Evaluation of Seasonal Closures of Red Hind, *Epinephelus guttatus*, Spawning Aggregations to Fishing off the West Coast of Puerto Rico Using Fishery-dependent and Independent Time Series Data

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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, *Abrir la Sierra*, *Bajo de Cico*, and *Tourmaline*. Although the closure continues at present, its effectiveness toward population recovery has not been fully assessed. Fishery-independent red hind data from the Caribbean Southeast Area Monitoring and Assessment Program (SEAMAP-C) 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.

KEY WORDS: Red hind, *Epinephelus guttatus*, spawning aggregations, seasonal closures, Puerto Rico

Evaluación de los Encierros Sesonales de las Agregaciones Reproductivas del Mero Cabrilla, *Epinephelus guttatus*, a la Pesca en la Costa Oeste de Puerto Rico con Datos Dependientes y Independientes de la Pesca

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, *Abrir la Sierra*, *Bajo de Cico*, y *Tourmaline*, 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.

PALABRAS CLAVES: Mero cabrilla, *Epinephelus guttatus*, agregaciónes de reprodución, encierros sesonales, Puerto Rico

INTRODUCTION

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.* 1993), which have been heavily targeted due to their predictability in space and time. High fishing pressure at red hind aggregations has led to the Puerto Rico stock

being classified as both growth- and recruitment-overfished (Sadovy and Figuerola 1992, Sadovy 1993).

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. Increases in red hind spawning density, biomass, and average size have been observed in the U.S. Virgin Islands following enactment of seasonal and permanent closures (Beets and Friedlander 1998, Nemeth 2005). 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°10'W, during the spawning period (PR DRNA 2007, NOAA-NMFS 2007).

While the initial spawning aggregation closures continue at present, their effectiveness towards population recovery has not been fully assessed. 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. Through analysis of both fishery-independent data, 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

Several data sets were used in this study to evaluate the impacts of the seasonal closures. Primary red hind data came from the Caribbean Southeast Area Monitoring and Assessment Program (SEAMAP-C), a fisheries-independent sampling program that targets the western insular platform of Puerto Rico, and collects data on standardized catch rates and fish sizes throughout the year. Within this program, fishes, particularly red hind, have historically been sampled year round, and during spawning periods, within seasonally protected and unprotected areas, by trap and hooked line (Rosario 1998). Started in 1988, fish data are collected on a cycle of 3 years out of every 5, beginning in April of the first year, and culminating in March of the final year. 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. Fishery-dependent red hind landings and biostatistical data from port-samplings covering the period 1988 - 2005 were obtained from the Puerto Rico Department of Natural and Environmental Resources Fisheries Research Laboratory (DNER-FRL), whose collection methodologies are found in Matos-Caraballo *et al*. 2006.

Fishery-independent red hind annual average Catch per Unit of Effort (CPUE) values (kg/day), length-frequency distributions, and the average proportion of females captured per day were quantified per sampling year (April - March) and per spawning period (December - March) for the western Puerto Rico platform, and within seasonally protected and unprotected sites. Commercial landings data and biostatistical length data corresponding to red hind captured and landed within the SEAMAP-C sampling area (Cabo Rojo and Mayagüez offshore regions of Puerto Rico) were used to quantify annual average nominal CPUE values (kg/fishing trip) and length-frequency distributions per SEAMAP-C project year and red hind spawning period. Annual variations of fishery-dependent and fishery-independent parameters during SEAMAP-C project years and spawning periods were each assessed at a coast-wide spatial resolution with 1-way Kruskal-Wallis tests, followed by *post-hoc* pair-wise comparisons with Nemenyi tests ($\alpha = 0.05$).

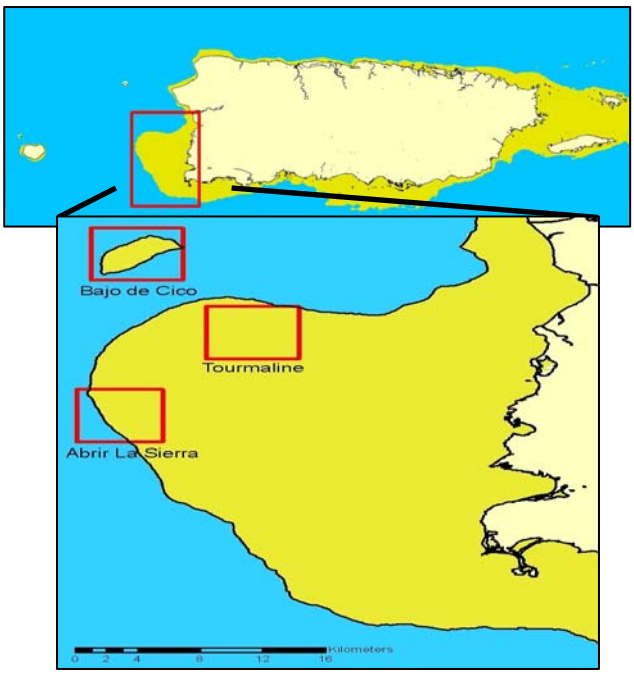

Figure 1. Map of the Puerto Rico Archipelago and insular platform up to 100 m, with western shelf and seasonally closed areas highlighted.

RESULTS

Fishery-Independent SEAMAP-C Data

Within the western insular platform, annual average red hind CPUE (kg/day) values throughout sampled project years (Figure 2) were found to significantly differ ($p < 0.05$). Little variation in average CPUE was found within subsequent years prior to the enactment of the closures until the 1995/1996 period, during which a significant decrease relative to all previous project years was observed. Annual CPUE increased significantly between the 1995/1996 sampling period (before closure) and the 1997/1998 sampling period following enactment of the closure. Decreases during subsequent periods were not found to be significantly lower than the peak in the 1997/1998 project year, nor significantly lower than values prior to the enactment of the closures. However, average CPUE of the 2005/2006 project year was found to be significantly lower than the 1997/1998 - 1999/2000 project years (and the 1990/1991, 1993/1994 - 1994/1995 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 ($p < 0.05$). CPUE during the 1997/1998 project year was not found to be significantly higher than during pre-closure periods, which did not include the 1995/1996 period, but 2004/2005 - 2005/2006 spawning period CPUE values were found to be significantly lower than pre-enactment values. During later sampling years, annual spawning period CPUE values were found to be lower than those of project years.

Annual average CPUE within seasonally protected areas during project years and red hind spawning periods closely mirrored those observed for the entire coast, but more pronounced decreases were observed in the years prior to the enactment of closure. Comparatively, highest average CPUE was observed within *Bajo de Cico*, where captures made up 66% of the total catch from all sampling years throughout the western platform. Annual CPUE values at *Abrir la Sierra* directly paralleled those observed for the entire western platform. As witnessed for the entire platform, initial post-enactment increases in CPUE were observed during the 1997/1998 project year and spawning period within the *Bajo de Cico* and *Abrir la Sierra* platform regions, and were followed by progressive decreases during subsequent project years and more pronounced decreases during subsequent spawning periods. Average annual CPUE of the *Tourmaline* platform region was consistently low at < 2 kg/day throughout all project years and spawning periods. Prior to the enactment of the closures, values within unprotected areas were much lower than those within protected areas. However, an initial post-enactment CPUE increase during the 1997/1998 project year and spawning period was observed within unprotected areas. Due to low post-enactment CPUE throughout the platform, lesser variation was observed between protected and unprotected areas within later sampling periods.

Significant differences between annual average lengths were found for SEAMAP-C project years and spawning periods for the entire western platform (Figure 3; $p < 0.05$). Continual decreases in annual average length were observed throughout all project years and spawning periods prior to the enactment of the seasonal closures. A significant increase in average length was found during the 1997/1998 project year, compared to values before closure, with values within later years remaining similar until another significant increase for the 2005/2006 period. Trends and significances during spawning periods were nearly identical to those of project years. However, decreases in average length following the 1997/1998 spawning period were observed, including a significant decrease during the 2000/2001 spawning period, relative to that of the 1997/1998 spawning period. Between the 2000/2001 and 2005/2006 spawning periods, a significant increase of 5.64 cm average length was found to have occurred. During pre-enactment project years, length-frequency distributions revealed larger samples ($n_{1998/99} = 846$), heavy contributions of recruiting individuals to the bulk of the catch, and although low in number, greater numbers of larger males (e.g. FL > 400 mm). Recruitment of subsequent years appeared to be lower (truncation at smaller sizes), or occur at a later age relative to what was observed in years prior to closure. Within the 2005/2006 project year, very low numbers of individuals were observed ($n = 143$) with particularly low numbers of males, minimal numbers of recruits (age 0 - 2 yr = 5.6%), and few remnants of previously stronger cohorts.

Average proportions of females within the entire western platform of Puerto Rico were found to significantly differ between project years ($p < 0.05$). However, no inter-annual significant differences were measured following the enactment of closures. An increase in the proportion of females was observed immediately following the enactment of the closures. During spawning periods, little variation was observed in the proportion of females, with the only significant difference in the average proportions of females observed between the 1988/1989 and 1993/1994 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.

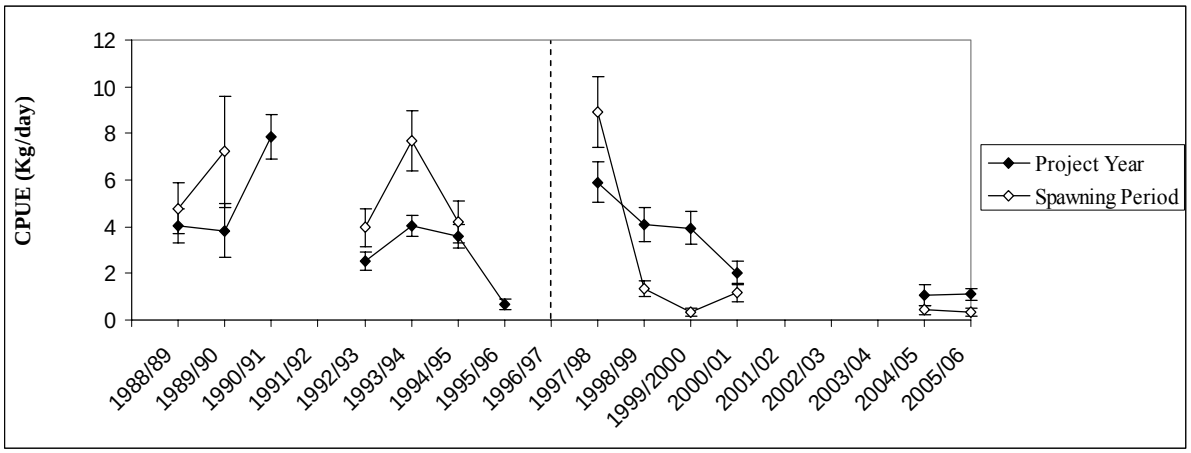

Figure 2. Annual average CPUE (kg/day) and standard error of red hind (*Epinephelus guttatus*) from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period. The dashed line represents the time of enactment of the seasonal closures.

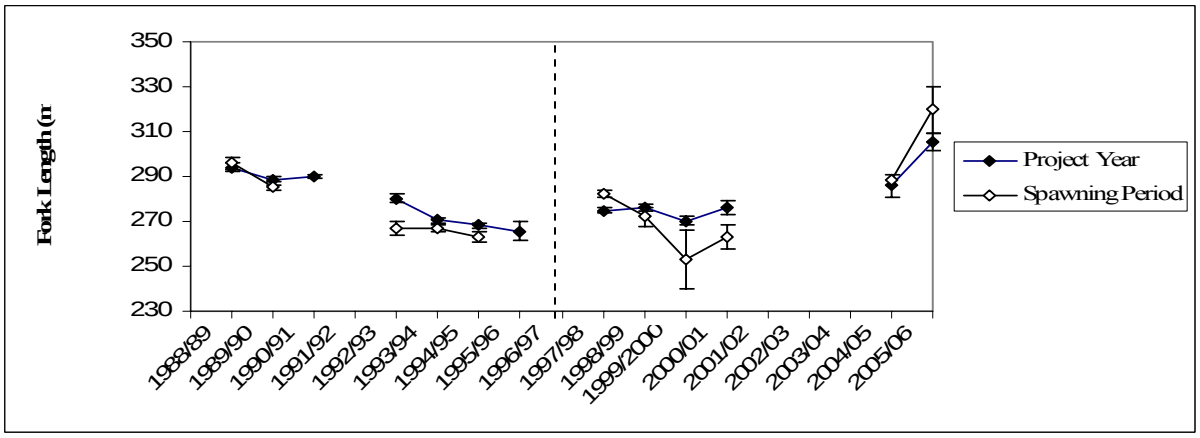

Figure 3. Annual average length and standard error of red hind (*Epinephelus guttatus*) from SEAMAP-C samplings along the western insular platform of Puerto Rico per project year and red hind spawning period. The dashed line represents the time of enactment of the seasonal closures.

Fishery-Dependent DNER-FRL Data (Cabo Rojo and Mayagüez)

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 (1997/1998 - 1998/1999), the number of recorded fishing trips increased two- to three-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. 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 2004/2005 project year only 15% of the reported fishing effort came from trips during spawning periods.

Annual nominal CPUE (kg/trip) values within the combined Cabo Rojo and Mayagüez municipalities of Puerto Rico (Figure 4) were found to significantly differ throughout project years and spawning periods ($p < 0.05$). Earlier annual CPUE values of the period of interest were

generally higher than within 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 1993/1994 - 1995/1996 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 2003/2004 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.

During SEAMAP-C project years, significant progressive increases in the average length of port-sampled red hind were observed (Figure 5). No significant difference in the average length of individuals was observed between sequential project years, or from the baseline average length of the 1988/1989 project year, until the 2003/2004 project year. Within following project years, decreases in average length were observed, but values were not significantly lower than that of the 2003/2004 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. Pre-enactment length-frequency distributions of port-sampled red hind within Cabo Rojo and Mayagüez municipalities revealed low numbers of sampled individuals, but high contributions of recruits to the bulk of the catch. 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, and a pronounced shift in distribution was found in 2005, with few age 0 - 2 individuals sampled, and increased proportional abundance of age 5 - 7 individuals (FL = 280-340 mm)

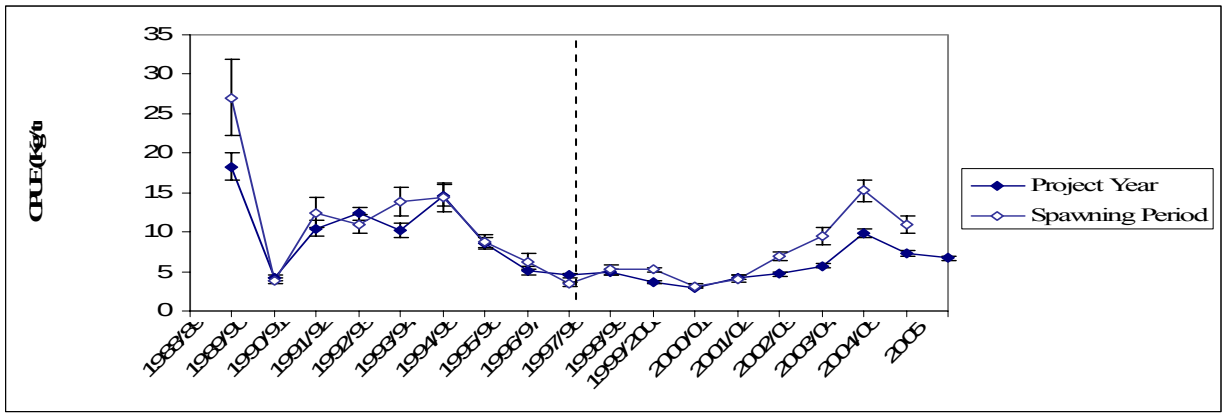

Figure 4. Annual average CPUE (kg/trip) and standard error of red hind (*Epinephelus guttatus*) from reported landings of combined Cabo Rojo and Mayagüez municipalities of Puerto Rico, per SEAMAP-C project year and red hind spawning period. The dashed line represents the time of enactment of the seasonal closures.

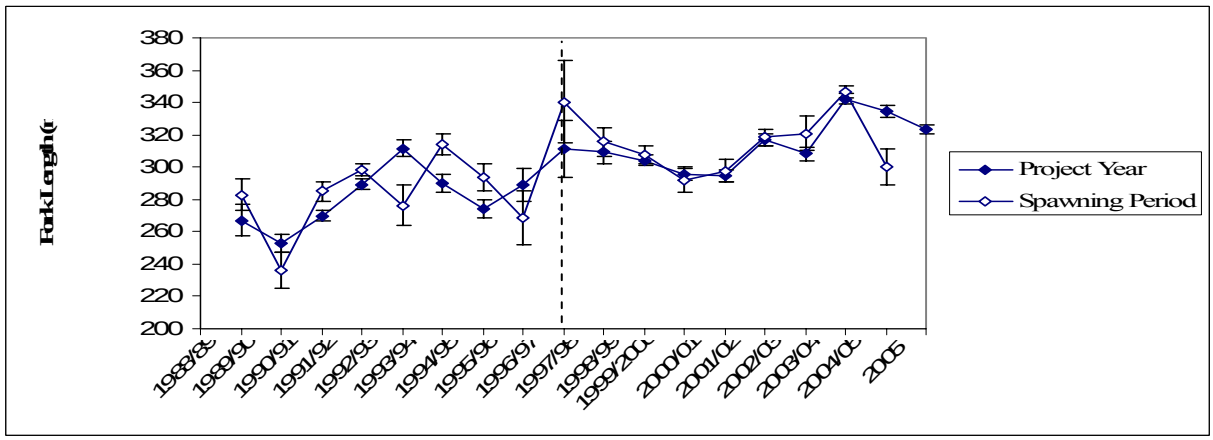

Figure 5. Annual average length and standard error of red hind (*Epinephelus guttatus*) from port samplings of the Cabo Rojo and Mayaguez municipalities of Puerto Rico per project year and red hind spawning period. The dashed line represents the time of enactment of the seasonal closures.

DISCUSSION

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. 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 1996/1997. This reduction in fishing pressure may have allowed for a faster response throughout the western platform. Factors such as initial increases in the abundance and average size of females, and the movement of fish between protected areas and unprotected areas across the shelf may have contributed to this shelf-wide response in CPUE.

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. 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, subsequent changes in fishing behavior in response to the closure (i.e. shifting fishing effort to previously under targeted regions, proportional gear shifts, and increased use of Global Positioning Systems) to locate and target red hind found within previously underfished regions would explain the sustained catch levels over time and subsequent increases (while CPUE from SEAMAP-C data showed a steady decline). Later increases in nominal CPUE, particularly during the 2003/2004 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.

Nevertheless, 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. 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 3 x 3 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 within protected and unprotected sites, particularly during the non-closure period, were observed, and these may have overrode any positive impacts that the seasonal closures may have produced. 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.

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. 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), and that more frequent monitoring of the stock by scientists serves to deter poaching (Nemeth Pers. comm.), it would appear that a less pronounced response in fishing effort was observed within the US Virgin Islands following enactment. Although the known presence of scientific observers together with already present legal enforcers appears to be a factor in regulating compliance, Nemeth 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. 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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