001).

Although red hind is the most frequently captured grouper species in Puerto Rico (Matos-Caraballo *et al.*, 2006), recent landings have been substantially lower than those of earlier peak years. Intensive fishing during the 1970s led to continually decreasing annual catches during the 1980s, resulting in low landings in the 1990s (Matos-Caraballo, 1997). Historically, a major component of these landings has come from fishing red hind at their known annual spawning aggregations along the west coast of Puerto Rico (Colin *et al.*, 1987; Shapiro *et al.*, 1993b).

Throughout the Caribbean, red hind, like many other fishes, have been documented to form short-term annual spawning aggregations at specific times and locations (Burnett-Herkes, 1975; Colin *et al.*, 1987; Sadovy, 1990; Sadovy, 1992; Sadovy *et al.*, 1992; Shapiro *et al.*, 1993a; Sadovy *et al.*, 1994). Domeier and Colin (1997) define a spawning aggregation as "a group of conspecific fish gathered for the purpose of spawning with fish densities or numbers significantly higher than those found in the area of aggregation during the non-reproductive periods." This reproductive strategy is common in a wide variety of fishes, and has been suggested to enable the efficient transport of pelagic eggs and larvae into the water column offshore, as a result of the upward rush behavior observed during spawning (Thresher, 1984), while minimizing predation risk (Sancho *et al.*, 2000). The general location of serranid aggregations along the edge of an insular platform enables deeper water males to set up territories, and gives refuge to females, which generally advance from areas further inshore (Colin *et al.*, 1987; Shapiro *et al.*, 1993a; Shapiro *et al.*, 1994; Russell, 2001). The presence of many fishes spawning within a given area leads to large numbers of eggs being released simultaneously, which may swamp the feeding ability of planktivores (Johannes, 1978). Aggregations may also enable individuals to find mates with ease, as indicated by the presence of clusters of single males with several females in red hind aggregations (Shapiro *et al.*, 1993b). While these suggested benefits may aid the species, they are overshadowed by the fact that fishermen have historically targeted these aggregations due to their predictability in space and time.

Extensive fishing of spawning aggregations has led to the collapse of several commercially important grouper stocks (Olsen and LaPlace, 1979; Sadovy, 1990;

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Sadovy, 1992). Protection of spawning aggregations is essential, as egg production and fertilization are severely diminished by reduced aggregation numbers (Russell, 2001), which may lead to decreased recruitment of replenishing larvae (Sadovy, 1996). Reductions in mean female size and extremely skewed sex ratios have been noted in annually fished spawning aggregations (Beets and Friedlander, 1989; Coleman *et al.*, 1996). Protogynous species have been suggested to be more susceptible to overexploitation than gonochoristic species (Huntsman and Schaaf, 1984; Bannerot *et al.*, 1987). Due to the protogynous nature of most grouper species, such as the red hind (Shapiro, 1987; Sadovy *et al.*, 1992), and fishing selection for larger individuals, particularly while spearfishing, high fishing pressure upon larger males within aggregations has been suggested to result in sperm limitation (Koenig *et al.*, 1996).

Within the Caribbean, the red hind reproduces annually from December to February, with peak spawning usually around the full moon in January (Colin *et al*., 1987; Shapiro *et al*., 1993b). By contrast, in Bermuda spawning takes place during the summer (Burnett-Herkes, 1975). Consistent aggregations within the western Puerto Rico insular platform edge have been identified at depths of approximately 18-90 meters (Sadovy, 1993a), and individuals may travel significant distances to reach aggregation sites (Sadovy *et al*., 1992). Homing behavior, site fidelity, and return migrations to aggregations have been noted in Bermuda and Puerto Rico (Luckhurst, 1998; Rosario and Figuerola, 2001; Sabat, 2001).

Although limited local recruitment has been suggested as a deleterious impact of fishing spawning aggregations, Colin *et al.* (1987) suggested that fishing upon one red hind aggregation in western Puerto Rico was unlikely to impact local recruitment

success. However, within Puerto Rico fishing generally has not occurred solely within solely one aggregation (CFMC, 1996), and little assessment has been made of the impacts of fishing multiple aggregation sites upon local recruitment. In some cases, the spawn of aggregating species has been suggested to be unlikely to return to the spawning site because of ocean current patterns (Bohnsack, 1989). Ojeda (2002) agreed that due to the westward current dispersal of red hind larvae following the winter spawning aggregation in La Parguera, PR, it was possible that these assessments were valid. However, he also suggested that observed calmer currents during spring months may aid in the variable retention of some larvae and eggs along Puerto Rico.

Sabat *et al*. (2000) modeled the Puerto Rico red hind population under assumptions of either a closed or open population. Under the former assumption, and simulated values of fishing pressure, a significant reduction in the number of larger females could be observed. Following the latter assumption, it was found that recruits from another population, equivalent to 20% of the contribution of that made by local females, resulted in the stabilization of the local population at a size 90% smaller than its pre-exploitation size. As Sabat *et al*. considered these assessments to be consistent with the behavior of the Puerto Rico red hind population; they suggested that fishing mortality needed to be reduced significantly in order for the local population to attain its original size. They classified the western population as a "sink", and concluded that recruitment from other stocks was maintaining the population. However, they made note of the possibility that gyres off the west coast of Puerto Rico were contributing to the retention of locally produced red hind larvae. Preliminary findings have suggested that there is no genetic differentiation between identified spawning aggregations off the west coast of

Puerto Rico (Ward, 1997), or between the western Puerto Rico aggregations and individuals from the USVI (Sabat, 2001), which could be indicative of an open population. Nevertheless, previous findings have indicated that the Puerto Rico stock is both growth- and recruitment-overfished (Sadovy and Figuerola, 1992; Sadovy, 1993b), and that red hind recruitment has been poor during more recent periods (Appeldoorn *et al.*, 1992).

Under these circumstances, one management approach that may lead to the recovery of overfished, aggregating grouper species is the enactment of seasonal area closures during spawning seasons. Seasonal closures have been historically enacted in the US Virgin Islands (USVI), while marine reserves have been used in Belize (Heyman *et al.*, 2000; Pomeroy and Goetze, 2003) and the Bahamas (Sluka *et al.*, 1997) to protect aggregating spawners. Beets and Friedlander (1998) evaluated the effectiveness of seasonal closures of red hind spawning aggregation sites in the USVI, and detected an increase in average size following enactment of the closures; suggesting that the stock was recovering. Sluka *et al.* (1997) illustrated that Nassau grouper biomass increased within the Bahamas reserve, finding that the area was exporting groupers outside the boundaries. Chiappone *et al.* (2000) demonstrated that managed areas subjected to lighter fishing in the Caribbean, resulted in larger groupers and increased diversity of grouper species. Recently, Nemeth (2005) found that following the 1999 conversion of the seasonally closed USVI Red Hind Bank Marine Conservation District into a permanently closed area, a 60% increase in spawning density and biomass, in addition to an increase in maximum size, had occurred when compared to the findings of Beets and Frielander (1998).

Anticipating similar outcomes, the Caribbean Fisheries Management Council (CFMC), in conjunction with the government of Puerto Rico, initially closed one known western red hind spawning aggregation area (*Tourmaline*) to fishing during the spawning events in 1993. Redefinition of the area of this closure occurred in 1996, along with the closing of two additional aggregations identified within the *Bajo de Cico* and *Abrir la Sierra* regions of the west coast (CFMC, 1996). Fishing has continued at the identified La Parguera and Mona aggregations, among other shelf edge regions speculated to be spawning locations. However, within 2004 a spawning season fishing ban (PR DRNA 2004) was enacted for all red hind within all Puerto Rican state waters (<9 nm offshore). Subsequently, a further regulation has been enacted as of 2006, which prohibits the fishing of red hind within all state and federal waters of Puerto Rico, west of $67^{o}10'W$, during the spawning period (PR DRNA 2007; NOAA-NMFS, 2007). A preliminary study using tag and recapture data sampled from 2000-2001, in conjunction with fishery-dependent data from 1990-2000, had suggested that red hind was recovering in Puerto Rico (Sabat, 2001). However, this study was limited by low recaptures, and only used length-frequency information at a broad resolution to make these conclusions. Therefore, a more detailed assessment of stock recovery is warranted.

Fishery-dependent and independent data have been historically collected about red hind within Puerto Rico. However, these datasets have only been partially analyzed, and have not been comprehensively applied toward measuring the effectiveness of the seasonal closures upon the recovery of the western Puerto Rico red hind population. Therefore, the impact of these seasonal closures has yet to be satisfactorily determined. Through analysis of both fishery-independent data, and Puerto Rico reported landings

and biostatistical data of red hind collected from 1988 to present, an assessment of the degree of recovery of the stock following the enactment of the annual spawning aggregation closures was performed.

MATERIALS AND METHODS

Databases

The primary data used in this study were fishery-independent red hind data, obtained from the Caribbean Southeast Area Monitoring and Assessment Program (SEAMAP-C) database. The SEAMAP-C conducts fishery-independent surveys of shallow water reef fishes, queen conch (*Strombus gigas*), and Caribbean spiny lobster (*Panulirus argus*) in order to build a long term database in which temporal changes can be detected (Rosario, 1998).

Since its onset, SEAMAP-C has collected Puerto Rico red hind data by sampling individuals within their annual spawning aggregations, and at areas within and away from identified aggregation sites (Figure 1) during non-spawning periods. Surveys are undertaken in three year sampling blocks, beginning in April of the first year, and culminating in March of the final year. Samplings occur within 2x2 nautical mile (3.70x3.70 km) quadrat stations of the insular platforms of western Puerto Rico, Mona, Monito, and Desecheo islands (Figure 2). Reef fishes are sampled at 1-2 randomly selected stations per sampling day. However, during the red hind spawning period, stations encompassing known aggregation sites are more frequently targeted. Samplings are carried out using two concurrent methods: squid-baited hooked lines (mean number of lines deployed per sampling = 3.08 +/- 0.03 SE; mean number of hooks per line = 9.18 +/- 0.09 SE; mean number of hours soaked = 4.88 +/- 0.02 SE), and sardine-baited standard Antillean fish traps with 3.81 cm square vinyl coated mesh (mean number of traps deployed per sampling = 11.9 +/- 0.13 SE; mean number of hours soaked = 5.29 +/- 0.13 SE).
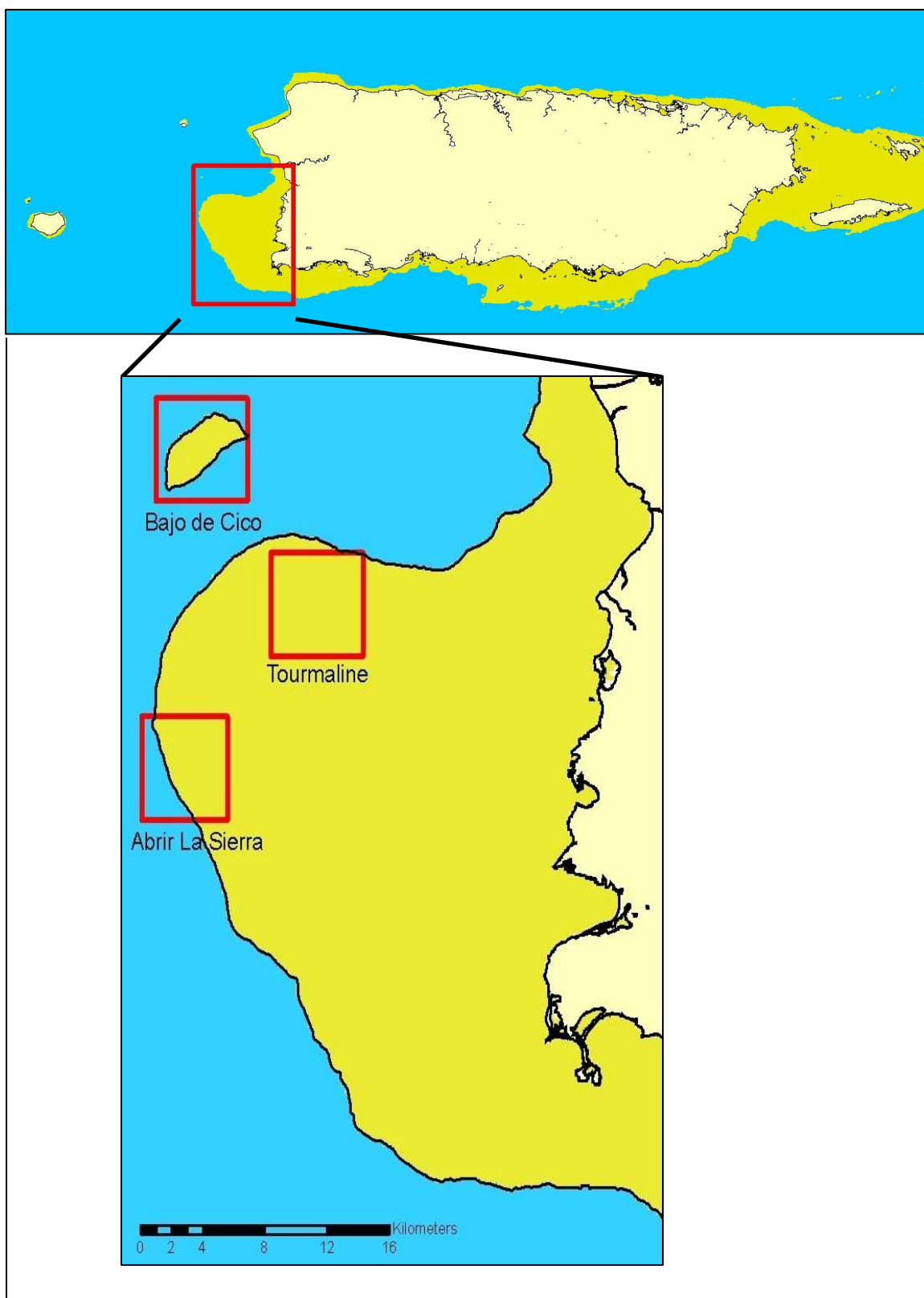
Figure 1. Map of the Puerto Rico Archipelago and insular platform up to 100 m, with western shelf and seasonally closed areas highlighted.

Figure 2. SEAMAP-C 2x2 nautical mile sample stations along the insular platforms of western Puerto Rico, Mona, Monito, and Desecheo (shown up to 200 m). Station regions that intersect with seasonally protected spawning aggregation sites are highlighted.

Traps are generally set at least 45 meters apart from each other in order to avoid inter-trap interference. Since the 1991/92 project year, sampling locations have been recorded using Global Positioning System (GPS), with data recorded for sampling date, quadrat number, depth, gear type, gear quantity; soak time, number, length (FL), weight (g), sex, and species of each fish caught per individual trap and hook. Data are entered into the database using DBASEIII+, and stored within the SEAMAP program software. Data were viewed in Microsoft Excel.

Fishery-dependent landings data and port-sampled biostatistical data of red hind from 1988 to 2005 were obtained from the Puerto Rico Department of Natural and Environmental Resources Fisheries Research Laboratory (DNER-FRL). Commercial landings information are voluntarily submitted to port agents from fishers on landing trip tickets, upon which data pertaining to fishing dates, municipality fishing area, hours fished, number of fishing trips, total weight (lbs) captured per species, gear type, and gear quantity are recorded. Biostatistical data are obtained by port agents who randomly visit the 42 coastal municipalities of Puerto Rico, and sample randomly selected commercial landings. Under the fisher's voluntary cooperation, port agents identify every individual caught at the species level, and record the fork length (FL, mm) and weight (g) of every fish. Additional information regarding municipality fishing area, depth, gear type, number of gear, fishing period, and total catch are also recorded. Port agents deliver data to the DNER-FRL, following which data are entered into a separate database using DBASEIII+, and stored and analyzed using FoxPro, Lotus 123, and Microsoft Excel. Data were viewed in Microsoft Excel.

Data Editing and Calculations

Fishery-independent SEAMAP-C data

Fishery-independent data were inspected for errors, and appropriate corrections were made. Data pertaining to date, gear type, individual hooked line or trap number code, and gear quantity were cross checked with all other encoded entries, as occasional errors of incorrectly entered date or gear number code were encountered. When available (sampling years 1991/92-2000/01), latitude and longitude data were used to plot sampling locations within a Geographic Information System (GIS) to verify station locations along the 2x2 nautical mile grid. If inconsistencies were discovered, then station numbers were modified, unless other data components (e.g. date, gear number code) suggested otherwise.

All corresponding red hind length and weight data collected were plotted in order to determine the presence of erroneous data. In order to test for errors, recorded weight data were subjected to a residual test in which they were compared with predicted weights calculated from the fork length (FL) to weight (W) relationship proposed for the Puerto Rico red hind population by Sadovy *et al.* (1992):

$$\text{Log W} = -5.21 + 3.1422 \text{ Log FL} \tag{1}$$

Weight data that were found to be greater than three standard deviations from the predicted weight values of equation 1 were identified as outliers (n=196). A relation between all remaining valid corresponding length and weight data was calculated by a regression (Figure 3), whose relationship is given in equation 2:

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Log W = -5.1549 + 3.1216 Log FL [n=15,122; r^2=0.97]   (2)

Weight data identified as outliers were converted to more appropriate estimates using

equation 2.
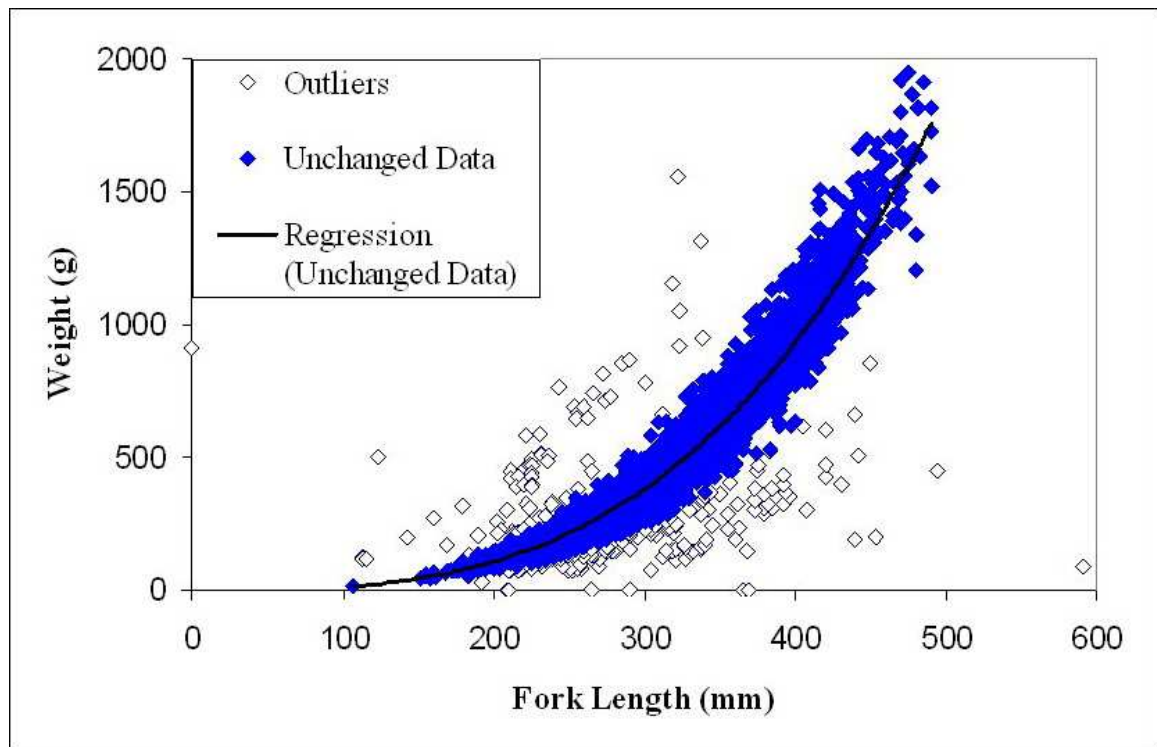
Figure 3. A length to weight regression calculated from all SEAMAP-C red hind
(*Epinephelus guttatus*) data (1988-2006).

Following correction of the dataset, red hind catches were summed according to

total weight (kg) caught per day fished; total weight (kg) caught per all hooked lines

deployed per day fished; and total weight (kg) caught per all traps deployed per day

fished. Due to the low capture values observed per individual hooked line or trap and per

hour fished, and because sampling was standardized by day fished, fishing effort was

defined as the number of days fished. Annual average Catch per Unit of Effort (CPUE)

values (kg), length-frequency distributions, sex ratios, and the average proportion of

females captured per day were quantified per sampling year (Apr-Mar) and per spawning period (Dec-Mar) at the following spatial scales:

a) Coast-wide (i.e., all sampling stations encompassing the western platform of Puerto Rico combined, excluding Mona, Monito, and Desecheo islands).

b) Within all seasonally protected areas combined (i.e., all sampled station regions encompassing the *Abrir la Sierra*, *Bajo de Cico*, and *Tourmaline* locations of the western platform of Puerto Rico).

c) Within all unprotected areas of the western platform of Puerto Rico combined.

d) Independently within the *Abrir la Sierra*, *Bajo de Cico*, and *Tourmaline* regions of the western platform of Puerto Rico.

All sampling locations with latitude and longitude data were plotted in a GIS (Figure 4) in order to classify data collections as having occurred within protected or unprotected areas. Sampling locations for data that did not include latitude and longitude information were estimated as having occurred at the most frequently sampled location within a given station. Data were classified according to location, and values were calculated at the appropriate scale of comparison. Due to inconsistencies in the recording of depth data and infrequent annual sampling of stations, stratified analyses per depth gradients between shallower and deeper regions of the western insular platform, and within seasonally protected red hind spawning locations, were not included in this study.
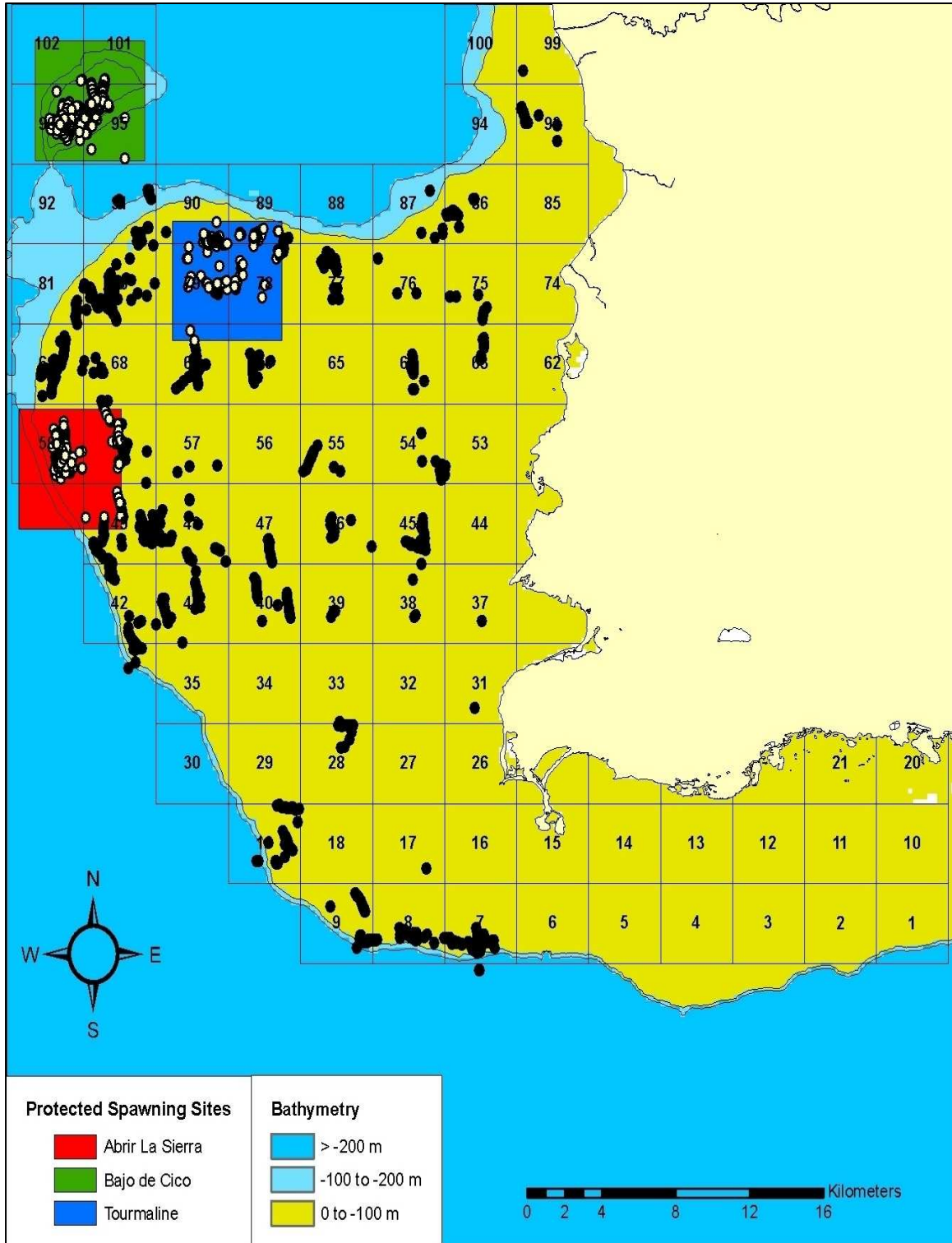
Figure 4. Mapped locations of 1988-2006 SEAMAP-C sampling events along the insular platform of the west coast of Puerto Rico. Samplings which occurred within seasonally protected red hind spawning sites are highlighted.

Fishery-dependent commercial landings and biostatistical data

Red hind fishery-dependent commercial landings data and biostatistical length data were inspected for errors, and none were found. Commercial landings data and biostatistical length data corresponding to red hind captured and landed within the area encompassed by the Lajas, Cabo Rojo, and Mayaguez offshore regions of Puerto Rico (Municipality codes 36, 37, and 38, respectively) were used to quantify annual average CPUE values (kg/fishing trip) and length-frequency distributions per SEAMAP-C project year (Apr-Mar), and red hind spawning period (Dec-Mar). The Cabo Rojo and Mayaguez offshore regions comprise the SEAMAP-C sampling area of the western insular platform, which has historically been an area of significant red hind commercial catch in Puerto Rico (Matos-Caraballo *et al.*, 2006). Observed trends in CPUE and length for Cabo Rojo and Mayaguez offshore regions were compared to those measured within the Lajas offshore regions (predominantly the area of La Parguera) of the southwestern insular platform Puerto Rico. The La Parguera region contributes heavily to red hind landings of the south coast of Puerto Rico (Matos-Caraballo *et al.*, 2006), and was determined of sufficient distance from the area of interest in order to serve as a control indicator of the effectiveness of the closures.

Statistical Analysis

Measured parameters from both fishery-independent and fishery-dependent datasets were not found to conform to the assumptions of parametric testing. Within SEAMAP-C data, annual variations of CPUE, length, and the proportion of females captured during SEAMAP-C project years and spawning periods were each assesed at a

coast-wide spatial resolution with 1-way Kruskal-Wallis tests, using sequential

Bonferroni corrections (Holm, 1979) to account for multiple testing. Relationships

between parameters of length and catch, and length and proportion of females, were

assumed to be dependent in terms of alpha determination. A regression comparing

proportion of females and CPUE found no significant relationship (r^2=0.004; n=732;

p=0.099). *Post-hoc* pair-wise comparisons between years were performed with Nemenyi

tests (α=0.05). Annual variations of both CPUE and length, from fishery-dependent

datasets, were tested with 1-way Kruskal-Wallis tests, followed by *post-hoc* pair-wise

comparisons with Nemenyi tests (α=0.05).

If management measures have resulted in protection of the red hind spawning stock

and potentially the entire population, the expected population responses to the closures

would be detected within the western platform of Puerto Rico by the following trends

subsequent to enactment of the seasonal closures:

- Increase within closed areas of CPUE from fishery-independent (SEAMAP-C)
  data. This will be examined for project years and for spawning periods. Parallel
  trends should be observed within the three closed areas.

- Gradual or delayed increase within unprotected areas of CPUE from fishery-
  independent (SEAMAP-C) data, and over the entire platform in CPUE from
  fishery-dependent data. This will be examined for project years and for spawning
  periods.

- Increase within closed areas of average length from fishery-independent
  (SEAMAP-C) data. This will be examined for project years and for spawning
  periods. Parallel trends should be observed within the three closed areas.

- Gradual or delayed increase within unprotected areas of average length from
  fishery-independent (SEAMAP-C) data, and over the entire platform in average
  length from fishery-dependent data. This will be examined for project years and
  for spawning periods.

- Gradual or delayed shift in length-frequency distributions due to a higher proportion of larger individuals (while maintaining recruitment) over the entire platform in both fishery-independent (SEAMAP-C) data and fishery-dependent data. This will be examined for project years.

- Decrease within closed areas of the proportion of females from fishery-independent (SEAMAP-C) data. This will be examined for project years and for spawning periods. Parallel trends should be observed within the three closed areas.

- Gradual or delayed decrease within unprotected areas of the proportion of females from fishery-independent (SEAMAP-C) data. This will be examined for project years and for spawning periods.

RESULTS

Fishery-independent SEAMAP-C data

Throughout the duration of the SEAMAP-C program (Apr 1988-Mar 2006), a total of 4,795.6 kg of red hind (n=13,889) were sampled within the western insular platform of Puerto Rico. Annual total catches of red hind from all sampled areas within the western insular platform per project year and spawning period are presented in Table 1. Red hind captured by hooked line (91% of all individuals sampled) made up the bulk of annual catches. However, due to a period during which traps comprised the sole

Table 1. Annual SEAMAP-C total catches (kg) of red hind (*Epinephelus guttatus*) and number of sampled individuals (in parenthesis) per project year and red hind spawning period throughout the western insular platform of Puerto Rico, with breakdown of annual catches by percent gear type (HL=hooked line; TR=trap) and number of sampled individuals by percent sex (F=Female; M=Male).

Year	Project Year						Spawning Period					
	Total Catch		%HL	%TR	% F	% M	Total Catch		%HL	%TR	% F	% M
1988/89	367.04	(886)	83.7	16.3	90.5	9.5	181.87	(426)	90.0	10.0	91.1	8.9
1989/90	260.53	(700)	99.2	0.8	89.9	10.1	224.09	(618)	100.0	0.0	89.3	10.7
1990/91	779.35	(2045)	100.0	0.0	79.8	20.2	508.03	(1394)	100.0	0.0	89.4	10.6
1991/92	1045.53	(3041)	80.0	20.0	93.9	6.1	721.59	(2242)	81.7	18.3	92.6	7.4
1992/93	268.11	(757)	83.6	16.4	76.6	23.4	79.08	(250)	88.6	11.4	65.2	34.8
1993/94	527.12	(1685)	86.6	13.4	78.8	21.2	222.85	(733)	90.0	10.0	71.0	29.0
1994/95	380.01	(1258)	86.5	13.5	74.9	25.1	138.96	(484)	92.1	7.9	69.0	31.0
1995/96	26.81	(92)	64.0	36.0	95.7	4.3	---------	(-----)	-----	------	------	------
1996/97	----------	(------)	------	------	-----	-----	---------	(-----)	-----	------	------	------
1997/98	514.57	(1556)	94.3	5.7	84.2	15.8	321.09	(885)	90.9	9.1	73.1	26.9
1998/99	275.04	(837)	100.0	0.0	90.4	9.6	44.32	(135)	100.0	0.0	77.0	23.0
1999/00	189.46	(597)	79.7	20.3	88.1	11.9	1.95	(8)	56.7	43.3	100.0	0.0
2000/01	78.03	(230)	90.3	9.7	82.6	17.4	24.46	(80)	93.4	6.6	72.5	27.5
2001/02	---------	(----)	------	------	-----	-----	---------	(-----)	-----	------	------	------
2002/03	---------	(----)	------	------	-----	-----	---------	(-----)	-----	------	------	------
2003/04	---------	(----)	------	------	-----	-----	---------	(-----)	-----	------	------	------
2004/05	21.64	(61)	94.0	6.0	88.5	11.5	5.95	(17)	95.7	4.3	70.6	29.4
2005/06	62.38	(144)	76.0	24.0	90.9	9.1	6.49	(13)	63.1	36.9	66.7	33.3
Total	4795.61	(13889)	88.8	11.2	85.1	14.9	2480.72	(7285)	90.9	9.1	84.0	16.0

gear used for sampling, traps contributed to a higher proportion of the total catch of the 1995/96 project year than in other years. Higher proportions of annual catches came from females (85% of all individuals sampled), while males contributed no more than 39% of the catch of a given year. Catches obtained along the western platform during spawning periods made up a significant component of annual catches during most project years (mean=37.6% +/- 0.07 SE). However, lower contributions to annual catches from spawning period samplings, as well as declines in total catches, were observed in later years.

From the onset of the SEAMAP-C program, a total of 1,021 sampling events have occurred, of which 34% took place during the red hind spawning period. Within project years and spawning periods, annual sampling efforts have varied (Table 2). Out of all sampling events, only 31% have occurred within years following the enactment of the seasonally protected aggregation sites. However, due to highly variable annual sampling rates post closure, there was no significant difference in the number of annual sampling events prior to and following the enactment of the protected shelf regions (Mann-Whitney U-test value=7.000; P-value=0.028, >0.025 with Bonferroni correction); the same was true for annual samplings that occurred during red hind spawning periods (Mann-Whitney U-test value=16.500; P-value=0.332).

Cumulatively, samplings within the seasonally protected areas of the western platform made up 45% of all sampling events, and comprised 60% of the samplings undertaken during the red hind spawning period. Low annual sampling frequencies were observed in each of the three protected aggregation sites. However, following their designation as protected areas, sampling frequencies within *Abrir la Sierra,* and within

Table 2. Annual number of SEAMAP-C sampling events per project year and red hind spawning period (in parenthesis) throughout the western insular platform of Puerto Rico, and within seasonally protected and unprotected platform regions.

Year	Total Sampling Events		*Abrir la Sierra*		*Bajo de Cico*		*Tourmaline*		Unprotected Areas	
1988/89	91	(38)	-----	-----	10	(3)	6	(3)	75	(32)
1989/90	68	(31)	-----	-----	12	(12)	4	(4)	52	(15)
1990/91	99	(26)	9	-----	35	(26)	18	-----	37	-----
1991/92	61	(39)	-----	-----	61	(39)	-----	-----	-----	-----
1992/93	107	(20)	2	-----	22	(8)	10	(3)	73	(9)
1993/94	130	(29)	16	(7)	29	(12)	18	(3)	67	(7)
1994/95	106	(33)	14	(9)	27	(16)	10	(2)	55	(6)
1995/96	41	-----	3	-----	6	-----	5	-----	27	-----
1996/97	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1997/98	87	(36)	7	(2)	9	(4)	7	(2)	64	(28)
1998/99	67	(33)	20	(13)	9	(4)	7	(5)	31	(11)
1999/00	48	(6)	11	-----	4	-----	6	(1)	27	(5)
2000/01	39	(21)	21	(15)	5	(2)	5	(3)	8	(1)
2001/02	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
2002/03	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
2003/04	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
2004/05	20	(14)	2	(1)	2	(1)	4	(2)	12	(10)
2005/06	57	(19)	4	(1)	8	(1)	12	(3)	33	(14)
Total	1021	(345)	109	(48)	239	(128)	112	(31)	561	(138)

Tourmaline during spawning periods, were higher than in earlier years. Samplings within *Bajo de Cico* occurred much more frequently in earlier years, especially during red hind spawning periods. Throughout the 1991/92 project year, all sampling was restricted to *Bajo de Cico*, during which the area was most frequently targeted (n=61 samplings). As sampling was limited to *Bajo de Cico* during this period and during the 1990/91 spawning period, these data were not included in analyses at the coast-wide scale.

Within the western insular platform, annual average red hind CPUE values throughout sampled project years (Figure 5) were found to significantly differ (p<0.05). While a significant annual increase in CPUE was observed between the 1989/90 and 1990/91 project years, no significant difference in average CPUE was found

Figure 5. Annual average CPUE (kg/day) and standard error of red hind (*Epinephelus guttatus*) from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period. The dashed line represents the time of enactment of the seasonal closures.

within subsequent years prior to the enactment of the closures until the 1995/96 period, during which a significant decrease relative to all previous project years was observed. Annual CPUE increased significantly between the 1995/96 sampling period (before closure) and the 1997/98 sampling period following enactment of the closure. Decreases during subsequent periods were not found to be significantly lower than the peak in the 1997/98 project year, nor significantly lower than values prior to the enactment of the closures. However, average CPUE of the 2005/06 project year was found to be significantly lower than the 1997/98-1999/2000 project years (and the 1990/91, 1993/94-1994/95 project years).

Trends observed during spawning periods were similar to those of project years, except that significant decreases in average CPUE also occurred following the post-enactment peak (p<0.05). Due to greater variability and lower sample size, the CPUE during the 1997/98 project year was not found to be significantly higher than during pre-

Figure 6. Annual average CPUE (kg/day) and standard error of red hind (*Epinephelus guttatus*) per gear type from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period (HL=hooked line; TR=trap). Dashed lines represent the time of enactment of the seasonal closures.

closure periods, which did not include the 1995/96 period. However, values from the

2004/05 and 2005/06 spawning periods were found to be significantly lower than in years

prior to enactment of the closures. Curiously, prior to the closures, spawning period

CPUE values were higher than those calculated for their corresponding project years, but

during later sampling years, annual spawning period values were found to be lower than

those of project years.

Inter-annual variability was found between annual average CPUE values

calculated per gear type within project years and spawning periods (Figure 6).

Throughout the 1988/89 to 1995/96 project years and spawning periods, annual CPUE

values of red hind sampled by hooked lines were found to be considerably higher than sampling values from traps. Although measurable differences in CPUE were observed between gear types during the 1997/98 project year and spawning period, little differentiation between CPUE per gear type was found during subsequent project years and spawning periods. Due to the overwhelming contribution of hooked lines to total catch, CPUE from hooked lines greatly mirrored CPUE calculated independent of gear type. However, the magnitude of decrease during the 1995/96 project year, and increase of the 1997/98 project year previously observed independent of gear type was not found for hooked line CPUE. Despite this, considerable decreases within subsequent project years and spawning periods were observed. Few notable differences were detected between annual red hind CPUE values of traps during project years and spawning periods. Although increases in trap CPUE were observed during the 1997/98 sampling periods, extremely low values were later found during the 2004/05-2005/06 sampling periods.

When seasonally protected areas were grouped, CPUE values during early project years (1988/89 to 1990/91) were found to be higher than those calculated for the entire western platform (Figure 7), and decreases in CPUE during the years prior to the enactment of closure were more pronounced than those for the entire western platform. As was observed for the entire western platform, a major increase in CPUE was found during the 1997/98 project year, which was followed by subsequent decreases that resulted in low CPUE values in recent years that were comparable to the minimal CPUE observed during the 1995/96 project year. During spawning periods (Figure 7, bottom), CPUE trends within protected areas were nearly identical to those found for the

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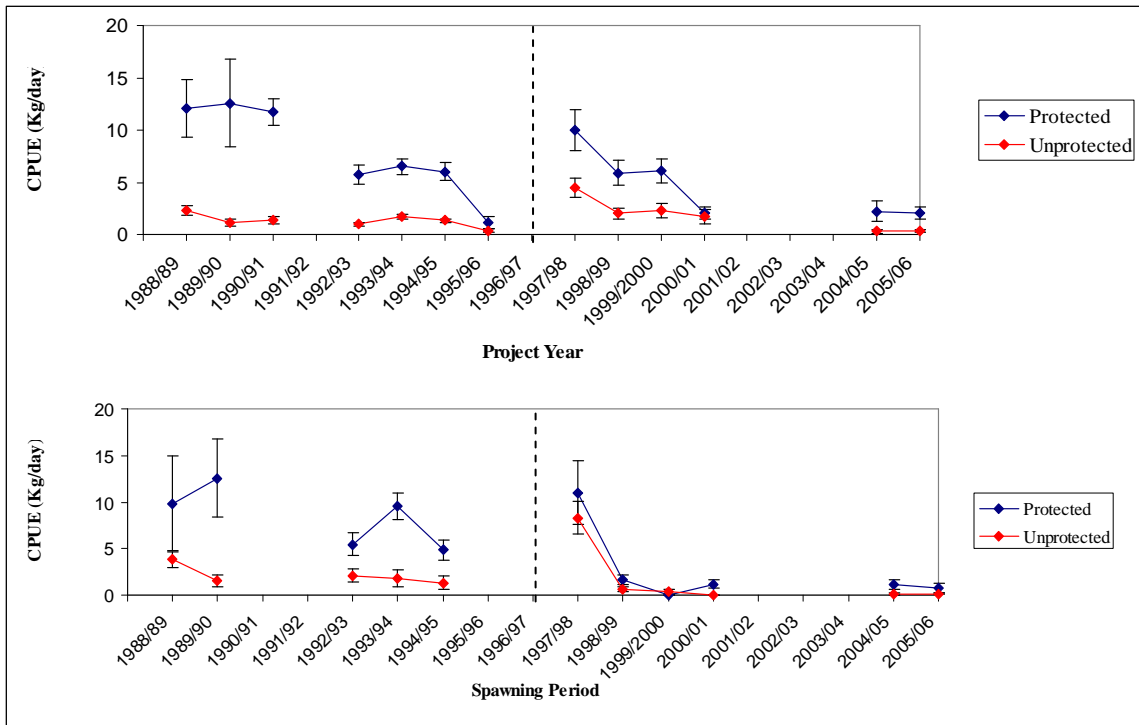
Figure 7. Annual average CPUE (kg/day) and standard error of red hind (*Epinephelus guttatus*) from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period within protected and unprotected sampling areas. Dashed lines represent the time of enactment of the seasonal closures.

western platform, with little inter-annual differentiation in CPUE prior to the enactment

of the closures, and a massive decrease in CPUE following the post-enactment increase

of the 1997/98 spawning period.

Red hind CPUE values within grouped unprotected areas were substantially lower

than those of protected areas prior to the enactment of the closures. Little differentiation

within CPUE of unprotected areas was observed until an increase during the 1997/98

project year and spawning period, following which decreases of similar magnitudes to

those measured in seasonally protected areas were found. Following the enactment of the

closures, CPUE within protected areas remained marginally higher than within

unprotected areas during project years, but little differentiation was observed in more
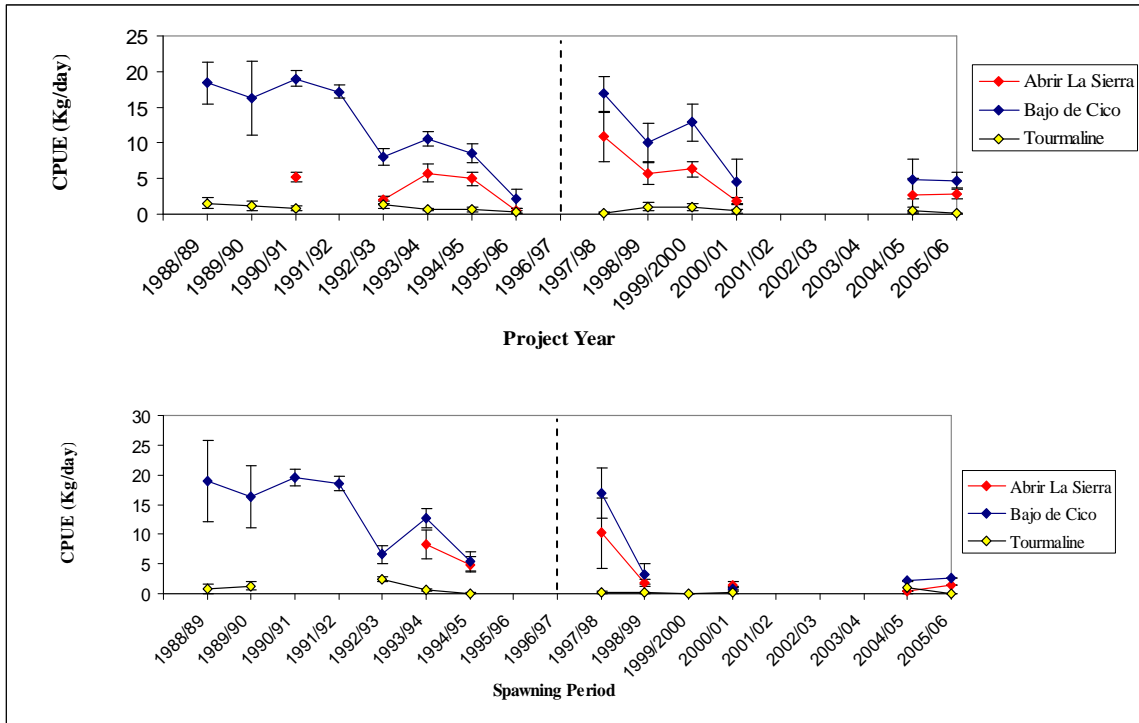
Figure 8. Annual average CPUE (kg/day) and standard error of red hind (*Epinephelus guttatus*) from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period within seasonally protected aggregation sites. Dashed lines represent the time of enactment of the seasonal closures.

recent sampling periods. Within spawning periods, notable differentiation in CPUE between protected and unprotected sites was observed prior to the enactment of the closures. During the 1997/98 spawning period, increases of CPUE within both protected and unprotected areas to highly similar values were observed. However, as of the 1998/99 spawning period, nearly equivalent decreases in CPUE to extremely low values had occurred, and minimal subsequent differentiation in CPUE was observed between protected and unprotected areas.

Within independent seasonally protected red hind spawning aggregation sites, trends of CPUE were similar to those found for when sites were grouped, and at the entire western platform spatial scale (Figure 8). During project years and spawning

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periods, CPUE values within *Bajo de Cico* were higher than those of the *Abrir la Sierra* and *Tourmaline* regions of the western platform, representing the bulk abundance of red hind within the western platform. Captures at *Bajo de Cico* made up 66% of the total catch from all sampling years, of which 58% of the captures at *Bajo de Cico* came from samplings during spawning periods. Within project years and spawning periods, overall trends were highly similar between the *Bajo de Cico* and *Abrir la Sierra* regions. However, decreases in CPUE prior to the enactment of the closures, and the 1997/98 increase following enactment, were much more pronounced within *Bajo de Cico*. While CPUE within *Bajo de Cico* remained highest following enactment of the closures, lesser differentiation was observed between the low CPUE values of all three independently protected areas within recent samplings. Low CPUE values were continuous throughout all project years and spawning periods within the *Tourmaline* region, and no observed increase in CPUE was measured during the 1997/98 sampling periods.

Significant differences between annual average lengths were found for project years and spawning periods for the entire western platform (Figure 9; p<0.05). Continual decreases in annual average length were observed throughout all project years and spawning periods prior to the enactment of the seasonal closures. Prior to the enactment of closure, average length values following the 1990/91 project year were found to be significantly lower than earlier values of 1988/89-1990/91. A significant increase in average length was found during the 1997/98 project year, compared to values before closure, with values within later years remaining similar until another significant increase for the 2005/06 period. Average length calculated for the latter year was found to be significantly higher than even the peak value of the 1988/89 project year. Following the
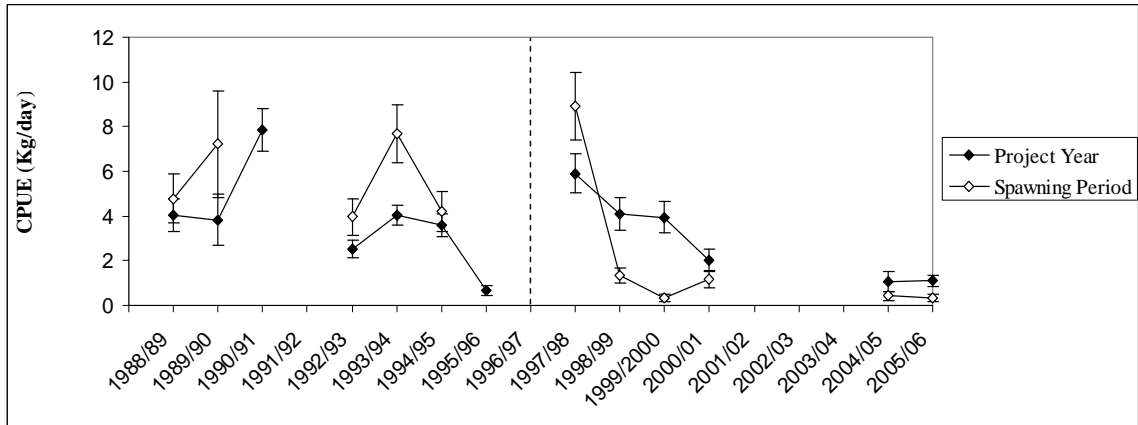
Figure 9. Annual average length and standard error of red hind (*Epinephelus guttatus*) from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period. The dashed line represents the time of enactment of the seasonal closures.

enactment of closure, an increase of average length by 3.98 cm was observed between the 1995/96 and 2005/06 project years. Trends and significances during spawning periods were nearly identical to those of project years. However, decreases in average length following the 1997/98 spawning period were observed, including a significant decrease during the 2000/01 spawning period, relative to that of the 1997/98 spawning period. Between the 2000/01 and 2005/06 spawning periods, a significant increase of 5.64 cm average length was found to have occurred.

Within trends of average length per gear type (Figure 10), values from hooked lines directly paralleled those calculated independent of gear type during project years and spawning periods, but average length measured during the 2005/06 sampling periods was not found to differ significantly from the earliest peak values of the 1988/89 project year and spawning period. The average length of individuals captured by traps also increased significantly in the 2005/06 project year, but only to a value comparable to those found

Figure 10. Annual average length and standard error of red hind (*Epinephelus guttatus*) per gear type from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period (HL=hooked line; TR=trap). Dashed lines represent the time of enactment of the seasonal closures.

during the 1992/93-1993/94 periods. Little differentiation in the average lengths of individuals captured by traps was found during spawning periods. Within most sampling periods, larger individuals were captured within traps than by hooked line, and 80% of all individuals captured within traps were females.

Inter-annual variations of average length by sex within project years and spawning periods were observed (Figure 11). Trends of female average lengths greatly paralleled those of average lengths of all individuals, and of individuals captured by
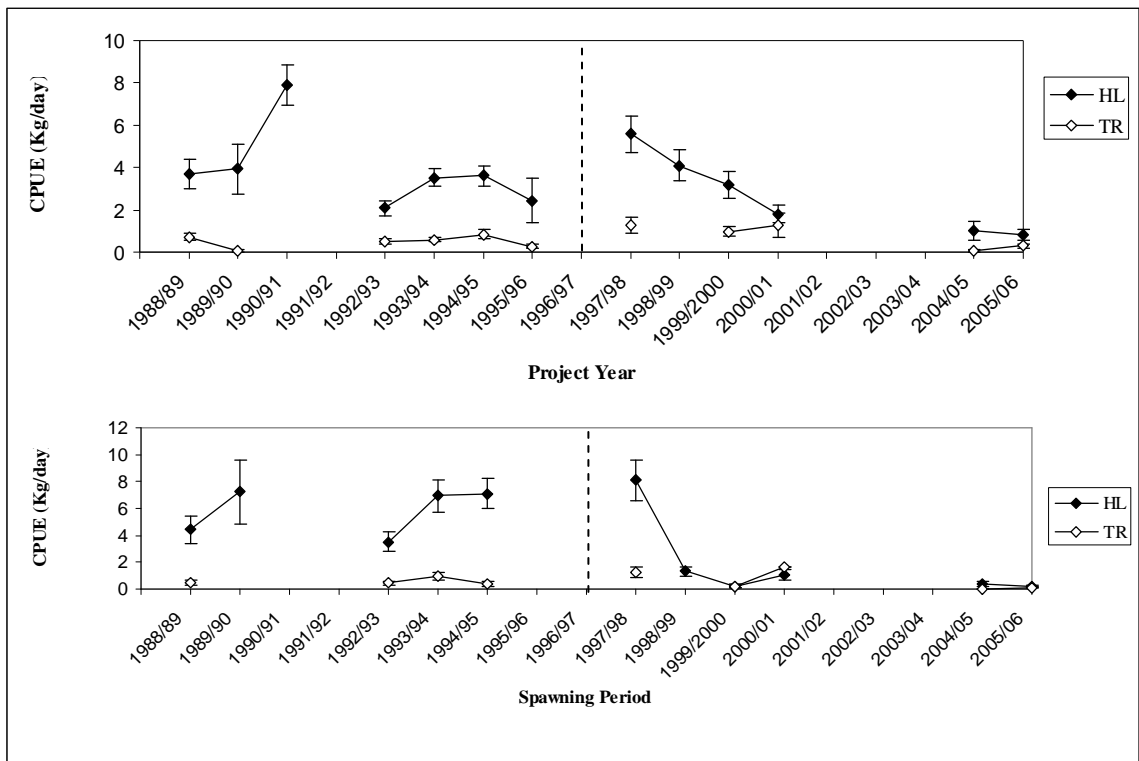
Figure 11. Annual average length and standard error of red hind (*Epinephelus guttatus*) per sex from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period. Dashed lines represent the time of enactment of the seasonal closures.

hooked lines. Female average length of the 2005/06 project year was found to be higher than all values observed within earlier years, with an increase in average length by 4.05 cm, relative to average length observed following the onset of the closure (1997/98). A noteworthy increase in average size of females occurred during the 1997/98 spawning period (after closure), but no further increase occurred until a 5.88 cm increase was observed in 2005/06. Decreases in the average lengths of males during project years were observed prior to the enactment of closure. A major decrease was observed in average length immediately prior to the enactment of the closures, with a subsequent

increase immediately following their enactment. Following the enactment of closure, further decreases were observed in the average lengths of males. Overall trends of average lengths of males during spawning periods were similar to those of project years. However, an additional marginal increase in average length was observed during the 2005/06 spawning period. Throughout most sampling periods (i.e. all project years except 1995/96, 2004/05-2005/06; all spawning periods except 2000/01, 2004/05-2005/06), males were found to be considerably larger than females.

Length-frequency distributions of males and females sampled throughout the entire western platform (Figure 12) during prominent project years (1988/89, 1992/93, 1994/95, 1997/98, 2000/01, 2005/06) revealed that age 2 females (FL=200 mm; Sadovy *et al.* 1992) were the basis of early recruitment into the SEAMAP-C sampling program, and most likely the fishery. Recruiting individuals were observed to contribute heavily to the bulk of the catch throughout subsequent project years, with peak abundance observed in age 3-5 individuals (FL=230-300 mm). Larger males (e.g. FL >400 mm), while low in number, were observed in greater numbers within project years prior to the enactment of the closures. Although fewer larger males were observed during the 1997/98 project year, high numbers of age 3-5 females were found together indicating good recruitment in recent years. However, recruitment of this and subsequent years appears to be lower (truncation at smaller sizes), or occur at a later age relative to what was observed in years prior to closure. Total numbers of individuals observed during the 2000/01 project year were much lower than in previous samplings, but proportional bulk contributions of age 3-5 females and the presence of age 2 recruits continued to be observed. However, the distribution was further truncated at the high end, with minimal numbers of larger males.
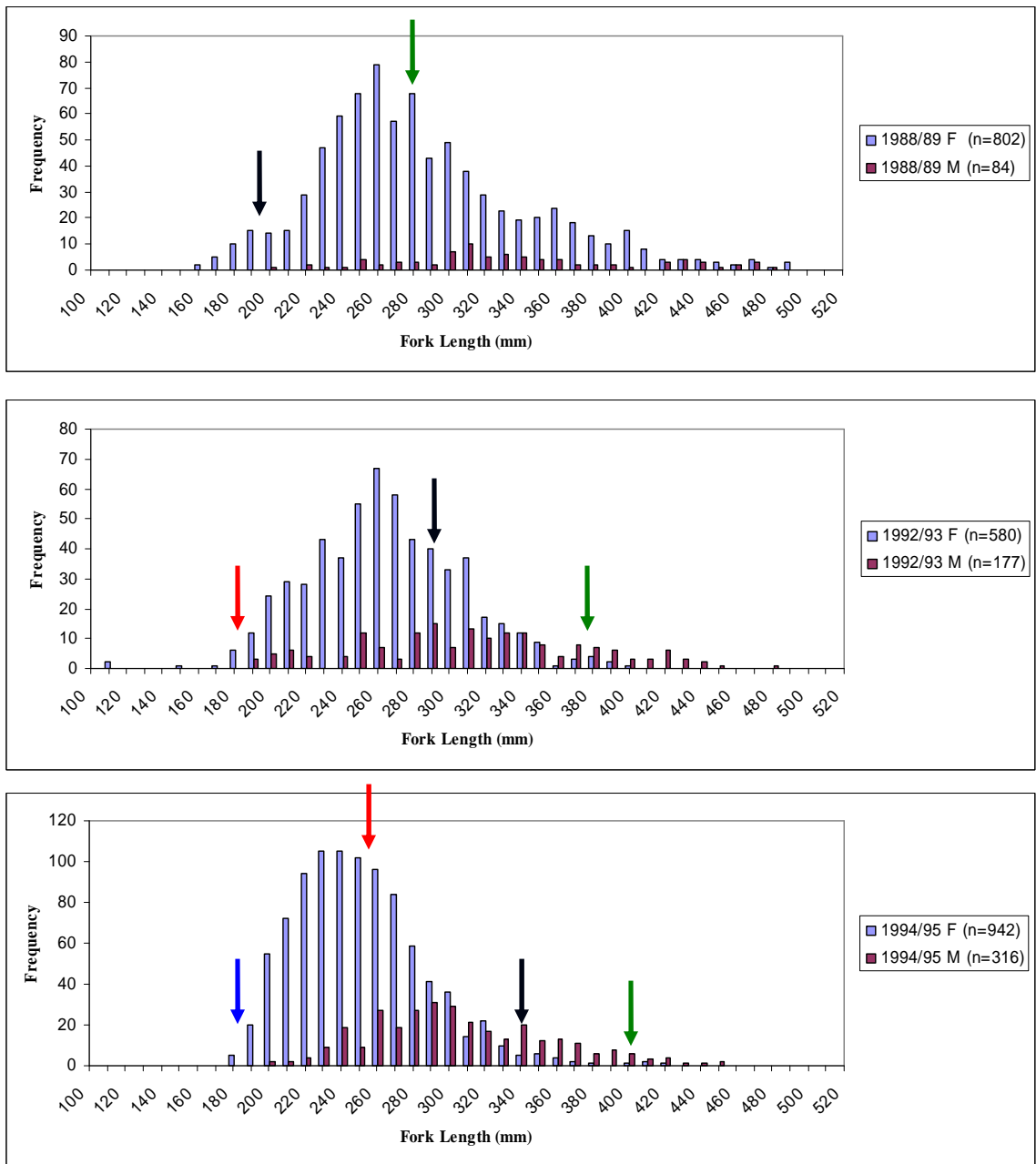
Figure 12. Length-frequency distributions per sex (F=Female; M=Male) of red hind (*Epinephelus guttatus*) per project year from SEAMAP-C samplings along the western insular platform of Puerto Rico, with age cohorts, as identified by colored arrows in accordance with Sadovy et al. 1992, traced throughout the sampling period.
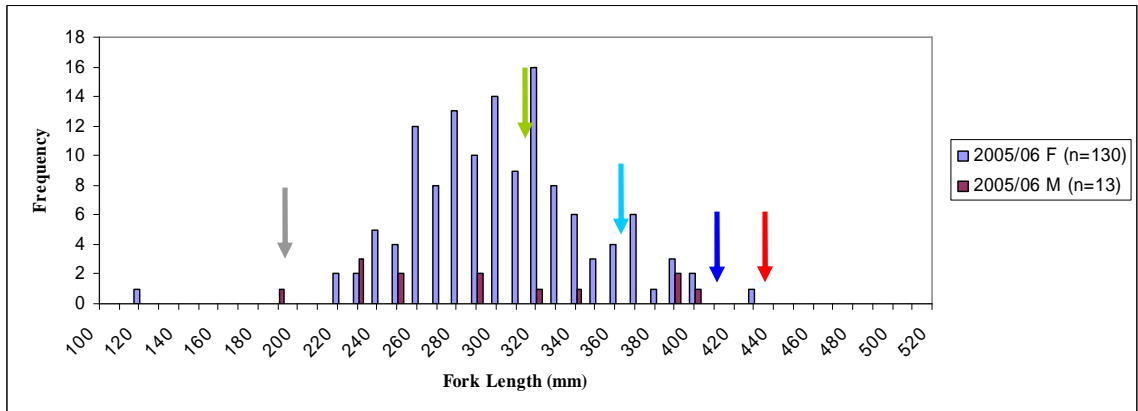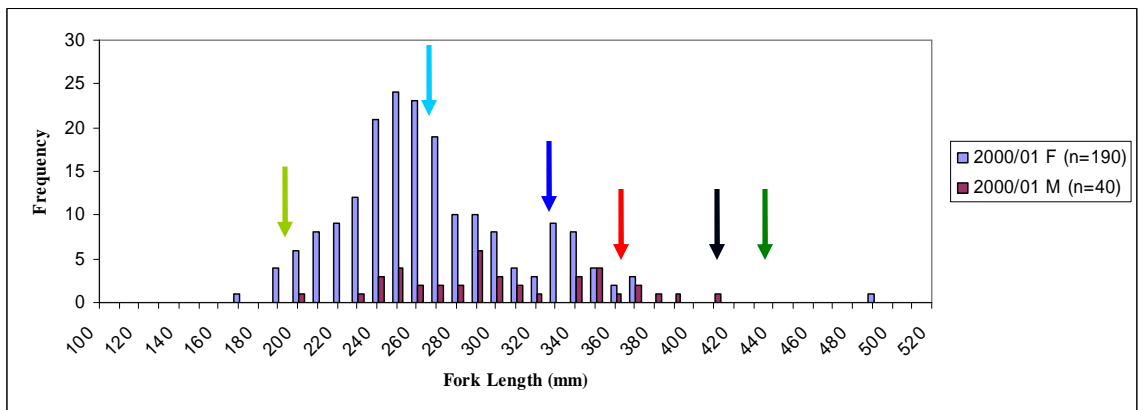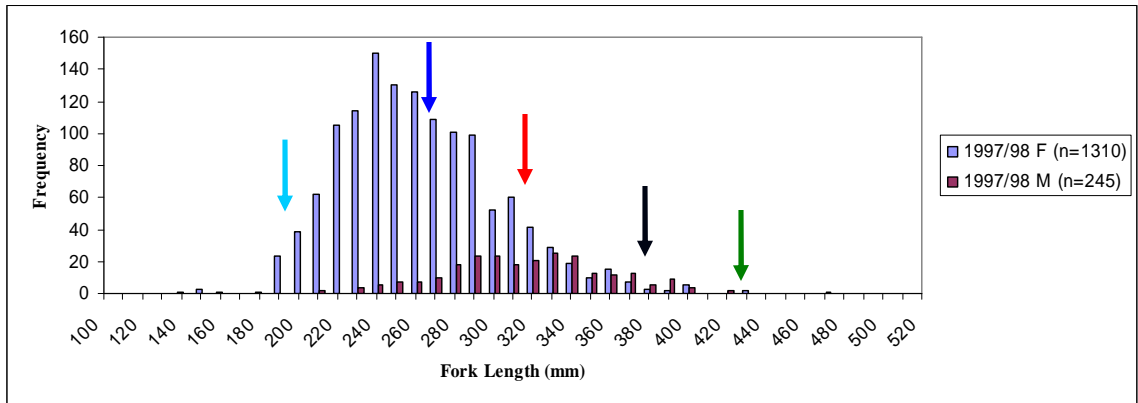
Figure 12 (cont'd). Length-frequency distributions per sex (F=Female; M=Male) of red hind (*Epinephelus guttatus*) per project year from SEAMAP-C samplings along the western insular platform of Puerto Rico, with age cohorts, as identified by colored arrows in accordance with Sadovy et al. 1992, traced throughout the sampling period.

Within the 2005/06 project year, still low numbers of individuals were observed with particularly low numbers of males, minimal numbers of recruits, and remnants of previously stronger cohorts in low abundance.

Percent contributions of age classes throughout SEAMAP-C project years are shown in Table 3. Generally, the bulk of captures consisted of individuals of ages 0-10 years. While little variation was observed in values of dominant age 3-4 individuals throughout project years, a noteworthy decrease was found during the 2005/06 project year. Prior to the enactment of the closures, contributions of age 0-2 individuals were found to increase, while those of older individuals decreased. Following enactment,

Table 3. Percent abundance of SEAMAP-C sampled red hind (*Epinephelus guttatus*) age classes (in years calculated using Sadovy *et al.* 1992) per project year throughout the western insular platform of Puerto Rico.

| Year	Ages 0-2 yrs (%) [0-230 mm FL]	Ages 3-4 yrs (%) [230-280 mm FL]	Ages 5-6 yrs (%) [280-325 mm FL]	Ages 7-10 yrs (%) [325-385 mm FL]	Total (%)
1988/89	12.75	38.26	23.81	16.25	91.08
1989/90	12.14	41.14	26.43	15.00	94.71
1990/91	6.94	44.74	27.43	17.36	96.48
1991/92	10.39	46.66	26.24	13.45	96.74
1992/93	17.31	39.63	26.02	13.08	96.04
1993/94	22.02	43.86	21.31	10.80	97.98
1994/95	23.69	44.91	19.79	9.30	97.69
1995/96	22.83	48.91	19.57	7.61	98.91
1996/97	-------	-------	-------	-------	-------
1997/98	18.39	43.22	24.37	12.41	98.39
1998/99	17.20	42.53	26.52	11.71	97.97
1999/00	21.48	42.62	22.99	11.24	98.32
2000/01	15.22	49.13	18.26	16.09	98.70
2001/02	-------	-------	-------	-------	-------
2002/03	-------	-------	-------	-------	-------
2003/04	-------	-------	-------	-------	-------
2004/05	8.20	40.98	34.43	16.39	100.00
2005/06	5.56	26.39	38.89	22.92	93.75
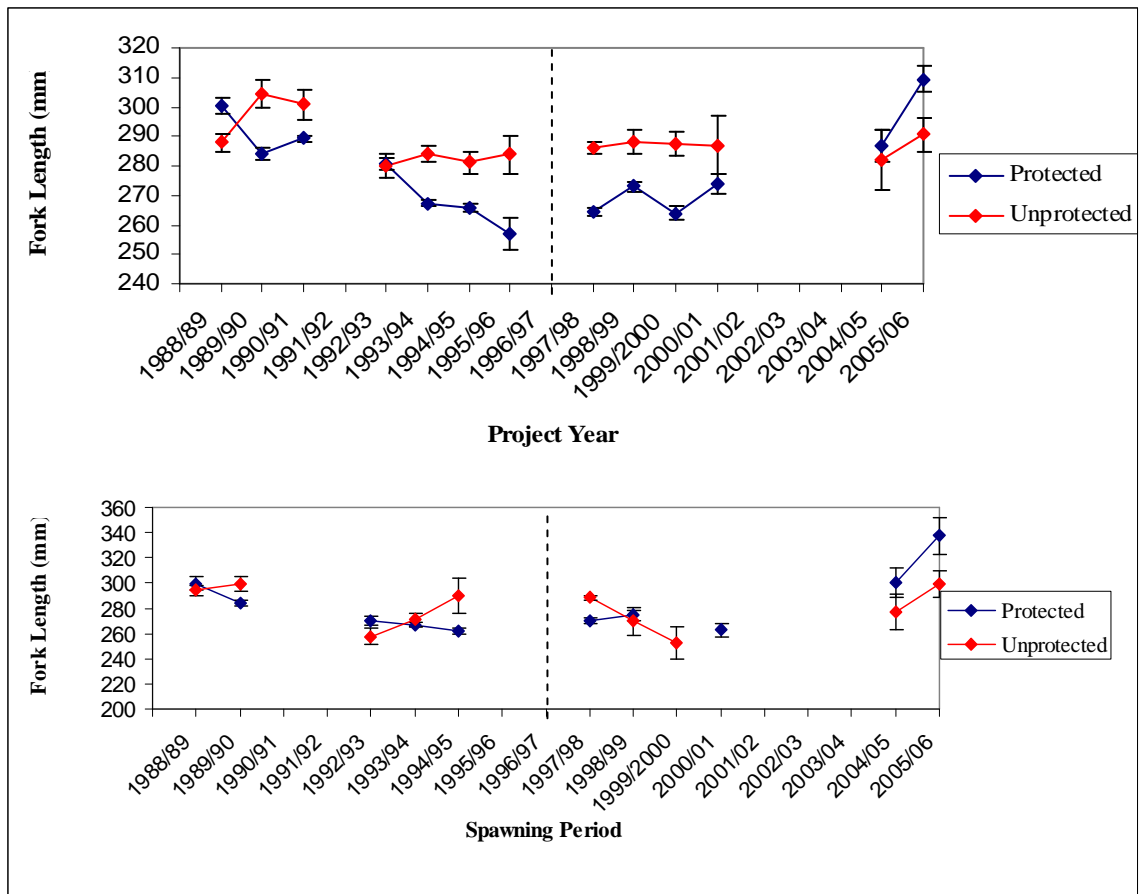
Figure 13. Annual average length and standard error of red hind (*Epinephelus guttatus*) from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period within protected and unprotected areas. Dashed lines represent the time of enactment of the seasonal closures.

percent contributions of age 0-2 individuals declined, with decreases in recent project years to only 5.56%, whereas percent contributions of age 5-6 and 7-10 year individuals were observed to increase to previously unmeasured values in recent project years.

Decreases in average length were observed within grouped seasonally protected areas during project years and spawning periods prior to the enactment of closures (Figure 13), and later trends greatly mirrored those observed for the entire western platform, with major increases not being observed until the 2004/05-2005/06 periods. An

increase in the average length of individuals by 5.25 cm was observed within project years following the onset of the closures, while individuals captured during spawning periods were found to increase by 7.55 cm. Little differentiation in inter-annual average length was measured between project years or spawning periods for individuals sampled within unprotected areas. During most project years, average lengths of individuals within unprotected areas were found to be higher than those within protected areas, with notable differentiation during the 1989/90, 1993/94-1994/95, and 1997/98-1999/2000 project years. However, little differentiation between protected and unprotected areas was noted during spawning periods, with a notable difference measured only during the 1997/98 spawning period. Within more recent sampling periods, larger individuals were found within protected areas.

Within seasonally protected areas, notable differences were observed for inter-annual average lengths between project years, with trends of individuals sampled in *Bajo de Cico* most closely approximating those observed for grouped protected areas and the western platform (Figure 14). While early decreases were observed within *Abrir la Sierra*, there was little overall differentiation in average length prior to and immediately following the enactment of closure. However, following the 2000/01 project year an increase in average length of 5.43 cm was observed throughout later years. Little differentiation in average length was observed within *Abrir la Sierra* throughout spawning periods. However, an increase in average length of 5.99 cm was observed throughout the period following the enactment of the closure.

Within *Bajo de Cico*, progressive decreases in average length were observed within project years prior to the enactment of the closures. Following enactment,
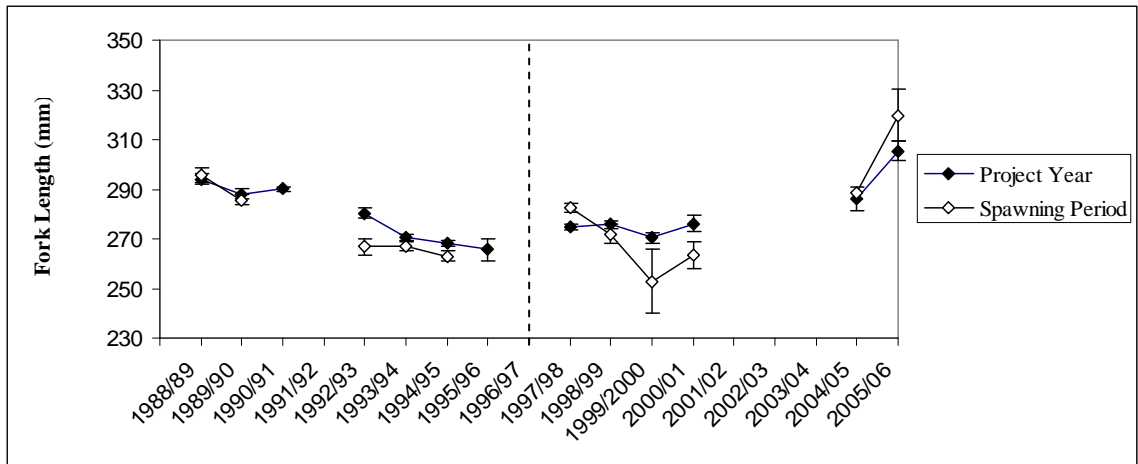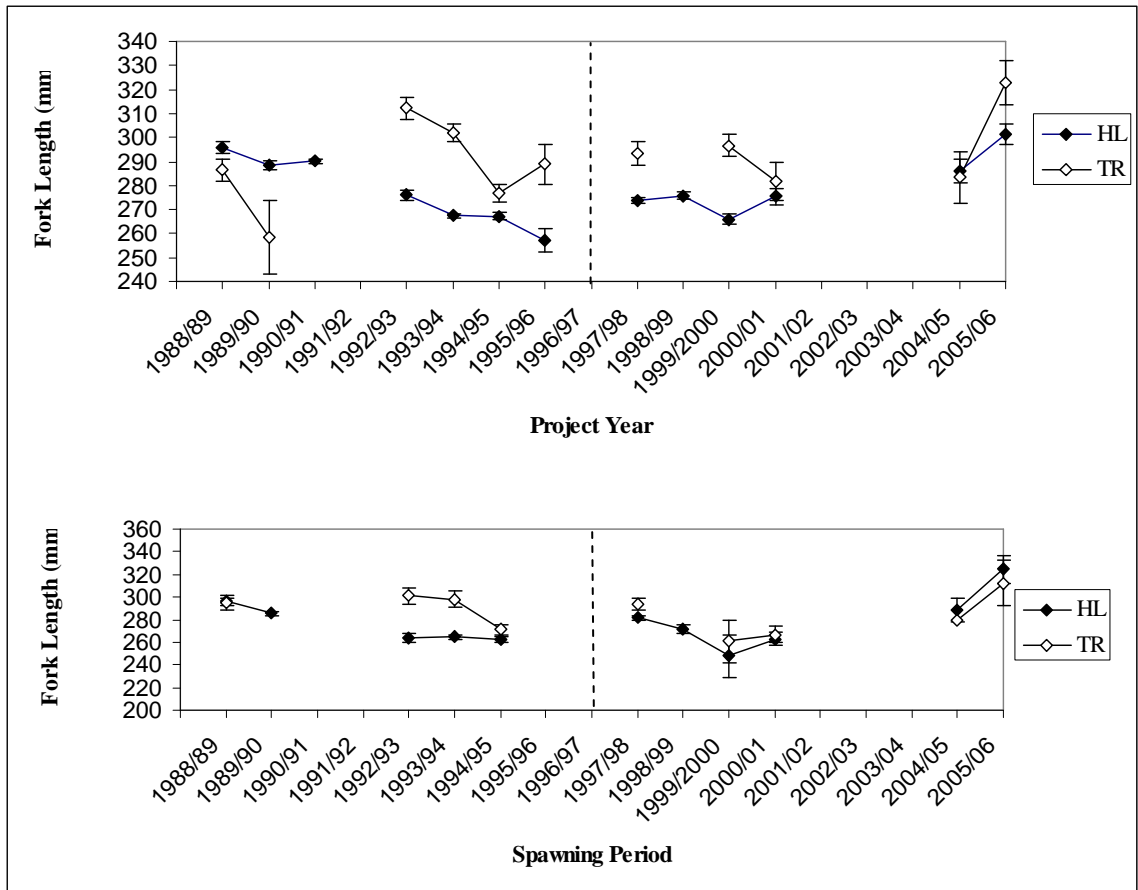
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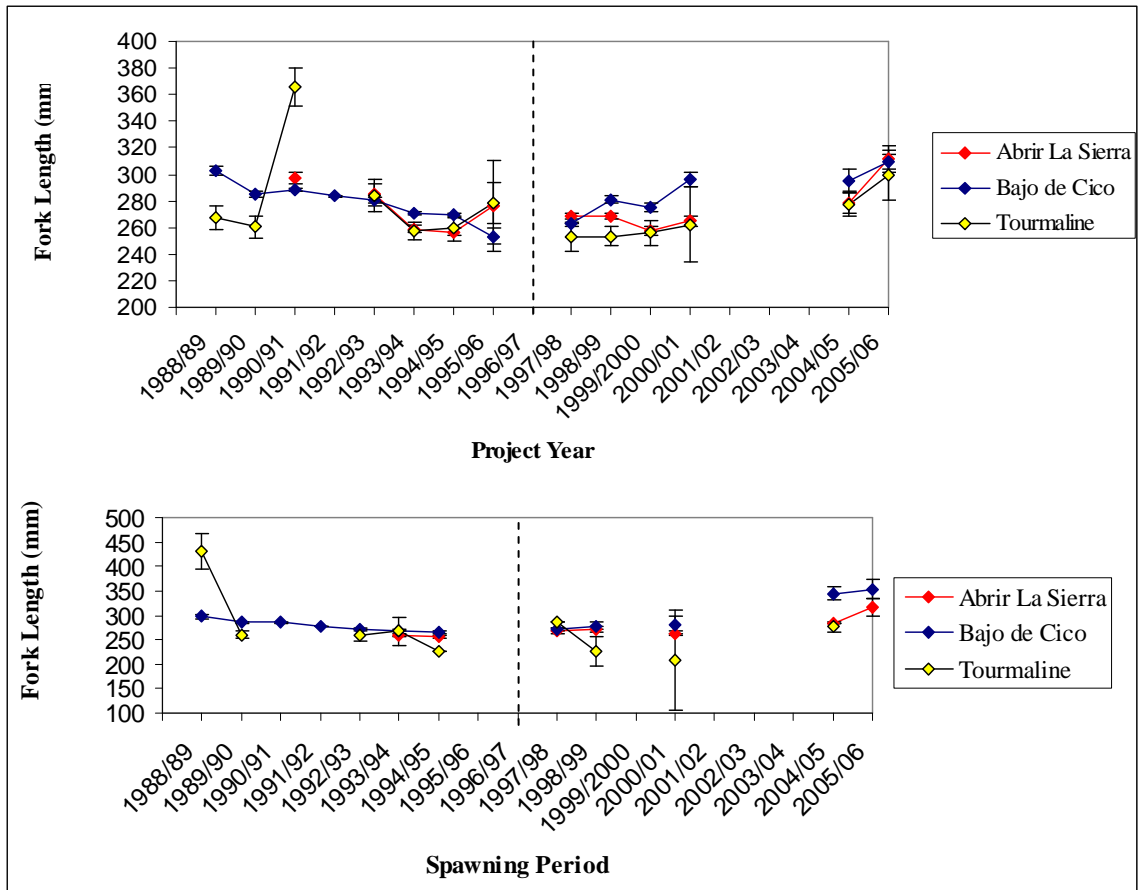
Figure 14. Annual average length and standard error of red hind (*Epinephelus guttatus*) from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period within seasonally protected areas. Dashed lines represent the time of enactment of the seasonal closures.

progressive increases were observed, representing a 5.57 cm increase in average length throughout this period. During spawning periods, similar trends were found, where progressive decreases were observed within earlier years. Although an increase in average length of 8.81 cm was observed throughout spawning periods following enactment of closure, little differentiation was observed between inter-annual values immediately following the enactment of the closure. Overall, average length was found to be highest within *Bajo de Cico* during project years and spawning periods, but
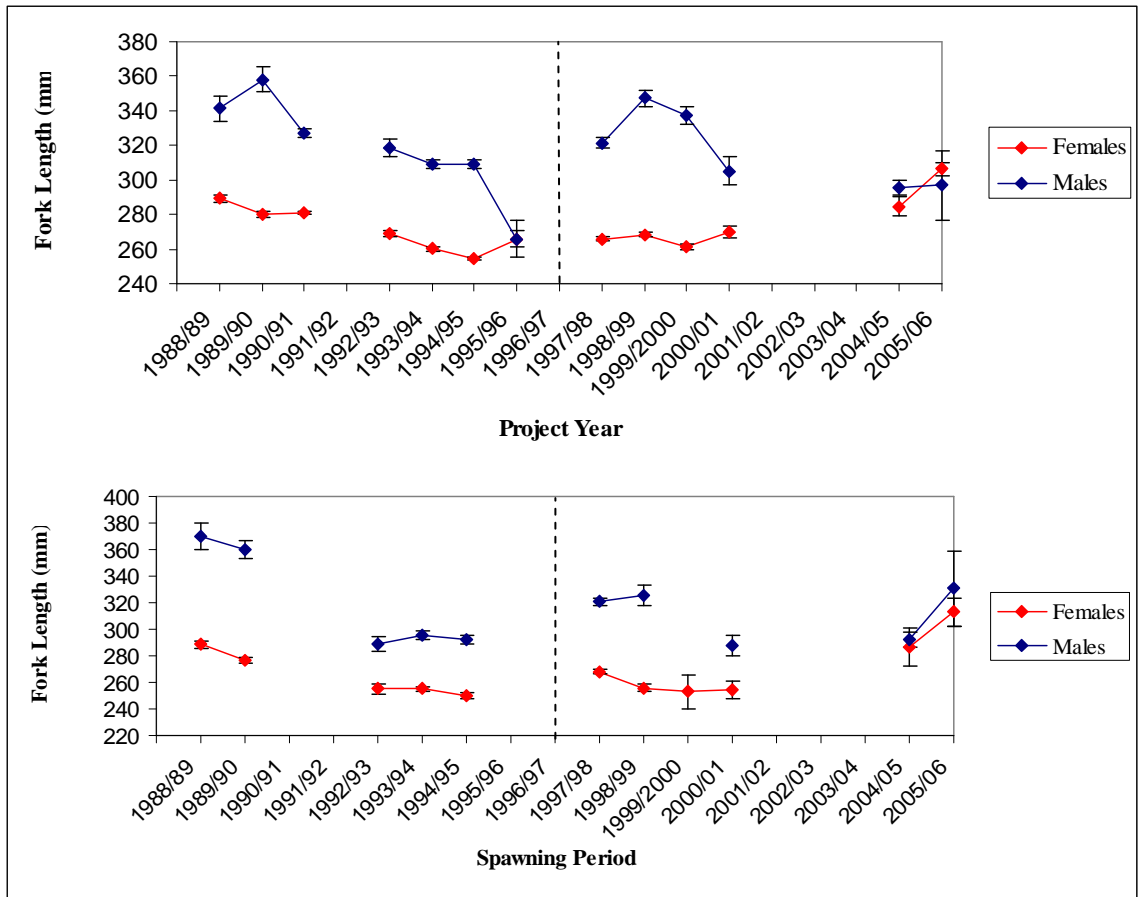
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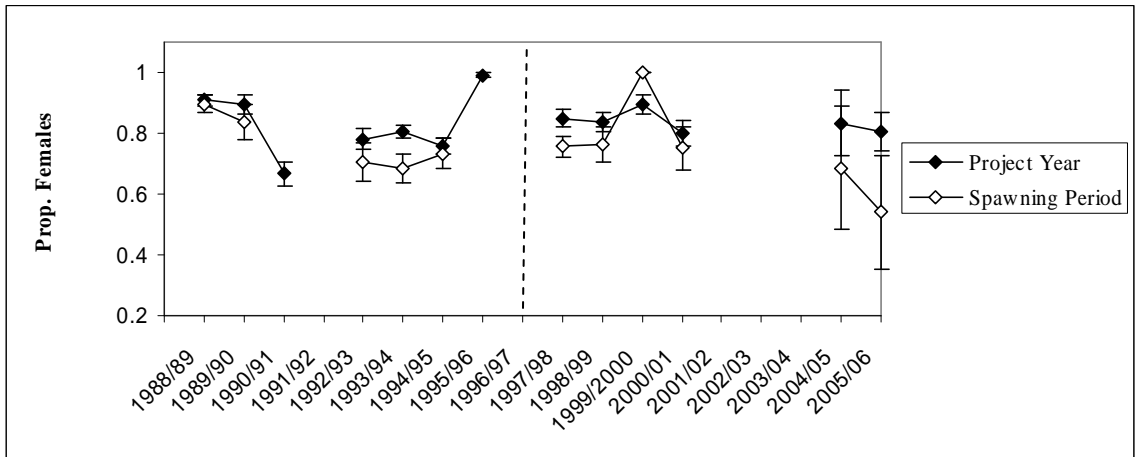
Figure 15. Annual average proportions and standard error of female red hind (*Epinephelus guttatus*) from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period. The dashed line represents the time of enactment of the seasonal closures.

variations in average length per sampling period between protected areas were often marginal.

Within *Tourmaline*, major differentiations in average length were only found between early high annual average length values, which were the result of capturing an occasional larger individual in very low catches. However, trends and values during project years and spawning periods closely approximated those found within *Abrir la Sierra*. Although little differentiation was found between later project years within *Tourmaline*, an increase of average length of 4.02 cm was observed throughout the period following the enactment of closure. Very little differentiation was found between average lengths of individuals captured within spawning periods.

Average proportions of females within the entire western platform of Puerto Rico (Figure 15) were found to significantly differ between project years ($p < 0.05$). Significant differences were measured between years prior to the enactment of the closures, especially during a decrease in the proportion of females observed within the 1990/91

project year. A significant increase in female proportion immediately followed, but

values remained significantly lower than those of the 1988/89-1989/90 project years until

a following significant increase during the 1995/96 project year, where 99.2% of the

sampled population was female. However, this value did not differ significantly from

initial values. No inter-annual significant differences were measured following the

enactment of closures. During spawning periods, little variation was observed in the

proportion of females, with the only significant difference ($p<0.05$) in the average

proportions of females observed between the 1988/89 and 1993/94 spawning periods.

Trends of annual average female proportions were similar to coast-wide trends at all

spatial scales. Inter-annual significant differences at higher resolutions were found

between few sampling periods, and no significant variation in annual trend was observed

prior to and following the enactment of closures.

Fishery-dependent commercial landings data (Cabo Rojo and Mayaguez)

Throughout the SEAMAP-C sampling period, a total of 122,994 kg of red hind

were reported landed from the Cabo Rojo and Mayaguez municipalities combined (Table

4). These two regions comprise the bulk of the sampling area of SEAMAP-C, and have

historically contributed the majority of the west coast landings of Puerto Rico. Although

this component of the west coast has historically contributed a large percentage of the

total red hind landings in Puerto Rico, landings within this area represented only 31% of

the total island-wide red hind catch throughout the SEAMAP-C period of study. Annual

contributions to Puerto Rico total landings have been no higher than 46%, with

Table 4. Annual total reported landings of red hind (*Epinephelus guttatus*) per SEAMAP-C project year and red hind spawning period (in parenthesis) from the Cabo Rojo and Mayaguez municipalities of Puerto Rico combined, with breakdown of annual catches by percent gear type (HL=hand line; TR=trap; SCUBA=spearfishing while SCUBA diving; Other=other gear types) and percent contribution to total west coast and Puerto Rico landings.

Year	Total Landings		% TR		% HL		%SCUBA		% Other		% W Coast		% All PR	
1988/89	4367.46	(1705.22)	63.5	(62.7)	25.4	(30.9)	0.0	(0.0)	11.2	(6.4)	51.1	(69.7)	29.7	(33.2)
1989/90	4697.17	(1725.62)	55.7	(24.3)	30.2	(50.4)	2.8	(5.3)	11.3	(19.9)	63.7	(87.1)	29.8	(41.7)
1990/91	9187.53	(5195.24)	52.4	(52.3)	30.7	(33.2)	15.6	(13.7)	1.4	(0.9)	71.4	(84.8)	35.7	(43.5)
1991/92	9419.50	(3910.88)	41.6	(29.0)	25.1	(38.1)	28.7	(24.0)	4.5	(8.9)	80.9	(85.5)	44.4	(46.6)
1992/93	6863.72	(3252.83)	44.6	(38.1)	30.6	(19.8)	21.9	(37.7)	2.9	(4.4)	75.2	(75.2)	35.7	(40.7)
1993/94	6718.71	(2526.98)	51.9	(59.7)	17.4	(15.8)	18.5	(1.4)	12.2	(23.1)	78.8	(84.5)	41.4	(43.0)
1994/95	2494.56	(1541.50)	15.4	(2.1)	67.6	(74.8)	19.1	(14.5)	7.9	(8.6)	57.9	(89.8)	18.0	(22.0)
1995/96	4264.85	(2606.12)	13.0	(12.1)	70.1	(67.2)	10.2	(13.3)	6.7	(7.4)	73.4	(97.4)	19.4	(25.7)
1996/97	4700.68	(1577.78)	17.5	(11.9)	62.6	(62.4)	15.2	(24.0)	4.7	(1.7)	93.2	(91.2)	18.5	(12.9)
1997/98	8884.69	(4654.76)	24.6	(27.5)	41.8	(41.4)	26.4	(26.3)	7.2	(4.8)	96.5	(98.9)	33.9	(43.6)
1998/99	10501.03	(4636.52)	23.6	(16.3)	33.0	(39.2)	40.8	(43.9)	2.6	(0.7)	95.2	(93.7)	39.5	(37.7)
1999/00	8344.10	(2703.51)	16.7	(4.3)	34.4	(53.0)	46.2	(38.4)	2.8	(4.3)	82.8	(91.5)	28.6	(22.5)
2000/01	7688.66	(2526.08)	21.7	(31.9)	36.4	(33.2)	38.2	(32.3)	3.7	(2.6)	80.5	(67.2)	27.8	(22.8)
2001/02	8428.80	(3668.93)	18.8	(15.9)	38.2	(45.2)	40.9	(36.8)	2.1	(2.1)	89.8	(94.4)	25.7	(26.5)
2002/03	8420.86	(2691.16)	16.6	(15.7)	42.4	(47.1)	39.7	(36.5)	1.3	(0.8)	78.6	(73.5)	23.8	(22.9)
2003/04	8377.10	(3885.03)	33.9	(24.6)	33.1	(29.2)	29.1	(44.4)	3.9	(1.8)	76.0	(90.0)	33.4	(39.9)
2004/05	4953.29	(1143.65)	9.9	(8.8)	29.9	(41.7)	52.6	(49.5)	7.6	(0.0)	72.5	(78.8)	36.3	(36.5)
2005	4681.29	(----------)	7.5	(-----)	32.8	(-----)	59.7	(-----)	0.0	(-----)	67.6	(-----)	46.4	(-----)
Total	122994.00	(49951.82)	29.9	(27.3)	35.8	(40.2)	29.6	(27.4)	4.6	(5.1)	77.8	(85.7)	30.7	(31.8)

contributions immediately following the enactment of the closure being no more than 20%.

Most red hind were captured by hook and line, while catches from fish traps and spearfishing while SCUBA diving contributed significant proportions to total landings. Although other gear types such as gill and trammel nets, troll lines, and long lines are used within the red hind fishery, their contribution to annual reported catch was no more than 12% in a given year. Within earlier SEAMAP-C project years during the period of interest, red hind captured by traps overwhelmingly made up the largest component of the

catch. However, near the enactment of the seasonal closures, catches from hand lines, and later by spearfishing, comprised the majority of the commercial fishery. During the most recent years of study (2004/05-2005), catches from traps made up no more than 10% of the total catch of the Cabo Rojo and Mayaguez regions of the west coast, while catches from spearfishing made up the majority of the landings.

Trends and percent contributions of gears to landings during spawning periods were very similar to those of project years. On average, landings during spawning periods made up 42.5% +/- 2.64 SE of annual landings per SEAMAP-C project year. However, immediately prior to the enactment of the seasonal closures (1995/96 project year), landings reported during the spawning period made up 61% of the reported catch. Within the years following enactment of closure, landings during spawning periods averaged 38.3% +/- 3.44 SE of project year landings. However, during the 2004/05 project year, only 23% of the annual landings came from catches during spawning periods.

Throughout the SEAMAP-C sampling period, 21,109 fishing trips have been reported with red hind landings data within the Cabo Rojo and Mayaguez municipalities of Puerto Rico (Table 5). Fishing trips from these areas have comprised 82% of the trips of the west coast of Puerto Rico, but only 26% of total island-wide reported fishing effort for red hind. Annual contributions to total reported red hind fishing effort within Puerto Rico during project years have been low (mean=31.6% +/- 2.01 SE), but variable. Trends of percent contributions of fishing trips mirrored those of catches, as evidenced by low percentages during the years around the enactment of the

Table 5. Annual number of fishing trips reported for red hind (*Epinephelus guttatus*) per SEAMAP-C project year and spawning period (in parenthesis) from the Cabo Rojo and Mayaguez municipalities of Puerto Rico combined, with breakdown of annual trips by percent gear type (HL=hand line; TR=trap; SCUBA=spearfishing while SCUBA diving; Other=other gear types) and percent contribution to total fishing trips reported for red hind for the west coast and Puerto Rico.

Year	Total Trips		% TR	% HL	% SCUBA	% Other	% W Coast	% All PR
1988/89	239	(63)	45.2 (30.2)	38.9 (58.7)	0.0 (0.0)	15.9 (11.1)	29.5 (34.2)	15.5 (14.8)
1989/90	1126	(451)	31.6 (21.5)	62.2 (75.8)	0.6 (1.1)	5.6 (1.6)	72.5 (85.9)	42.5 (53.9)
1990/91	877	(417)	28.1 (24.5)	63.9 (66.2)	4.3 (4.6)	3.8 (4.8)	67.2 (78.1)	31.7 (37.2)
1991/92	764	(355)	43.6 (29.3)	44.0 (59.2)	6.2 (5.4)	6.3 (6.2)	69.0 (78.9)	19.2 (26.8)
1992/93	671	(236)	48.4 (30.1)	43.2 (52.1)	6.7 (15.7)	1.6 (2.1)	70.8 (69.8)	23.6 (19.9)
1993/94	458	(176)	36.0 (46.0)	44.5 (43.8)	14.4 (7.4)	5.0 (2.8)	66.9 (76.2)	18.9 (16.4)
1994/95	290	(175)	21.4 (7.4)	63.4 (74.3)	7.2 (10.9)	7.9 (7.4)	58.4 (85.8)	10.1 (11.3)
1995/96	840	(415)	15.8 (13.7)	48.0 (35.9)	21.1 (31.6)	15.1 (18.8)	81.6 (98.1)	13.9 (21.5)
1996/97	1048	(465)	22.9 (14.6)	51.2 (56.3)	20.4 (28.0)	5.4 (1.1)	97.2 (97.9)	16.8 (18.9)
1997/98	1828	(888)	29.2 (41.3)	24.8 (25.9)	36.2 (22.7)	9.9 (10.0)	98.5 (99.2)	32.7 (44.2)
1998/99	2832	(888)	12.0 (19.5)	31.0 (28.8)	55.0 (51.5)	1.9 (0.2)	95.2 (91.7)	38.3 (31.8)
1999/00	2800	(858)	8.3 (2.0)	27.1 (39.6)	61.1 (50.0)	3.5 (8.4)	87.2 (92.2)	32.7 (30.1)
2000/01	1819	(621)	23.0 (33.7)	35.3 (43.8)	38.9 (18.8)	2.8 (3.7)	81.5 (68.2)	24.8 (23.7)
2001/02	1807	(533)	11.8 (15.0)	37.9 (38.6)	48.2 (44.1)	2.0 (2.3)	87.4 (86.5)	23.1 (20.5)
2002/03	1480	(285)	23.6 (18.2)	28.6 (40.4)	45.2 (35.8)	2.6 (5.6)	92.3 (74.2)	22.5 (53.5)
2003/04	850	(255)	20.9 (15.7)	38.9 (32.9)	37.6 (48.2)	2.5 (3.1)	74.3 (85.0)	28.1 (30.5)
2004/05	680	(105)	7.1 (10.5)	25.4 (34.3)	61.9 (55.2)	5.6 (0.0)	79.0 (80.2)	36.8 (27.5)
2005/05	700	(----)	7.1 (-----)	27.9 (-----)	65.0 (-----)	0.0 (-----)	79.4 (-----)	48.5 (-----)
Total	21109	(7186)	20.5 (21.7)	37.2 (43.8)	37.8 (29.2)	4.5 (5.3)	81.7 (84.5)	26.1 (27.1)

closures. Prior to the enactment of the closures, average reported fishing effort was 701.44 +/- 105.25 SE trips, with highest monthly fishing intensity generally within January, and periodic peaks in effort during August and October months.

Immediately following the enactment of the closures, the number of recorded fishing trips increased 2-3 fold, following which effort gradually decreased to values comparable to those observed prior to the enactment of the closures. Similar observations were found during spawning periods in which reported trips increased two-fold immediately following the enactment of the closures. Monthly fishing intensity

remained prominent during spawning months with noteworthy increases. However,

increases in fishing intensity were found throughout nearly all months following

enactment of the closures, with highest intensities observed during summer months,

particularly July-August. Within project years prior to the enactment of the closures, a

higher percent of fishing effort occurred during the spawning period (average %

spawning-period effort relative to total annual effort = 43.1% +/- 3.21 SE) relative to

project years after enactment (average % spawning-period effort relative to total annual

effort = 29.9% +/- 3.52 SE). Although the majority of fishing trips generally occurred

during the non-spawning period throughout the duration of study, during the 2004/05

project year only 15% of the reported fishing effort came from trips during spawning

periods.

Nearly equivalent fishing effort was performed with hook and line and

spearfishing (while SCUBA diving) throughout the entirety of the period of interest.

Within years prior to the enactment of closure, hook and line was the dominant reported

fishing gear, with little reported use of spearfishing with SCUBA diving. However,

following the enactment of the closure, spearfishing soon became the preferred method of

capture, while hook and line use remained significant. Low numbers were observed for

trapping trips, with no more than 7% of the fishing effort coming from traps during the

2004/05-2005 project years. Similar trends were observed during spawning periods.

Annual nominal CPUE (kg/trip) values within the combined Cabo Rojo and

Mayaguez municipalities of Puerto Rico (Figure 16) were found to significantly differ

between project years and spawning periods ($p < 0.05$). Excluding the low observation
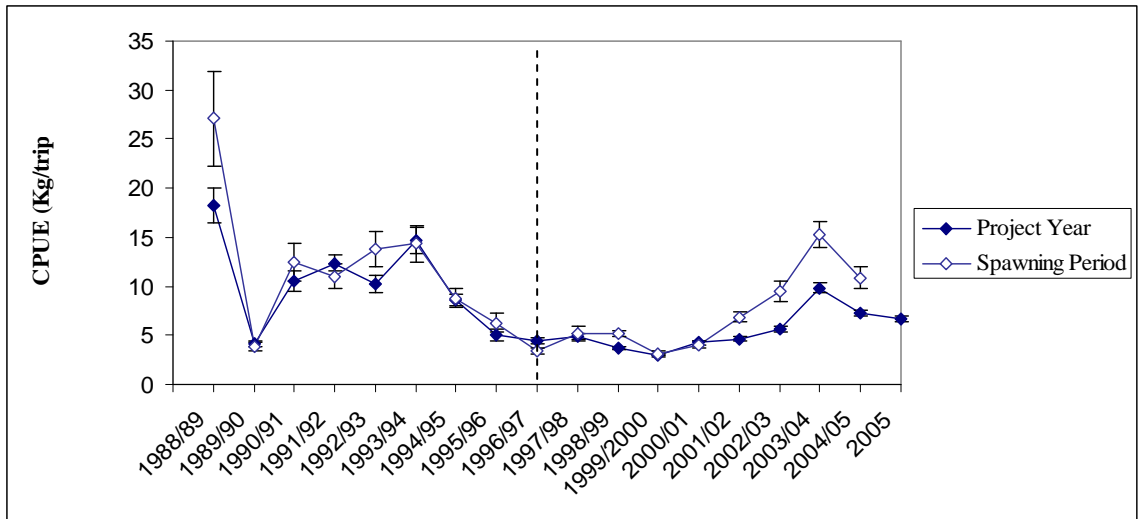
Figure 16. Annual average nominal CPUE (kg/trip) and standard error of red hind (*Epinephelus guttatus*) from reported landings of combined Cabo Rojo and Mayaguez municipalities of Puerto Rico, per SEAMAP-C project year and red hind spawning period. The dashed line represents the time of enactment of the seasonal closures.

during the 1989/90 SEAMAP-C project year, earlier annual CPUE values of the period of interest were generally higher than within most later years. Significant differences were measured between values of project years prior to the enactment of closures, and pronounced significant decreases were observed throughout the 1993/94-1995/96 project years. Little variation in CPUE was observed immediately following the enactment of the closure. However, significant increases were observed within later years, which peaked during the 2003/04 project year to a value comparable to those of years prior to the enactment of closure. Following this year, a significant decrease in CPUE was observed. CPUE during spawning periods closely paralleled that of project years. Although there was little differentiation of values, CPUE during spawning periods was generally higher than within corresponding project years, with more pronounced differences observed during later years.

Within the three most frequently employed gear types of the red hind fishery, annual nominal CPUE (kg/trip) was found to differ between project years and spawning periods (Figure 17). During spawning periods, CPUE values were found to closely mirror those of corresponding project years with few exceptions. Spawning period CPUE generally approximated, or was greater than, its corresponding project year CPUE. Within later years, increased differentiation was observed between project years and spawning period CPUE, especially within hook and line. Values within traps were variable, and following the initial decrease of the 1989/90 project year and spawning period, lesser sequential differentiation was observed until the 1994/95 period, during which a decrease to values much lower than the CPUE of most preceding years occurred. Throughout subsequent years, little variation was observed until a noteworthy increase during the 2003/04 project year, which was found to be compatible with higher values during the period prior to the closures. Throughout the 2004/05-2005 project years, decreases in CPUE were observed, but were not found to be much lower than the 2003/04 peak, nor than values within most years prior to the enactment of closures. CPUE of the 2004/05-2005 project years remained higher than prior values observed within project years following the enactment of closure.

As in traps, an early decrease of hook and line CPUE was observed during the 1989/90 project year, followed by increases which occurred until the 1994/95 project year, after which noteworthy decreases were observed within the years leading up to the closures. Although an increase in CPUE immediately following enactment was observed, it was not found to be highly different from previous values, and was followed by much lower values as of the 1998/99 project year. However within this period of

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Traps

Hook and Line

Spearfishing with SCUBA
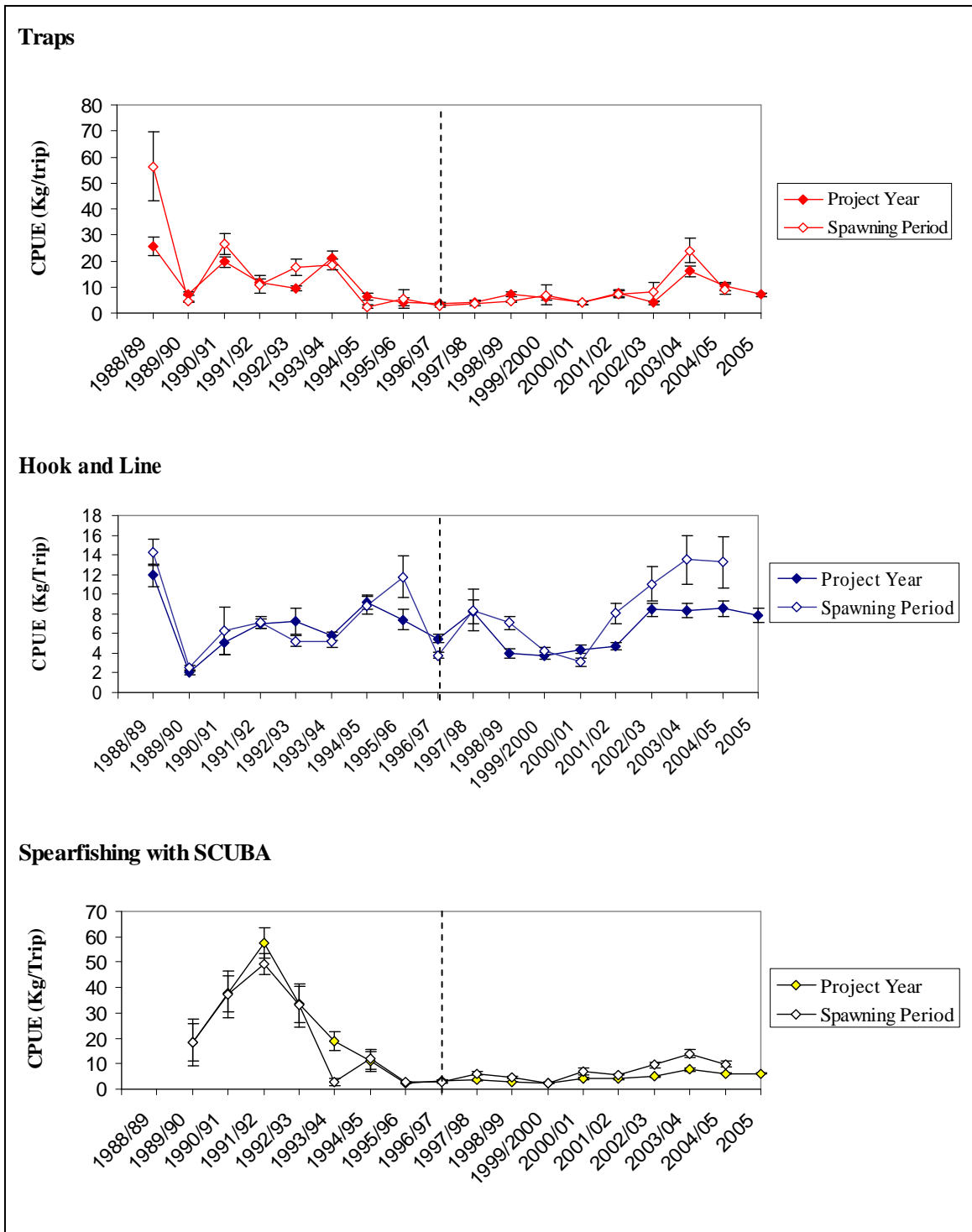
Figure 17. Annual average CPUE (kg/trip) and standard error of red hind (*Epinephelus guttatus*) by gear type from reported landings of combined Cabo Rojo and Mayaguez municipalities of Puerto Rico, per SEAMAP-C project year and red hind spawning period. Dashed lines represent the time of enactment of the seasonal closures.

lower CPUE, marginal progressive increases occurred, followed by a prominent increase, as of the 2002/03 project year, to values compatible with those of years prior to the enactment of closures.

CPUE of spearfishing with SCUBA was found to increase within the early project years of the period of interest until peaking at 57.6 kg/trip during the 1991/92 project year. Subsequent decreases were observed within project years leading up to the time of enactment of closures, following which little variation was observed. However, within post-enactment project years, sequential increases in CPUE were observed during the 2000/01 and 2003/04 project years.

Relationships of CPUE between gears were found to vary throughout the period of interest. Within earlier project years prior to the enactment of the closures, trap CPUE was observed to be higher than that of hook and line. However, as of the 1989/90 project year, CPUE by spearfishing with SCUBA was found to dwarf both gear types until values significantly decreased during the 1995/96 project year. While little differentiation in CPUE between gear types was observed during subsequent years close to the timing of the enactment of closures, hooked line CPUE was comparatively highest until trap CPUE increased throughout most of the period onward from the 1998/99 project year. Spearfishing CPUE was found to be comparatively lowest throughout the period following the enactment of closures. Similar trends were observed during spawning periods. Although differences between CPUE of traps and spearfishing were not as pronounced as during project years, more pronounced differences were observed between trap and hand line CPUE during spawning periods.

Fishery-dependent port-sampled biostatistical data (Cabo Rojo and Mayaguez)

Throughout the SEAMAP-C period of interest, biostatistical data for 2238 port-sampled red hind were collected within the Cabo Rojo and Mayaguez municipalities of Puerto Rico (Table 6). Overall, most sampled individuals were captured by hand lines or by spearfishing with SCUBA, with minimal numbers captured by traps. However, within this dataset many individuals were also obtained by other gears, particularly trammel nets, which generally play a minor role in total landings contributions. Red hind obtained during spawning periods made up 31% of all sampled individuals. During project years, increases in the number of sampled individuals were observed up to the 1991/92 project

Table 6. Annual number of port-sampled red hind per SEAMAP-C project year and red hind spawning period (in parenthesis) from the Cabo Rojo and Mayaguez municipalities of Puerto Rico combined, with percent breakdown of individuals by gear type captured (HL=hand line; TR=trap; SCUBA=spearfishing while SCUBA diving; Other=other gear types).

Year	Total Red Hind		% TR		%HL		%SCUBA		% Other	
1988/89	9	(3)	------	------	------	------	------	------	-------	-------
1989/90	82	(19)	48.8	(89.5)	1.2	(5.3)	0.0	(0.0)	50.0	(5.3)
1990/91	107	(35)	55.1	(31.4)	8.4	(20.0)	0.0	(0.0)	36.4	(48.6)
1991/92	136	(81)	21.3	(0.0)	56.6	(87.7)	2.2	(3.7)	19.9	(8.6)
1992/93	114	(17)	6.1	(41.2)	24.6	(0.0)	26.3	(23.5)	43.0	(35.3)
1993/94	81	(44)	33.3	(0.0)	51.9	(95.5)	3.7	(4.6)	11.1	(0.0)
1994/95	27	(5)	85.2	(40.0)	0.0	(0.0)	0.0	(0.0)	14.8	(60.0)
1995/96	18	(5)	11.1	(0.0)	0.0	(0.0)	22.2	(0.0)	66.7	(100.0)
1996/97	15	(8)	0.0	(0.0)	40.0	(75.0)	0.0	(0.0)	60.0	(25.0)
1997/98	37	(27)	2.7	(3.7)	0.0	(0.0)	16.2	(22.2)	81.1	(74.1)
1998/99	205	(44)	0.0	(0.0)	23.9	(0.0)	43.9	(45.5)	32.2	(54.5)
1999/00	94	(23)	4.3	(0.0)	13.8	(0.0)	51.1	(43.5)	30.9	(56.5)
2000/01	123	(16)	0.0	(0.0)	22.0	(6.3)	59.3	(93.8)	18.7	(0.0)
2001/02	171	(98)	0.0	(0.0)	66.7	(43.9)	25.7	(43.9)	7.6	(12.2)
2002/03	133	(20)	0.0	(0.0)	54.1	(0.0)	17.3	(30.0)	28.6	(70.0)
2003/04	277	(239)	7.6	(8.8)	30.3	(32.6)	54.5	(56.5)	7.6	(2.1)
2004/05	187	(7)	1.6	(0.0)	50.3	(0.0)	34.8	(42.9)	13.4	(57.1)
2005	402	-----	0.0	------	35.1	------	59.0	-------	6.0	-------
Total	2218	(691)	9.7	(8.5)	34.7	(36.0)	34.7	(35.7)	20.9	(19.7)

year and spawning period, following which progressive decreases occurred, and few sampled individuals were observed in the years surrounding the enactment of closure. Within more recent years, increased numbers of annually sampled red hind have been observed, with a peak of 402 individuals sampled during the 2005 component of the 2005/06 SEAMAP-C project year. However, samplings during spawning periods have remained relatively low throughout the years following enactment of the closure, with exceptions during the 2001/02 and 2003/04 periods.

Within project years prior to the enactment of closure, red hind captured by traps and hand lines made up a large component of sampled individuals. Few individuals were obtained by spearfishing with SCUBA, while moderate numbers were captured by trammel nets. Following the enactment of the closures, very few individuals captured by trap were observed, especially during spawning periods. Annual increases in the number of sampled individuals captured by spearfishing were also found, while red hind from trammel nets remained at moderate numbers. During periods of low red hind numbers immediately prior to and following the enactment of the closures, the bulk of sampled individuals came from trammel nets. Within later project years, most individuals were captured by hand line or by spearfishing. However, during later spawning periods the majority of sampled individuals came from trammel nets and spearfishing, with pronounced decreased contributions from hand lines.

During SEAMAP-C project years, progressive increases in the average length of port-sampled red hind were observed (Figure 18), and values were found to be significant (p<0.05). No significant difference in the average length of individuals was observed between sequential project years, nor from the baseline average length of the 1988/89

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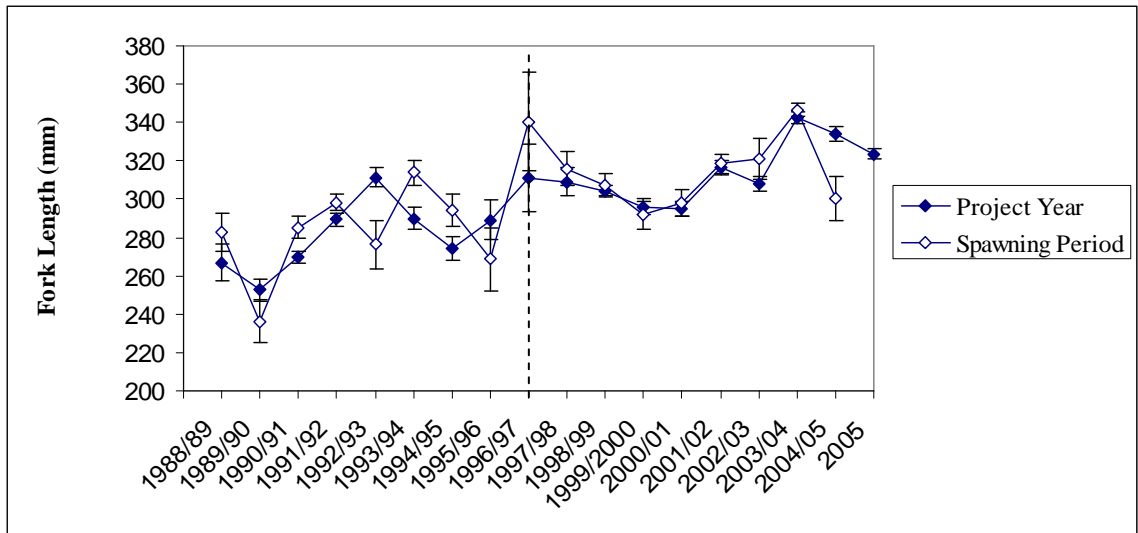
Figure 18. Annual average length and standard error of red hind (*Epinephelus guttatus*) from port samplings of the Cabo Rojo and Mayaguez municipalities of Puerto Rico per SEAMAP-C project year and red hind spawning period. The dashed line represents the time of enactment of the seasonal closures.

project year, until the 2003/04 project year. However, prior to the enactment of the

closures, the peak average length of the 1992/93 project year was found to be

significantly higher than the lower values of the 1989/90-1990/91 period. Within years

following enactment of the closure, little change in average length was observed until a

minor increase during the 2001/02 project year and a significant increase during the

2003/04 project year. Within following project years, decreases in average length were

observed, but values were not significantly lower than that of the 2003/04 project year,

and remained significantly higher than the average lengths of most preceding project

years.

     Trends during spawning periods closely followed those of project years. Annual

significant differences were only observed (1) between the low value of the 1989/90

spawning period and the values of most periods which followed it, and (2) between the

peak value of the 2003/04 spawning period and the values of most of its preceding

periods. A low average length value was observed during the 2004/05 spawning period, but it was not found to significantly differ from the values of any preceding spawning periods. Average lengths of individuals sampled during spawning periods were generally found to be higher than those sampled during corresponding project years, with more pronounced differences observed in the years prior to the enactment of closures.

Length-frequency distributions of port-sampled red hind within Cabo Rojo and Mayaguez municipalities (Figure 19) during periods of prominent abundance (1989/90, 1991/92, 1993/94, 1998/99, 2000/01, 2005 SEAMAP-C project years) revealed the importance of age 2 individuals (FL=200 mm; Sadovy *et al.* 1992) as the basis of early recruitment into the fishery. However, low numbers of sampled individuals were observed prior to the enactment of the closures. Contributions of recruits to the bulk of the catch were observed throughout subsequent project years, with peak abundance observed predominantly in age 3-5 individuals (FL=230-300 mm). Truncations in the number of larger individuals were observed within project years prior to and following the enactment of the closures. Losses of recruits, and shifts in distribution, were observed following enactment of the closures. The highest number of individuals were sampled within the 2005 SEAMAP-C project year, and a noteworthy increase in the prevalence of larger individuals was observed, as compared to the 1998/99 project year (1998/99 percent contribution of individuals >370 mm FL = 6.8%; 2005 percent contribution of individuals >370 mm FL = 14.2%). A pronounced shift in distribution was found in 2005, with few <250 mm individuals sampled, and increased proportional abundance of age 5-7 individuals (FL=280-340 mm).
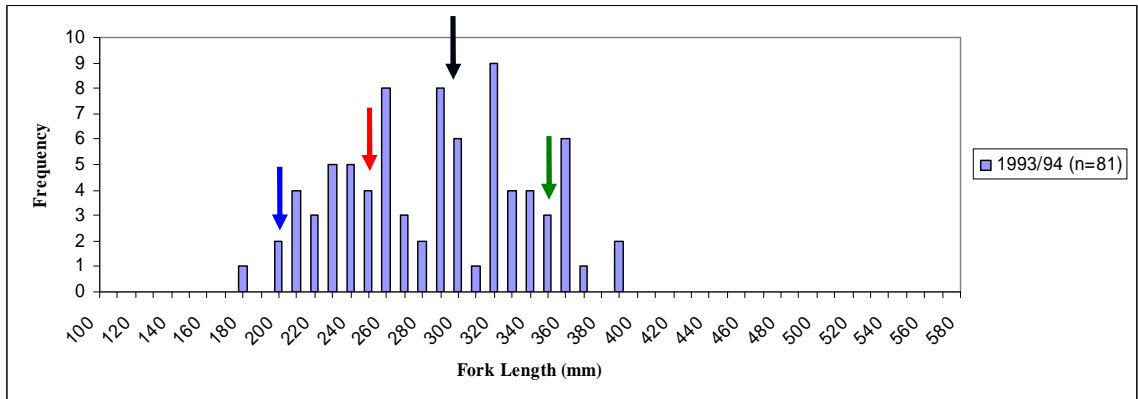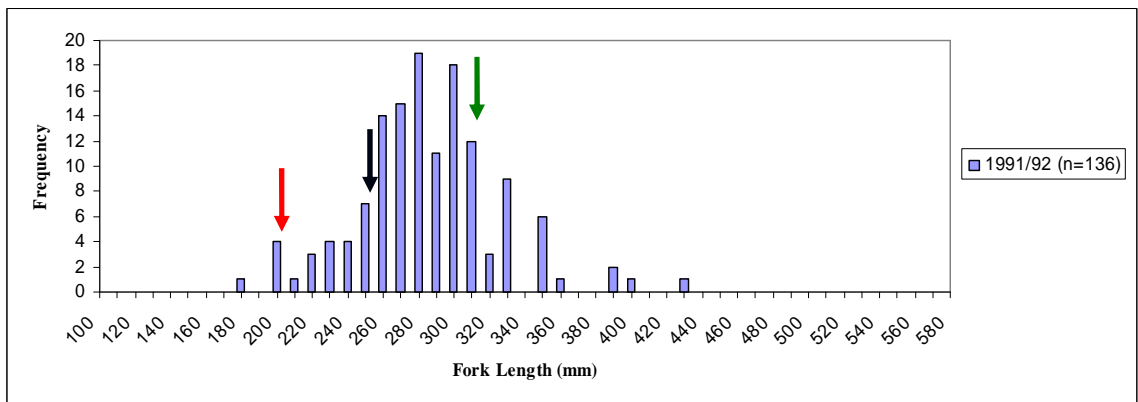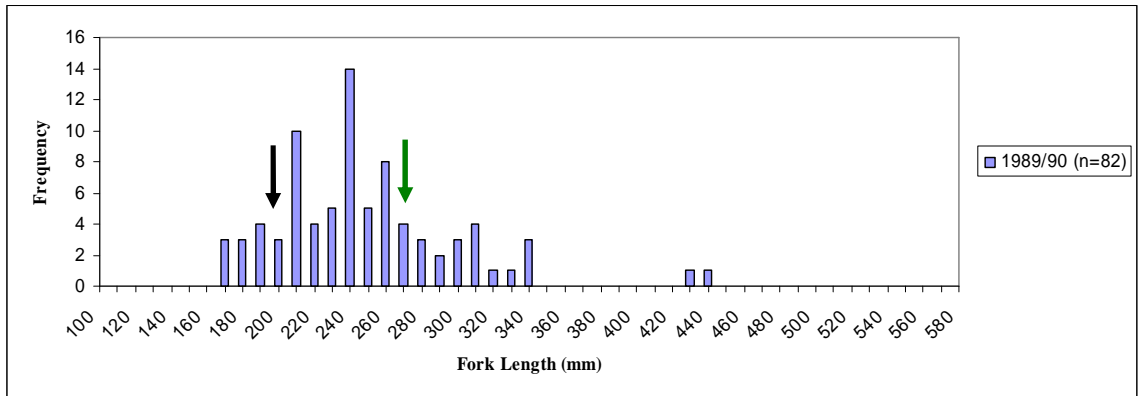
Figure 19. Length-frequency distributions of red hind (*Epinephelus guttatus*) from port-sampled biostatistical data of the Cabo Rojo and Mayaguez municipalities of Puerto Rico per SEAMAP-C project year, with age cohorts, as identified by colored arrows in accordance with Sadovy *et al*. 1992, traced throughout the sampling period
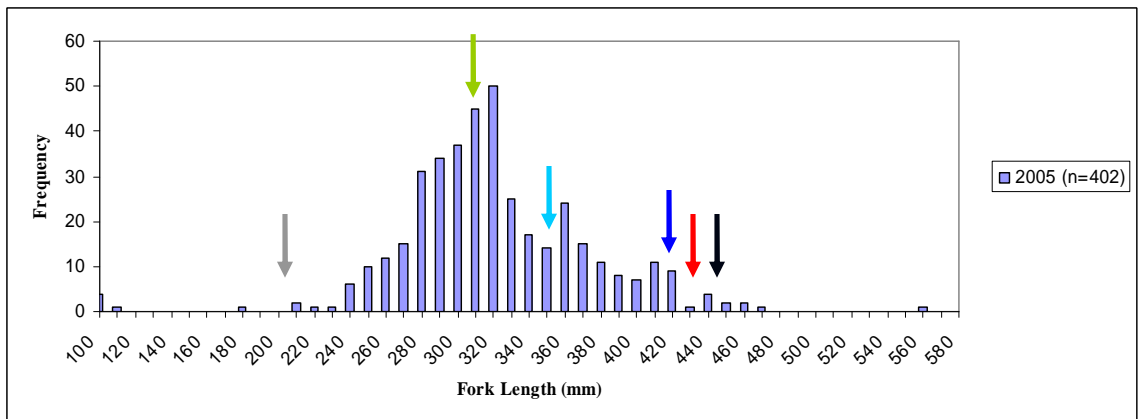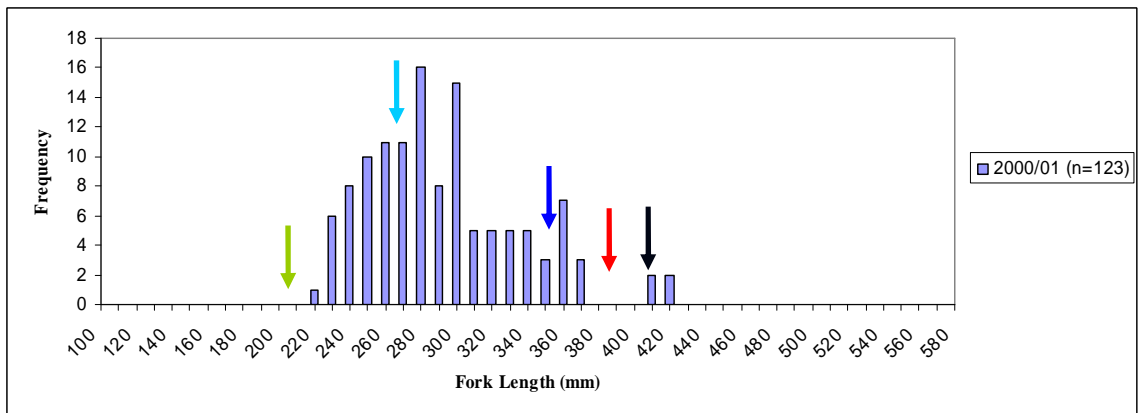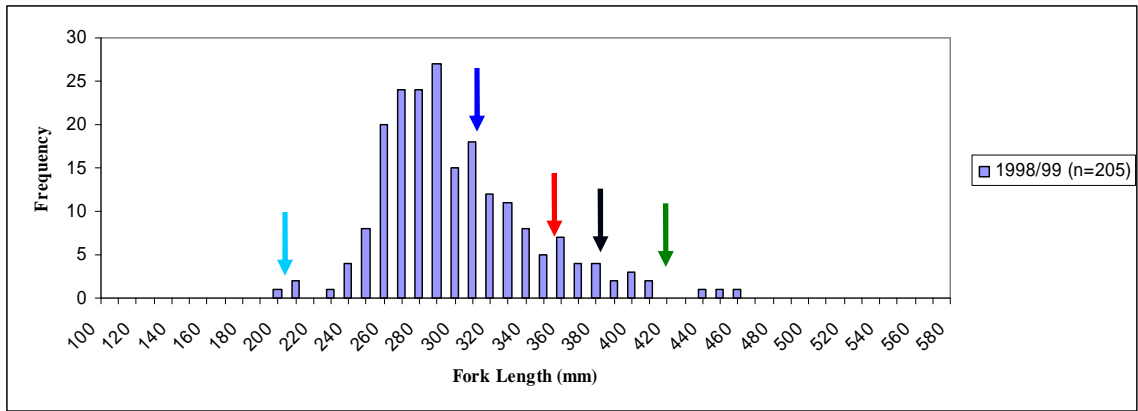
Figure 19 (cont'd). Length-frequency distributions of red hind (*Epinephelus guttatus*) from port-sampled biostatistical data of the Cabo Rojo and Mayaguez municipalities of Puerto Rico per SEAMAP-C project year, with age cohorts, as identified by colored arrows in accordance with Sadovy *et al*. 1992, traced throughout the sampling period.

Table 7. Percent abundance of port-sampled red hind (*Epinephelus guttatus*) age classes (in years calculated using Sadovy *et al.* 1992) per SEAMAP-C project year, from individuals within the Cabo Rojo and Mayaguez municipalities of Puerto Rico.

Year	Ages 0-2 yrs (%) [0-230 mm FL]	Ages 3-4 yrs (%) [230-280 mm FL]	Ages 5-6 yrs (%) [280-325 mm FL]	Ages 7-10 yrs (%) [325-385 mm FL]	Total (%)
1988/89	11.11	66.67	22.22	0.00	100.00
1989/90	34.15	45.12	13.41	4.88	97.56
1990/91	10.28	59.81	23.36	6.54	100.00
1991/92	8.09	36.76	39.71	12.50	97.06
1992/93	6.14	28.95	28.95	21.05	85.09
1993/94	17.28	25.93	29.63	24.69	97.53
1994/95	11.11	51.85	33.33	3.70	100.00
1995/96	16.67	33.33	27.78	22.22	100.00
1996/97	13.33	26.67	26.67	13.33	80.00
1997/98	2.70	24.32	37.84	32.43	97.30
1998/99	1.95	32.68	40.49	20.00	95.12
1999/00	6.38	32.98	37.23	21.28	97.87
2000/01	2.44	43.09	31.71	19.51	96.75
2001/02	2.34	21.05	40.35	26.90	90.64
2002/03	3.01	29.32	34.59	25.56	92.48
2003/04	1.44	12.27	22.38	43.68	79.78
2004/05	0.53	17.65	31.02	32.62	81.82
2005	2.24	13.43	44.28	28.11	88.06

Percent contributions of age classes throughout SEAMAP-C project years are shown in Table 7. Generally, individuals ages 0-10 years made up the bulk of captures. Contributions of age 0-2 individuals were found to be much higher prior to the enactment of the closures than during later years, in which they were observed at minimal presence. Highest contributions were observed in age 3-4 and 5-6 individuals at nearly equivalent values in several years leading up to, and immediately following, the enactment of the closures. This was subsequently followed by decreasing contributions of age 3-4 individuals to minimum values, and proportional increases in ages 5-6 and 7-10 individuals.

Traps

Hook and Line

Spearfishing with SCUBA
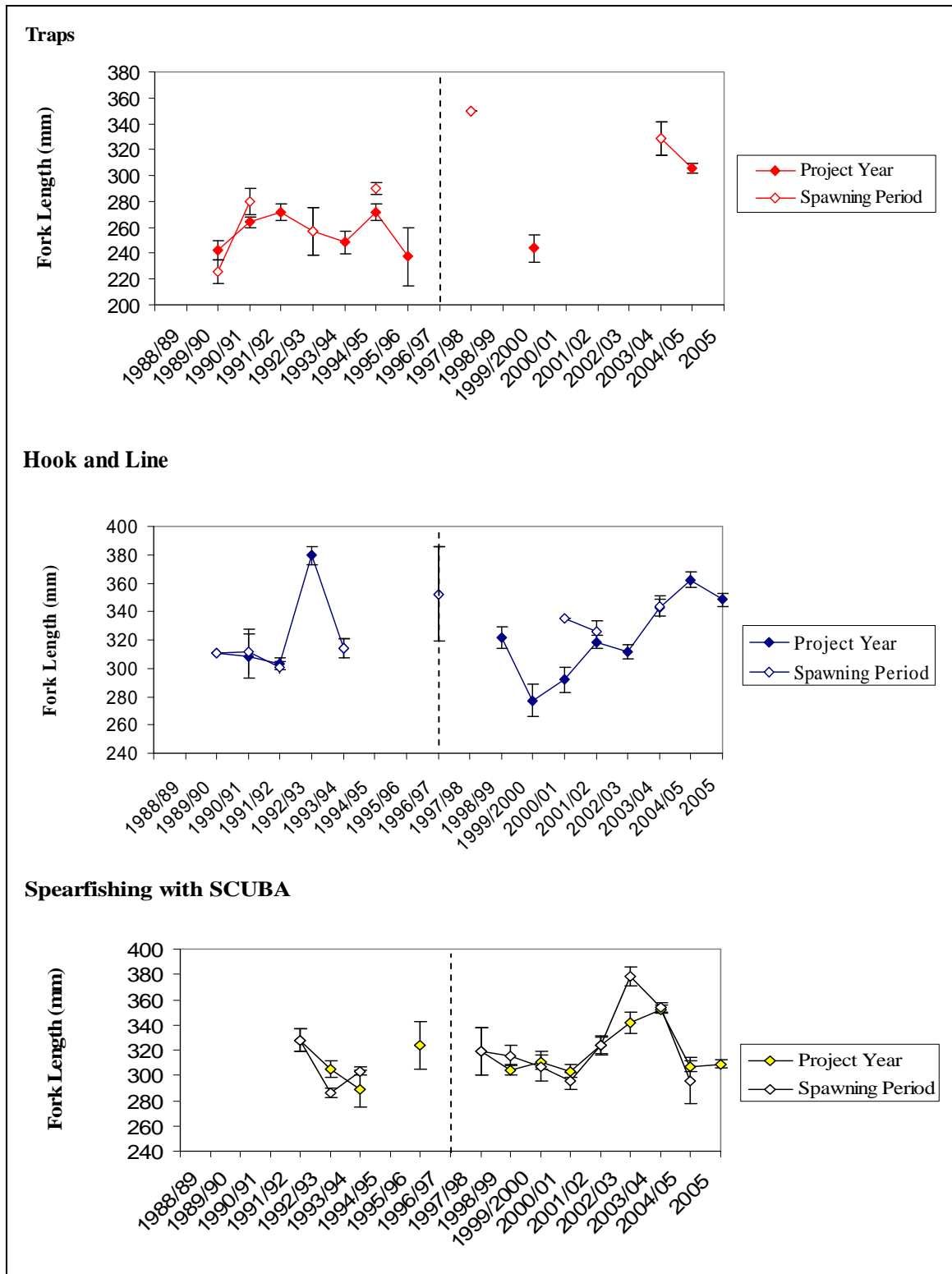
Figure 20. Annual average length and standard error of port-sampled red hind (*Epinephelus guttatus*) by gear type from combined Cabo Rojo and Mayaguez municipalities of Puerto Rico, per SEAMAP-C project year and red hind spawning period. Dashed lines represent the time of enactment of the seasonal closures.

Annual variation in the average lengths of port-sampled individuals per gear type captured was observed between project years and spawning periods (Figure 20). However, due to infrequent samplings, data were unavailable during many project years and spawning periods. Trends for all gear types generally mirrored those for average length independent of gear type, with progressive increases observed following the enactment of the closure. Within traps, little differentiation in length was observed prior to the enactment of the closure, but notable increases were observed during more recent project years and spawning periods. Noteworthy increases in the average length of individuals captured by hook and line were observed during the 1992/93 and 2003/04 project year. Within spearfishing captures, similar later year average length increases were observed, especially during the 2002/03 project year and spawning period. However, these were followed by subsequent decreases in size to values that were comparable with earlier average lengths. Although red hind captured by traps and hand lines were less frequently sampled during spawning periods, overall annual trends were similar to those of project years. Following enactment, little differentiation was observed in average length per gear until the 2004/05-2005 period, during which the largest individuals were obtained by hook and line. Although marginal separation was observed when annual average length values were compared between gear types, red hind captured by traps were generally smaller than those captured by the other two gear types.

Lajas (La Parguera) fishery-dependent commercial landings and port-sampled

biostatistical data

Throughout the SEAMAP-C sampling period, a total of 24,919 kg of red hind

were reported from the municipality of Lajas, predominantly the La Parguera region

(Table 8). Although this region has historically contributed recognizable red hind

landings within the south coast, contributions within recent years were very low.

Landings within this area represented no more than 11% of the total island-wide red hind

catch during SEAMAP-C project years, and only 6.2% of the total reported catch of

Table 8. Annual total reported landings of red hind (*Epinephelus guttatus*) per
SEAMAP-C project year and red hind spawning period (in parenthesis) from the
Lajas (La Parguera) municipality of Puerto Rico, with breakdown of annual catches
by percent gear type (HL=hand line; TR=trap; SCUBA=spearfishing while SCUBA
diving; Other=other gear types) and percent contribution to total south coast and
Puerto Rico landings.

Year	Total Landings		% TR		% HL		%SCUBA		% Other		% S Coast		% All PR	
1988/89	332.88	(246.26)	48.1	(36.8)	46.3	(57.3)	0.0	(0.0)	5.6	(5.9)	14.7	(18.5)	2.3	(4.8)
1989/90	401.36	(241.27)	63.2	(39.8)	36.8	(60.2)	0.0	(0.0)	0.0	(0.0)	7.0	(14.9)	2.5	(5.8)
1990/91	2484.35	(2267.12)	16.8	(15.0)	81.0	(82.8)	0.8	(0.9)	1.4	(1.3)	29.2	(51.7)	9.7	(19.0)
1991/92	1411.11	(1054.42)	39.4	(29.8)	55.6	(68.4)	2.2	(0.0)	2.8	(1.8)	32.1	(39.8)	6.7	(12.6)
1992/93	1046.71	(839.46)	16.5	(2.8)	83.5	(97.2)	0.0	(0.0)	0.0	(0.0)	17.8	(38.6)	5.4	(10.5)
1993/94	283.90	(268.48)	6.4	(3.9)	59.7	(63.2)	31.6	(30.6)	2.2	(2.4)	7.8	(18.0)	1.8	(4.6)
1994/95	1031.75	(726.53)	3.1	(4.4)	32.3	(45.3)	19.2	(26.3)	45.5	(24.0)	23.5	(27.2)	7.4	(10.4)
1995/96	1271.66	(1043.99)	34.2	(29.8)	60.4	(64.5)	0.5	(0.0)	4.9	(5.6)	15.1	(23.2)	5.8	(10.3)
1996/97	914.29	(677.10)	7.9	(7.0)	53.5	(51.0)	0.6	(0.8)	38.0	(41.2)	11.8	(17.5)	3.6	(5.5)
1997/98	837.64	(601.36)	4.6	(1.8)	71.2	(73.7)	4.9	(2.6)	19.3	(21.9)	12.5	(21.3)	3.2	(5.6)
1998/99	1869.39	(1385.94)	10.8	(6.9)	69.9	(81.0)	8.5	(3.7)	10.8	(8.4)	23.7	(32.4)	7.0	(11.3)
1999/00	2129.25	(1849.89)	9.7	(6.3)	71.1	(78.6)	4.7	(4.4)	14.5	(10.7)	21.6	(28.0)	7.3	(15.4)
2000/01	2828.34	(2173.02)	13.9	(7.4)	69.9	(81.0)	2.5	(0.0)	13.7	(11.6)	34.5	(55.6)	10.2	(19.6)
2001/02	2853.74	(2334.69)	7.1	(4.4)	74.7	(83.5)	1.9	(0.5)	16.3	(11.6)	28.0	(46.5)	8.7	(16.9)
2002/03	3735.60	(1903.40)	5.4	(0.8)	83.6	(83.8)	1.6	(0.5)	9.4	(15.0)	29.5	(36.7)	10.6	(16.2)
2003/04	1245.80	(1041.27)	17.6	(15.3)	63.5	(65.5)	17.2	(18.5)	1.7	(0.7)	20.1	(38.0)	5.0	(10.7)
2004/05	102.95	(2.27)	1.8	(0.0)	84.1	(100.0)	0.0	(0.0)	14.1	(0.0)	3.6	(0.3)	0.8	(0.1)
2005	138.32	(0.00)	0.0	(0.0)	6.2	(0.0)	79.3	(0.0)	14.4	(0.0)	12.0	(0.0)	1.4	(0.0)
Total	24919.05	(18656.46)	14.4	(10.3)	69.3	(76.2)	4.7	(3.5)	11.7	(9.9)	21.3	(33.3)	6.2	(11.9)

Puerto Rico throughout the period of study. Within recent project years and spawning periods, total reported landings were found to decrease to previously unmeasured values. However, prior to the 2004/05 project year, notable catches and contributions to south coast and Puerto Rico landings were observed within the region during spawning periods.

An overwhelming proportion of red hind were captured by hook and line, while total catches from fish traps and spearfishing while SCUBA diving were observed in much lower proportions to total landings throughout the sampling period. Contributions from traps were much higher in earlier years, and few individuals were captured by spearfishing with SCUBA until during the 2005 SEAMAP-C project year, in which 79% of landings were from spearfishing. Within Lajas, other gear types were found to be more prevalent than along the western platform, with more notable contributions to annual reported catch during earlier years. Within earlier SEAMAP-C project years during the period of interest, red hind captured by traps overwhelmingly made up the largest component of the catch. However, near the enactment of the seasonal closures, catches from hand lines, and later by spearfishing, comprised the majority of the commercial fishery. Trends and percent contributions of gears to landings during spawning periods were very similar to those of project years. Landings during spawning periods made up the majority of annual landings per SEAMAP-C project year. However within recent years, minimum reported landings were observed during spawning periods.

Throughout the SEAMAP-C sampling period, 5403 fishing trips have been reported with red hind landings data for the Lajas (La Parguera) municipality of Puerto Rico (Table 9). Fishing trips from these areas have comprised 24% of the trips of the south coast of Puerto Rico, but only 7% of total island-wide reported fishing effort for red

Table 9. Annual number of fishing trips reported for red hind (*Epinephelus guttatus*) per SEAMAP-C project year from the Lajas (La Parguera) municipality of Puerto Rico combined, with breakdown of annual trips by percent gear type (HL=hand line; TR=trap; SCUBA=spearfishing while SCUBA diving; Other=other gear types) and percent contribution to total fishing trips reported for red hind for the south coast and Puerto Rico.

Year	Total Trips		% TR		% HL		%SCUBA		% Other		% S Coast		% All PR	
1988/89	43	(16)	72.1	(50.0)	23.3	(43.8)	0.0	(0.0)	4.7	(6.3)	22.5	(16.7)	2.8	(3.7)
1989/90	102	(50)	94.1	(90.0)	5.9	(10.0)	0.0	(0.0)	0.0	(0.0)	17.1	(32.5)	3.8	(6.0)
1990/91	268	(196)	56.7	(52.0)	39.2	(42.9)	1.9	(2.6)	2.2	(2.6)	35.5	(50.8)	9.7	(17.5)
1991/92	331	(192)	47.7	(32.8)	39.6	(54.7)	2.4	(0.0)	10.3	(12.5)	29.4	(37.0)	8.3	(14.5)
1992/93	112	(17)	73.2	(35.3)	26.8	(64.7)	0.0	(0.0)	0.0	(0.0)	17.2	(8.9)	3.9	(1.4)
1993/94	41	(18)	68.3	(38.9)	17.1	(38.9)	12.2	(16.7)	2.4	(5.6)	7.0	(9.6)	1.7	(1.7)
1994/95	184	(150)	10.3	(12.7)	41.3	(50.0)	8.7	(10.0)	39.7	(27.3)	20.1	(28.2)	6.4	(9.7)
1995/96	531	(91)	65.7	(44.0)	28.8	(29.7)	0.6	(0.0)	4.9	(26.4)	27.1	(17.7)	8.8	(4.7)
1996/97	438	(200)	24.7	(3.0)	25.8	(30.0)	0.2	(0.5)	49.3	(66.5)	31.7	(38.6)	7.0	(8.1)
1997/98	167	(31)	28.7	(3.2)	35.3	(71.0)	6.0	(12.9)	29.9	(12.9)	17.3	(9.8)	3.0	(1.5)
1998/99	369	(227)	24.1	(26.9)	48.0	(62.6)	8.7	(3.5)	19.2	(7.0)	19.6	(27.5)	5.0	(8.1)
1999/00	506	(318)	26.1	(24.5)	32.0	(39.0)	2.4	(2.5)	39.5	(34.0)	23.2	(29.9)	5.9	(11.2)
2000/01	689	(256)	32.2	(23.0)	49.6	(57.0)	2.5	(0.0)	15.7	(19.9)	28.7	(29.8)	9.4	(9.8)
2001/02	504	(247)	34.9	(27.9)	38.5	(57.9)	8.1	(0.8)	18.5	(13.4)	20.5	(26.4)	6.5	(9.5)
2002/03	955	(204)	13.0	(2.5)	77.2	(80.4)	0.4	(0.5)	9.4	(16.7)	37.2	(39.3)	12.6	(13.3)
2003/04	79	(42)	32.9	(28.6)	50.6	(59.5)	10.1	(7.1)	6.3	(4.8)	8.9	(16.5)	2.6	(5.0)
2004/05	24	(1)	4.2	(0.0)	66.7	(100.0)	0.0	(0.0)	29.2	(0.0)	4.7	(0.7)	1.3	(0.3)
2005	60	(0)	0.0	(0.0)	5.0	(0.0)	86.7	(0.0)	8.3	(0.0)	21.4	(0.0)	4.2	(0.0)
Total	5403	(2256)	34.1	(25.8)	43.7	(50.9)	4.0	(2.2)	18.3	(21.1)	24.3	(28.2)	6.6	(8.2)

hind. Annual contributions to total reported red hind fishing effort within Puerto Rico during project years have been low, with annual percentages of total effort being no higher than 13%. Increases in the number of reported fishing trips were observed following the 1994/95 SEAMAP-C project year, but were found to plunge in recent project years and spawning periods. Intensity in monthly effort was similar to that observed along the western platform, with peak trips occurring during January throughout the period of study until the 2002/03 project year. Following the 1995/96 project year,

increased trips during summer months were observed, with particular intensity within July-August, and increased fishing effort during the fall of the 2002/03 project year.

Within earlier project years, fishing effort was dominated by trips associated with trap fishing, while hook and line fishing effort also played a key role. Contributions from spearfishing with SCUBA and other gears were minimal during this period of study. Within later project years, decreases in the number of trips from trap fishing were observed, while pronounced increases in hook and line trips relative to earlier observations were found following the 2001/02 project year. Increases in the number of trips associated with other gear types, primarily gill and trammel nets, were observed as of the 1994/95 project year, but declined in recent years. Although low effort from spearfishing with SCUBA was observed throughout the study period, spearfishing trips made up the bulk of those reported during the 2005 project year.

Annual nominal CPUE (kg/trip) values within the municipality of Lajas (La Parguera), Puerto Rico (Figure 21) were found to significantly differ between project years and spawning periods ($p < 0.05$). No sequential significant differences in CPUE were observed among project years until a significant decrease was observed between the 1994/95 and 1995/96 project years to a value significantly lower than all preceding values. A significant increase in CPUE was observed during the 1997/98 project year, following which little variation was observed until a significant decrease during the 2002/03 project year. Although this value was found to be significantly lower than values observed past the 1997/98 project year, it was still significantly higher than minimum values found within 1995/96 and 1996/97 project years. A strong significant increase was observed during the 2003/04 project year, followed by significant decreases

Figure 21. Annual average nominal CPUE (kg/trip) and standard error of red hind (*Epinephelus guttatus*) from reported landings of Lajas (La Parguera), and combined Cabo Rojo and Mayaguez municipalities of Puerto Rico, per SEAMAP-C project year and red hind spawning period. The dashed lines represent the time of enactment of the seasonal closures.

in more recent project years to minimal values on par with those observed prior to the

2002/03 increase. While CPUE during spawning periods closely paralleled that of

project years, significant spikes to values much higher than corresponding project year

CPUE were found to occur during the 1992/93 and 1997/98 spawning periods. CPUE

during spawning periods was generally found to be marginally higher than within

corresponding project years.

Trends of Lajas (La Parguera) nominal CPUE strongly paralleled those observed

within combined Cabo Rojo and Mayaguez municipalities during project years and

Table 10. Annual number of port-sampled red hind per SEAMAP-C project year and red hind spawning period (in parenthesis) from the Lajas (La Parguera) municipality of Puerto Rico, with percent breakdown of individuals by gear type captured (HL=hand line; TR=trap; SCUBA=spearfishing while SCUBA diving; Other=other gear types).

Year	Total Red Hind		%TR		%HL		%SCUBA		%Other	
1988/89	5	(0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	100.0	(0.0)
1989/90	87	(27)	50.6	(77.8)	9.2	(3.7)	0.0	(0.0)	40.2	(18.5)
1990/91	44	(11)	40.9	(18.2)	40.9	(81.8)	0.0	(0.0)	18.2	(0.0)
1991/92	35	(5)	62.9	(20.0)	25.7	(0.0)	0.0	(0.0)	11.4	(80.0)
1992/93	42	(9)	9.5	(44.4)	0.0	(0.0)	0.0	(0.0)	90.5	(55.6)
1993/94	88	(30)	27.3	(10.0)	52.3	(90.0)	0.0	(0.0)	20.5	(0.0)
1994/95	10	(1)	90.0	(100.0)	0.0	(0.0)	0.0	(0.0)	10.0	(0.0)
1995/96	0	(0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
1996/97	19	(0)	0.0	(0.0)	100.0	(0.0)	0.0	(0.0)	0.0	(0.0)
1997/98	5	(5)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	100.0	(100.0)
1998/99	78	(73)	2.6	(0.0)	85.9	(91.8)	0.0	(0.0)	11.5	(8.2)
1999/00	26	(17)	34.6	(0.0)	65.4	(100.0)	0.0	(0.0)	0.0	(0.0)
2000/01	34	(31)	5.9	(6.5)	70.6	(67.7)	2.9	(3.2)	20.6	(22.6)
2001/02	318	(165)	0.3	(0.6)	79.6	(94.6)	0.0	(0.0)	20.1	(4.9)
2002/03	72	(31)	0.0	(0.0)	75.0	(67.7)	0.0	(0.0)	25.0	(32.3)
2003/04	136	(94)	0.0	(0.0)	69.1	(70.2)	0.0	(0.0)	30.9	(29.8)
2004/05	21	(4)	4.8	(0.0)	95.2	(100.0)	0.0	(0.0)	0.0	(0.0)
2005	8	(0)	0.0	(0.0)	100.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Total	1028	(503)	13.1	(7.0)	61.6	(77.3)	0.1	(0.2)	25.2	(15.5)

spawning periods. When compared to Lajas (La Parguera) values, higher CPUE within combined Cabo Rojo and Mayaguez municipalities was observed within project years prior to the enactment of the closures off the west coast. However, little differentiation between values was observed following enactment, and the prominent 2003/04 increase in CPUE was found within both regions. Apart from during the 1992/93 and 1997/98 spawning periods, lesser differentiation and similar trends were observed between spawning period nominal CPUE of the two regions.

Throughout the SEAMAP-C sampling period, biostatistical data for 1028 port-sampled red hind were collected within the Lajas (La Parguera) municipality of Puerto

Rico (Table 10). During earlier project years, most sampled individuals were captured by traps or other gears, with few years of sizeable contributions from hook and line captures. Within later project years, overwhelming contributions of samplings came from individuals captured by hook and line, with minimal contributions from trap and spearfishing captures, and moderate contributions from captures from other gear types. Red hind obtained during spawning periods made up 49% of all sampled individuals. Variations in the number of sampled individuals were observed throughout the period of study with minimal numbers sampled from 1994/95-1997/98 project years and spawning periods, and increased numbers of observed individuals in later samplings until large declines in recent years.

Although little overall variation in the average length of port-sampled red hind from the municipality of Lajas (La Parguera) was observed (Figure 22) during SEAMAP-C project years, relationships between particular project years were found to be significant (p<0.05). Average lengths of the 1993/94 and 1997/98 project years were found to be significantly higher than values within 1989/90 and 1990/91 samplings. Subsequent average length values during 2000/01-2002/03 project years were found to be significantly lower than that of the 1997/98 project year, and average length of the 2003/04 project year was found to be significantly higher than values of the 1989/90, 1990/91, 1992/93, and 2001/02 project years. Trends during spawning periods closely followed those of project years, with annual significant differences observed between the average length value of the 1992/93 spawning period and values of 1993/94, 1998/99, and 2003/04 spawning periods, between average lengths of the 1998/99 spawning period
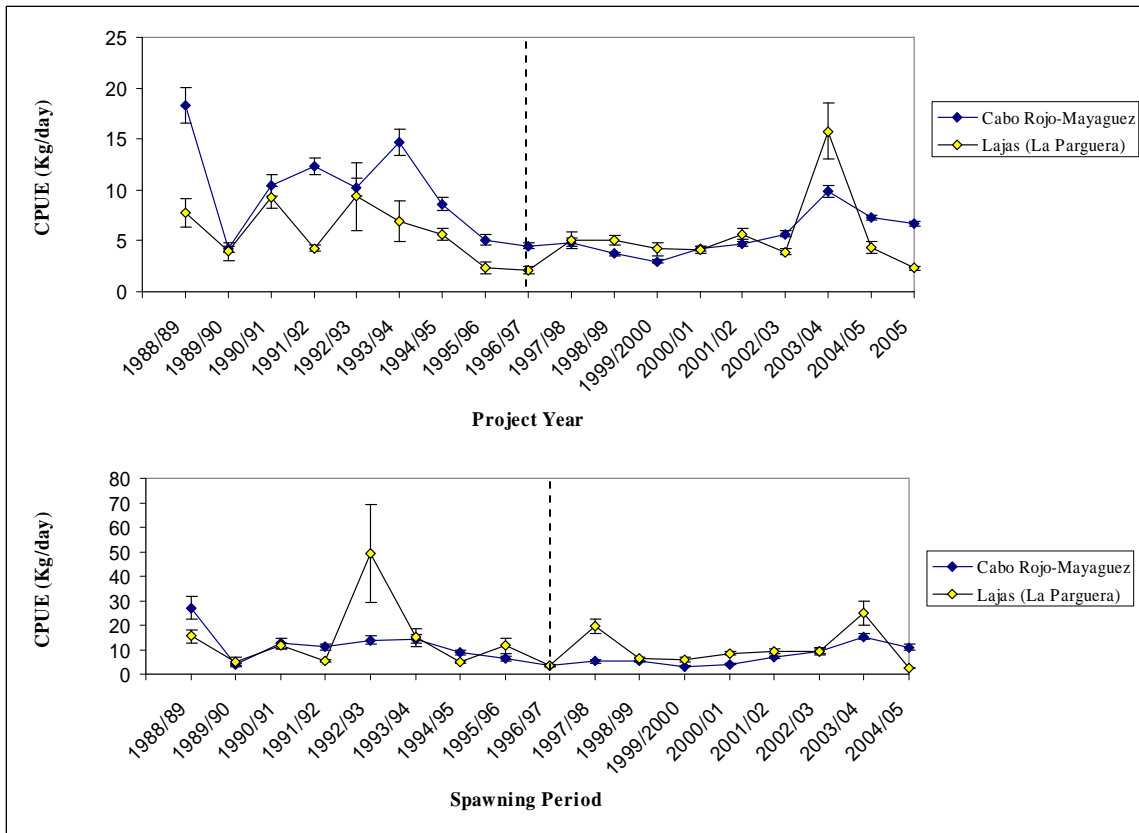
63
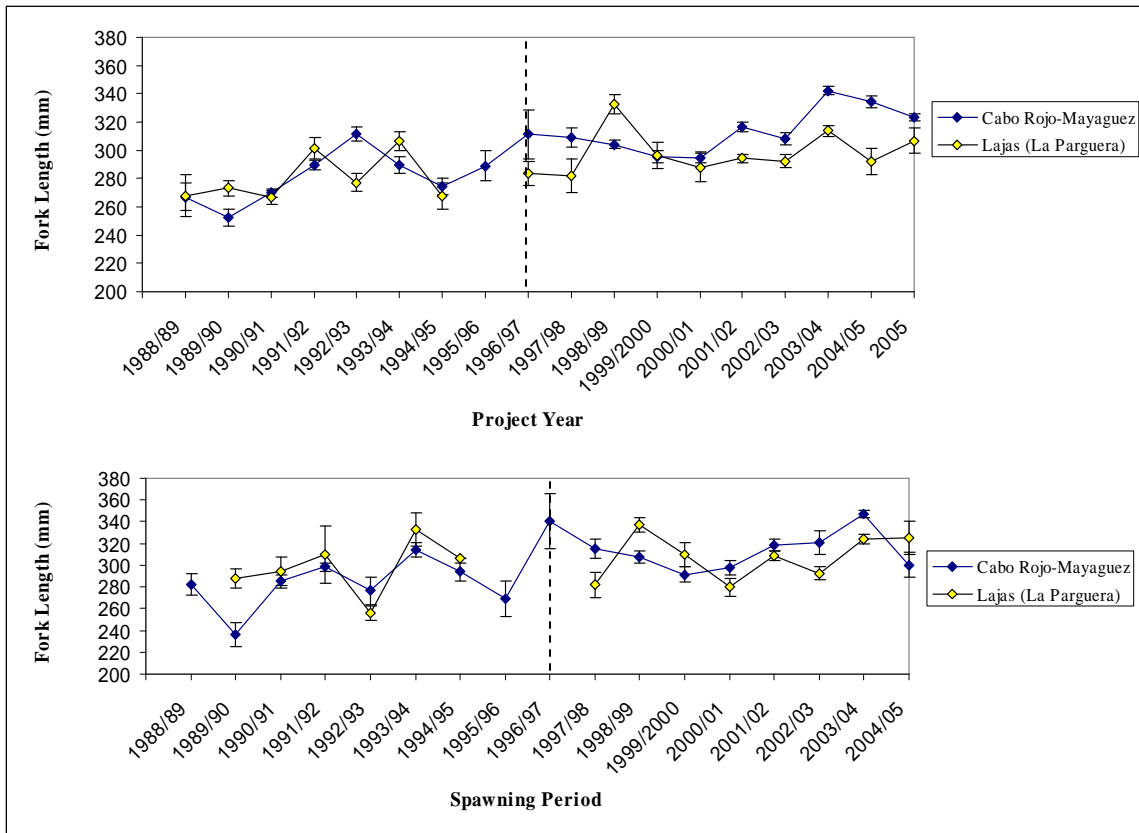
Figure 22. Annual average length and standard error of red hind (*Epinephelus guttatus*) from port samplings of Lajas (La Parguera), and combined Cabo Rojo and Mayaguez municipalities of Puerto Rico per SEAMAP-C project year and red hind spawning period. The dashed lines represent the time of enactment of the seasonal closures.

and 1989/90, 2000/01-2002/03 spawning periods, and between values of the 2000/01 and

2003/04 spawning periods.

Prior to the enactment of the closures off the west coast, little differentiation was

observed between corresponding annual average lengths of individuals sampled within

the municipality of Lajas (La Parguera) and those from the combined Cabo Rojo and

Mayaguez municipalities during project years and spawning periods. However,

individuals from Lajas (La Parguera) were generally found to be marginally larger.

Following enactment of the closures, greater marginal differentiation in average length

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was observed between the two regions, but overall trends remained similar. Larger individuals were observed within the combined Cabo Rojo and Mayaguez region than within Lajas (La Parguera) during later project years.

DISCUSSION

The degree of response of populations to enacted closures has been shown to result from a complex interaction of multiple factors that include the initial state of the population, natural variations in recruitment as related to current patterns and larval settlement dynamics, dispersal of individuals in and out of protected areas, and the relation of closed areas to total spawning area. These natural factors, together with fishery related components including past fishing intensity, spatial and temporal response of fishermen to closures, and general effectiveness of enforcement, greatly influence the effectiveness of closures upon populations (Sanchirico, 2000). Therefore, proper monitoring of their effectiveness, and overall understanding of population response, requires the use of a variety of data sources. In the case of the red hind population of Puerto Rico, fishery-independent and dependent data have been collected throughout the periods leading up to and following the enactment of three closures along the western platform of Puerto Rico. Although neither data collection strategy was designed to specifically test for the impact of closure, available trends of measured parameters within both datasets proved highly useful in evaluating the overall effectiveness of the closures upon the Puerto Rico red hind population.

As of 1993, the *Tourmaline* region of the western insular platform of Puerto Rico has been seasonally closed to red hind fishing during spawning events (Dec 1-Feb 28). Redefinition of this area occurred in 1996, with the addition of seasonal closures during red hind spawning events within the *Bajo de Cico* and *Abrir la Sierra* regions of the platform. Trends in CPUE, length frequencies, and sex ratios of sampled individuals within fishery-dependent and independent data suggested that, following a period of

declines in all parameters, an initial positive response of the population was observed after the enactment of the closures.

Increased fishery-independent CPUE was found within the *Bajo de Cico* and *Abrir la Sierra* regions immediately following enactment during the 1997/98 project year and spawning period, as well as within the unprotected regions of the western platform during the 1997/98 project year, and to a lesser extent during the spawning period. This increase is thought to be an initial response of the red hind population to the closures. While seasonally protected sites were targeted less frequently during the 1997/98 project year in comparison to some previous project years, little deviation in overall sampling strategy and sampling effort throughout the entire western platform was observed. However, within the *Tourmaline* region, no overall difference in very low CPUE during project years or spawning periods was observed following the 1993 or 1996 closures. These differences may result from the fact that historically the *Tourmaline* region of the western platform has been subject to higher fishing pressure due to its greater coastal proximity, location nearby the northwestern termination of the insular shelf, and favorable habitat for red hind spawning activity (CFMC, 1996; Appeldoorn, personal communication). Fish trap surveys confirm fishing to be greater at *Tourmaline* relative to *Abrir la Sierra* (Marshak *et al.*, unpublished trap survey data). Thus, the magnitude and extent of fishing at and around *Tourmaline* may have been sufficient to have prevented the population from responding to a detectable level.

The increases in CPUE observed immediately following closure were accompanied by changes in length-frequency and age proportion data. Relative to observations during the 1994/95 sampling period, 1997/98 length frequency data showed

substantial increases in the abundance of 250-290 mm FL individuals (ages 4-5), with relatively similar numbers of smaller individuals. During the 1997/98 project year, complementary proportional increases in age 5-6 and 7-10 individuals were also observed relative to the 1993/94-1995/96 project years, but a proportional decrease in the number of age 0-2 individuals, and no increase in the number of age 3-4 individuals were also found. These increases in the abundance of predominantly older females were responsible for the observed initial post-enactment significant increase in average length. Due to the bulk of increase being observed within females, and likely continual fishing pressure upon larger males, little increase in the average proportion of males was observed. Although studies have attributed increases in CPUE to natural recruitment events (Hearn *et al*., 2005; Kevrekidis and Thessalou-Legaki, 2006), the findings of this study suggest that increased recruitment of younger individuals was not the driving factor in the initial increase of CPUE throughout the platform following enactment of the closures. Therefore, given the later increases observed within older, sexually mature cohorts which would have been protected during the 1996/97 spawning period, there exists strongly implied evidence of a post-enactment initial response to the closures. While observed population responses to closures within other studies have generally not been as immediate (Russ and Acala, 1999; Beets and Frielander, 1998; Nemeth, 2005), the initial observed response within this study may be due to several factors.

Fishery-independent data showed that, prior to closure, the densities of red hind were concentrated within *Bajo de Cico*, and to a lesser extent within *Abrir la Sierra*, which was where fishing was concentrated (CFMC, 1996), with a large proportion of fishing effort occurring during the spawning period. Therefore, initial closure may have

resulted in a pronounced reduction in fishing pressure as there was little deviation in observed spatial and temporal fishing patterns until after the spawning events of 1996/97. This reduction in fishing pressure may have allowed for a faster response throughout the western platform.

Factors such as increases in abundance, increases in average size, and the movement of fish between protected areas and unprotected areas across the shelf may have contributed to this shelf-wide response in CPUE. Generally, female red hind migrate from unprotected regions further inshore to both seasonally protected and unprotected spawning aggregation sites, with homing behavior and site fidelity previously observed in the Puerto Rican stock (Rosario and Figuerola, 2001; Sabat, 2001). Previous tagging studies have demonstrated the magnitude of pre and post-spawning migrations from spawning sites into other platform regions during non-spawning periods, with movements as far as 24 km being recorded along the western platform (Rosario and Figuerola, 2001). Passage of individuals protected during the 1996/97 spawning period into unprotected regions during the 1997/98 sampling periods is likely to have occurred, and have contributed to the observed increase in CPUE throughout the platform.

Contributing to this increase in CPUE would be the increase in average size of individual fish. On average, larger individuals (predominantly females) were observed within unprotected regions of the platform than within seasonally protected areas during most project years, albeit in low abundance. However, this disparity between areas was greatly reduced during spawning periods. These differences, again, may be indicative of larger sized individuals leaving seasonally protected areas following spawning activity.

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Dramatic increases in fishing trips were observed as of the 1997/98 project year and spawning period. Assuming that fishers cooperated with the seasonal closures, fishing during the spawning period was likely concentrated within unprotected platform edge regions, where spawning activity is known to also occur (Ojeda-Serrano *et al.*, 2007). However, the bulk of fishing activity in the years following the enactment was observed to occur during non-spawning periods, during which seasonally protected and unprotected areas were likely targeted in much higher efforts than in previous years, with fishermen altering their strategy to compensate for the newly enacted management regulations. Increased fishing effort following enactment of the closures was observed during summer months, but also during later fall months when red hind tend to amass in preparation for spawning activity, well ahead of the onset of the closed season. This shift in fishing strategy was likely the cause of observed subsequent decreases of fishery-independent CPUE within later project years, and pronounced decreases in CPUE to near minimal values during spawning periods, in seasonally protected and unprotected sites. Russ and Alcala (1999) have commented upon the ability to fish down biomass relatively quickly in contrast to any slower increases in biomass over time.

Trends in nominal (fishery-dependent) and standardized (SEAMAP-C) CPUE departed after closure. Nominal CPUE did not show the pronounced increase and subsequent decrease observed with the SEAMAP-C data, and was found to increase in later years, especially within hooked lines. Although nominal CPUE is limited as a direct indicator of abundance (Walters, 2003; Maunder *et al.*, 2006), its use with fishery-independent catch data, together with observations in fishing effort can serve to characterize the behavior of the fishery. Changes in the behavior of the fishery may

explain the observed differences in CPUE between the two data sets. The lack of increase in nominal CPUE immediately after closure is thought to be due to the loss to the fishery of the known spawning aggregations. In contrast, the subsequent changes in fishing behavior in response to the closure would explain the sustained catch levels over time and subsequent increases (while CPUE from SEAMAP-C data showed a steady decline). These changes include shifting fishing effort to previously under targeted regions, proportional shifts in gear contributions from traps to hooked lines and spearfishing (with SCUBA), and increased use of Global Positioning Systems (GPS) to locate and target red hind found within previously underfished regions. Also supporting the initial nominal CPUE trends are the previously mentioned dispersal of fishes from protected areas, and potentially the breakdown of aggregations in protected areas (particularly *Tourmaline*) and their reformation (*sensu* Aguilar-Perera 2007) within previously under targeted areas. Later increases in nominal CPUE, particularly the 2003/04 sampling period, were likely due to discoveries of other previously unknown and less frequently targeted concentrations of older red hind, including other spawning aggregations (Ojeda-Serrano *et al.*, 2007), that may not have been randomly sampled during SEAMAP-C data collections. A recruitment pulse during the 2003/04 project year is unlikely, due to low observations of younger port-sampled individuals, and proportional increases within older cohorts.

Within previous studies, increases in average size have served as indicators of the effectiveness of marine protected areas and seasonal closures (Beets and Frielander, 1998; Chiappone *et al.*, 2000; Nemeth, 2005), and such an increase after closure was initially observed in this study. However, this effect was short-lived; as fishing effort

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increased in response to the closures, proportional contributions of age 7-10 year individuals were observed to decline, resulting in truncated length-frequency distributions. In later years, observations from fishery-independent and dependent length-frequency data revealed increases in average length to be the result of low numbers of recruiting individuals, with proportionally higher contributions of remaining older individuals. Trends within sexes support these conclusions.

Females were generally observed at an overwhelmingly greater abundance than males following enactment of the closure. Relative to years of similar catch, little differentiation in the total proportion of males, or proportion of males per sampling event, was observed during the 1997/98 project year. Minimal differentiation in the proportion of males was observed within the project years that immediately followed. Further trends are difficult to interpret as sex ratio represents a balance between fishing mortality rate, rate of recruitment (of females) and the factors affecting the rate of sex change. In later years, larger males were clearly disappearing from the population. Declines in the number of males puts increased pressure on females to change sex, and previous studies have suggested that females assess sex ratios during spawning events, and time sex changes as a result of their observations (Shapiro *et al*. 1994). Thus, increased numbers of females may have been changing sex to keep up with fishing pressure, and maintain sex proportions. Alternatively, limited recruitment of smaller females was occurring, and this may put pressure on females to prolong sex change.

In summary, observations in more recent years of minimal CPUE, and low numbers of recruiting individuals sufficient to cause an increase in average length at a time when large males were being removed from the population, indicate the presence of

a severely unhealthy stock. The Puerto Rico red hind stock has previously been identified as growth- and recruitment-overfished (Sadovy and Figuerola, 1992), and these findings confirm that this status has continued, and potentially worsened as a consequence of the significant increases in fishing effort that have occurred since closure.

Overall, similarities in trends between the western platform and Lajas (La Parguera) reconfirm the overall low effectiveness of the closures upon the western platform, particularly within recent project years and spawning periods. When trends of fishery-dependent data between both regions were compared, highly similar trends of nominal CPUE were observed. Decreases in CPUE during project years and spawning periods leading up to the enactment of the closures were found in both datasets, but pronounced periods of high CPUE were observed within the Lajas (La Parguera) region during spawning periods. Interestingly, during the 1997/98 project year and spawning period, increases in CPUE were observed in the Lajas (La Parguera) region. This is likely to be coincidental to the west coast closures, however, especially considering the low numbers of individuals observed during port-samplings. Sharp increases in CPUE during the 2003/04 project year and spawning period were observed within both regions. As on the west coast, this trend off of Lajas may be due the areal expansion of the fishery as traditional aggregations at *El Hoyo* and *La Laja* collapsed. Strong similarities in the average size of port-sampled individuals between the western platform and Lajas (La Parguera) region suggest that the recruitment limitations evident in length-frequency data from the western platform may also be prevalent throughout the southwestern platform.

Although the closures initially limited further rapid decline of the Puerto Rico red hind population, the stock continues to remain in poor form. In light of the limited

response observed within the Puerto Rico red hind population, it is important to put in perspective the causative factors that inhibited the long-term effectiveness of the seasonal closures. Within Puerto Rico, seasonal closures were only put forth within three 3x3 nautical mile areas along the western platform of Puerto Rico, leaving a large amount of red hind habitat open for fishing during spawning periods. Ojeda-Serrano *et al*. (2007) confirmed that fishing takes place within unprotected shelf edge regions along the western platform during spawning periods, and that additional spawning areas are common. Following enactment of the seasonal closures, pronounced increases in fishing effort, particularly during the non-closure period, were observed, and these may have overrode any positive impacts that the seasonal closures may have produced.

Initially following the enactment of the closures, an assessment of the red hind population of the western platform was performed by Sabat (2001), who observed increased average lengths of sampled individuals, and also suggested early effectiveness of the closures. Although monitoring of the effectiveness of these closures following this assessment by regulating agencies (i.e. NOAA-CFMC, PR DRNA) had been performed, limited change in management enabled further overfishing of the resource. Not until recently were further restrictions in fishing effort enacted. Not only have these been in effect only as of the 2007 spawning period, they are not supported by the fishermen, who in protest, openly fish in violation of the regulations (PR DRNA, 2007; NOAA-NMFS, 2007). Although recent studies have addressed the status of red hind within Puerto Rico (Matos-Caraballo *et al*. 2006), their analyses have only been performed at an island wide spatial scale, with little year to year identification of trends within the western platform. Trends of substantial increases in fishing effort along the western platform should have

been identified quickly, and quickly communicated to management agencies, so that appropriate responses to unhealthy fishing practices could have been effectively made. In addition, more thorough fishery-independent sampling is warranted, especially within protected areas. Following the enactment of the closures, pronounced decreases in sampling intensities were observed within *Abrir la Sierra*, *Bajo de Cico*, and *Tourmaline* regions of the western platform, especially during spawning periods. Ideally, sampling strategies should be amended to include more frequent assessments of these regions, throughout project years. Current SEAMAP-C sampling methods are destructive due to the mortality of most captured fishes (Rosario, 1998; Appeldoorn, personal communication), and increased samplings, together with commercial fishing practices, could affect the response of the population to closures. However, attempts to modify SEAMAP-C methods in order to mitigate sampling associated mortality (e.g. use of holding tanks to keep captured specimens alive), should be attempted in order to increase samplings, with minimal effect upon the population.

A seasonal closure within the USVI Red Hind Bank, with a subsequent permanent closure with the larger Marine Conservation District (MCD), served as a model for the seasonal closures in Puerto Rico. Initially, early pronounced decreases in recruitment within the USVI stock served as a major impetus for closure (Appeldoorn *et al.*, 1992). As of the 1990 spawning period at the Hind Bank, Beets and Friedlander (1998) observed an increase in average size of 10 cm and a decrease in sex ratio of females to males of 15:1 to 4:1. Observations of length frequency distributions confirmed the presence of recurring recruitment pulses. Five years after the permanent closure, maximum total length was found to increase by 7 cm, and substantial increases in average density and

biomass, and maximum spawning density were observed (Nemeth, 2005). Due to the limited available habitat for spawning along the platform surrounding the US Virgin Islands, and limited knowledge of other areas of highly concentrated red hind aggregations by fishermen, it would appear that a larger proportion of the spawning stock was initially protected during the seasonal closures, when compared to the management strategy in Puerto Rico.

While it is unknown what proportion of the spawning stock remains outside of the permanently protected area, red hind densities during non-spawning periods have been observed to be higher in regions outside of the MCD than within (Nemeth and Quandt, 2005), and many individuals tagged during spawning events within the MCD have been recaptured at sizeable distances from the protected area, ranging from coral reef habitat no more than 1.5 to 6 km from the protected area to as much as 15-33 km to the west (Nemeth, 2005). Although fishermen remained able to target red hind as they migrated from the closed area immediately following spawning periods, a high proportion remained protected during spawning events, and redefinition of the area into a permanent closure ensured more complete protection of the stock, and greatly decreased probability of capture as individuals dispersed from the MCD (Nemeth, 2005).

In contrast, within Puerto Rico numerous areas have remained open, and less of a dilution of fishing intensity could be observed given the flood of fishing effort observed following enactment of the closures. Also, given the apparently higher degree of cooperation of fishermen in permitting the implementation of the permanent closure (Nemeth, 2005), it would appear that a less pronounced response in fishing effort was observed within the US Virgin Islands following enactment. Despite similar distances

(~12 km) from shoreline to protected area, the rougher sea conditions within the MCD may serve to discourage fishing efforts of comparable intensities to those observed within the Puerto Rican protected areas along the calmer, leeward side of the island. Although, significant fishing effort is still observed within MCD surrounding waters (Nemeth, personal communication). Little information is available regarding the degree of enforcement observed within the MCD, but Rivera (personal communication) commented upon the large number of traps found within the MCD while mapping benthic habitat using a towed sidescan sonar. However, these were found to be dispersed and not particularly targeting the spawning site. Nemeth (personal communication) commented that the high frequency of scientists monitoring the red hind population within the MCD serves as a strong deterrent to poachers. Although the known presence of scientific observers together with already present legal enforcers appears to be a factor in regulating compliance, he noted that poaching activity has still been observed. In comparison, the low level of enforcement of fishery regulations within Puerto Rico has been detailed (Kimmel and Appeldoorn, 1992). Therefore, given the low level of voluntary cooperation observed in both regions, increased monitoring by law enforcers and continued presence of scientists within protected areas can complementarily serve to regulate compliance.

The importance of marine protected areas in contributing to increased biomass, spawning stock, recruitment, and overall health of marine populations has been documented in numerous studies (Russ *et al.*, 1992; Sluka *et al.*, 1997; Chaippone *et al.*, 2000). However, of key importance, as illustrated within this study, is the protection of a significant proportion of individuals as related to movement patterns, the distribution of

essential habitat and the potential response of fishermen, none of which was assessed

when implementing this management strategy for Puerto Rico. Shifts in fishing strategy

often accompany the enactment of marine protected areas, with fishers congregating near

borders of no-take zones, or increasing fishing effort in other regions (McClanahan and

Kaunda-Arara, 1996; Walters, 1999). Within Puerto Rico, increased intensity of fishing

within unprotected regions of presumed spawning activity, and significantly higher

fishing pressure during non-spawning periods within both protected and unprotected

areas, dictates that shifts in fishing strategies as a result of enacted regulations must be

considered in further management plans, and suggests that implementation of further

restrictions upon fishing pressure are necessary. Although the initial 2004 state water and

modified 2007 island-wide spawning season bans appear promising for the future of local

red hind, further restrictions of fishing effort during the non-spawning period appear to be

necessary. The addition of several permanent closures along the western platform may

become a further necessary restriction of fishing effort. Overall, given the initial

response of the red hind population to the closures, the findings suggest that the recovery

of this species in Puerto Rico may be possible, but stock rebuilding will require longer

time frames, additional restrictions upon fishing pressure, and stricter enforcement of

regulations. Continued monitoring, more complete protection of the stock, and increased

public cooperation will hopefully work towards saving and restoring red hind within

Puerto Rican waters.

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