Methodology at Bermuda

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ABSTRACT

The estimation of the number of fish at a spawning aggregation site by diver census can be logistically challenging. The spatial extent of the aggregation, underwater visibility, spawning time and other factors can influence the accuracy of the estimate. We use the results of an extensive tag-recapture program for red hind (*Epinephelus guttatus*) at two spatially-separated spawning aggregation sites to estimate maximum aggregation sizes. A total of three Peterson index values were derived from tag-recapture results obtained at two seasonally-protected aggregation sites from 1993-2000. The three maximum aggregation size estimates ranged from 926 to 1,153 fish. These values are compared to estimates of red hind aggregation size from two locations in the Caribbean.

KEY WORDS: *Epinephelus guttatus*, spawning aggregation size, Petersen index, Bermuda

Valoración del Tamaño de Agregaciones de Freza de Mero Colorado (*Epinephelus guttatus*) con una Metodología del Etiqueta-recobrar en Bermudas

La estimacion del número de individuos en bancos de desove usando censos de buceo puede ser un desafio logístico. La extension especial del banco de desove, la visibilidad subacuática, el tiempo del desove y otros factores pueden influenciar la exactitud de las estimaciones. Utilizamos los resultados de un extenso programa de marcado y recaptura para mero cabrilla (*Epinephelus guttatus*) en dos sitios de desove separados para estimar los tamaños máximos de las agregaciones. Un total de tres valores del índice de Peterson fueron derivados en los dos sitios protegidos durante la epoca de desove durante el periodo 1993-2000. Las tres estimaciones del tamaño maximo de la agregación variarion entre 926 a 1,153 individuos. Estos valores se comparan con las estimaciones del tamaño de las agregaciones de mero cabrilla con otras dos localidades en el Caribe.

PALABRAS CLAVES: Mero colorado, *Epinephelus guttatus*, agregaciones de freza, etiqueta-recobrar

INTRODUCTION

Reef fish spawning aggregations are documented throughout most of the wider Caribbean region, and there appears to be a general declining trend in landings from most known sites (Luckhurst 2004). The majority of the landings from spawning aggregation sites are of the commercially important groupers and snappers. Species from these two families comprise a significant proportion of the landings from aggregations in most countries in the region. Amongst the eight species of groupers known to form spawning aggregations in the region (Luckhurst 2003), the red hind, a medium-sized grouper, is known to form spawning aggregations in a number of countries including Bermuda (Luckhurst 1998).

Domeier and Colin (1997) defined two different types of spawning aggregations, "transient" and "resident”. Groupers and snappers form "transient" aggregations with the following characteristics:

i) Fish frequently migrate long distances to the aggregation site,
ii) Aggregations typically form for only 1-3 months during the same time period each year,
iii) The duration of the aggregation ranges from only a few days to several weeks,
iv) The formation of aggregations is entrained to the lunar cycle with the full moon period appearing to be the most common aggregation time for groupers and snappers in the wider Caribbean.

Due to the economic importance of groupers and snappers to most fisheries, research to date has concentrated largely on the species in these two families. However, relatively few spawning aggregations have been scientifically evaluated. As a consequence of this paucity of quantitative information from aggregation fisheries, it is difficult to evaluate aggregation status and formulate appropriate management measures.

The estimation of fish abundance at spawning aggregation sites has been conducted mainly by divers using various visual census techniques. Shapiro et al. (1993) produced an estimate of the size of a red hind spawning aggregation in Puerto Rico while Beets and Friedlander (1998) evaluated a red hind aggregation in St. Thomas, U.S. Virgin Islands. More recently, Nemeth (2005) has been documenting the recovery of this same red hind aggregation under permanent closure.

In conducting visual counts, protocols are typically standardized to minimize error and usually involve several divers and repeated counts. However, there are still a number of problems associated with visual assessments:

i) Underwater visibility – Poor visibility limits the field of vision for diver counts.
ii) Spatial extent of aggregation – Aggregations covering large areas may preclude the ability to survey the entire site during a given dive.

iii) Depth limitations – Many aggregations occur in relatively deep water (30+ m) limiting bottom time for divers.
iv) Temporal dynamics – Many aggregations are only fully formed just before spawning occurs which is frequently approaching dusk, hence low light conditions limit the ability of divers to make accurate counts.
v) Sea conditions – It appears that spawning aggregation sites are frequently in reef locations with strong currents and often rough sea conditions, making the task of working at these sites more difficult for divers.
vi) Species behaviour - Some species swim in the water column making them easier to count while others shelter in the reef infrastructure until just prior to spawning and are not readily observed by divers.

As a result of these problems, the use of underwater video cameras has become a common means of providing a permanent record of the aggregation and different videography techniques, e.g. freeze frame, can be used to estimate the abundance of aggregating fish. This video record can then be analyzed at a later date to examine detailed fish behaviour and other features of the aggregation. Lastly, sonar scanning of aggregations has come into use in recent years to estimate abundance. This technique requires ground truth work to interpret target size and strength in order to provide reasonable estimates of aggregation abundance from sonar records.

The first research on spawning aggregations in Bermuda was conducted on the red hind from 1973 - 1975 (Burnett-Herkes 1975). This research program was initiated due to a request from commercial fishermen to take management action in the face of the overfishing of aggregations. The research involved tagging and basic biology but there was very limited data on spawning dynamics and no estimates of aggregation size were made. Sampling of the aggregations continued on an intermittent basis through the 1980s but no tagging was conducted. Following the commencement of a long-term tagging program in 1993, the initial results indicated a relatively high recapture rate of tagged fish (15.2%) at the aggregation site and the recaptured fish demonstrated site fidelity (Luckhurst 1998). This provided the opportunity to use tag-recapture data to estimate aggregation abundance. Suitable data were available for only three of the seven years of the tagging program.

In this paper, we use a Petersen index to estimate abundance of red hinds at two spawning aggregation sites at opposite ends of the Bermuda reef platform.

MATERIALS AND METHODS

Sampling and tagging of red hinds from the northeastern (NE1) spawning aggregation site (Figure 1) was conducted during the peak spawning aggregation periods (full moon, May to July) in 1993 - 1995. At the southwestern (SW1) site (Figure 1), sampling and tagging took place during the spawning periods from 1997 - 2000.

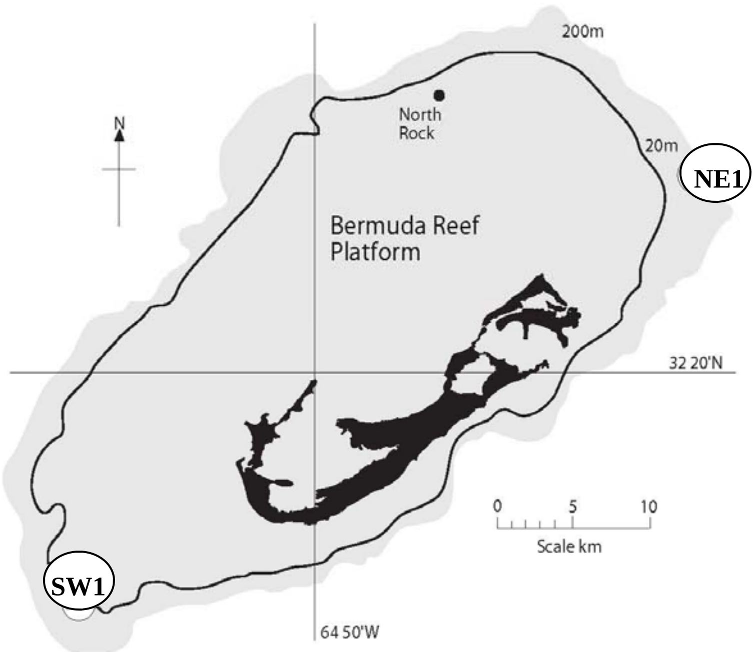

Figure 1. Map of Bermuda reef platform indicating locations of the two spawning aggregation sites (SW1, NE1) for red hind for which aggregation abundance values were estimated.

The details of the sampling and tagging protocol are outlined in Luckhurst (1998). It should be noted that from 1994 onward, all specimens were double-tagged with Floy T-bar anchor tags to minimize the effect of tag loss detected after the first year of tagging. To evaluate the possible increased vulnerability to predation of tagged fish upon release, the senior author observed (using SCUBA) the release, on three separate occasions of tagged fish (total of >50 fish) while stationed on the reef substrate under the research vessel. Observations were made of the behaviour upon release and tagged specimens were tracked for the first 10-15 minutes post-release. The visibility of the tags while fish were located within the reef infrastructure was also noted.

Following the theory outlined by Seber (1982), an estimate of maximum aggregation size is possible through the Peterson estimate, derived by;

$$N^* = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1 \qquad \textbf{(1)}$$

where N^* = estimate of the number of fish in a closed population

n_1 = number of fish tagged and released in the first sample,

n_2 = number of fish obtained in the second sample

m_2 = number of tagged fish in the second sample.

The variance (v^*) of N^* is given by Seber (1982);

$$v^* = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2(m_2 + 2)} \qquad \textbf{(2)}$$

and an approximate 95% confidence interval for N (the number of fish in a closed population) can be calculated by;

$$N^* \pm 1.96\sqrt{v^*} \qquad \textbf{(3)}$$

Before substituting experimental values into equation (1), handling mortality must be considered so that n_1 refers to the number returned alive to the population (Seber 1982). An element of post-release mortality of tagged fish probably occurred as a result of the invasive "winding" and tagging procedures. Mortality due to capture and "winding" was estimated from the proportion of red hinds that died while being retained in live-wells on board the research vessel or in holding tanks ashore during a 24 hour minimum observation period following capture. This time-period was selected as experience indicated it to be the most vulnerable period of captivity. Data from 1993 and 1994 indicated that the mortality rate in captivity was approximately 6%. Thus, the value substituted into equation (1) for survivorship of tagged and released fish was reduced accordingly.

RESULTS

Post-release Behaviour of Tagged Fish

Diving observations of tagged fish released overboard from the research vessel indicated that all marked fish behaved in a similar manner. Upon entering the water, they oriented momentarily and then swam rapidly downward to the reef substrate where they sought cover under ledges or within crevices in the reef infrastructure. Typically after 5 - 10 minutes, they left shelter and moved slowly and cautiously away remaining close to the substrate. There were no observations of attempted predation on any tagged fish.

Aggregation Size Estimates

Suitable data from the tagging program to generate aggregation size estimates was available for only one year at the northeastern aggregation site (NE1) while two years data were available for the southwestern site (SW1) (see Figure 1). Substituting values into equation (1) for the three data sets provided estimates of aggregation size (N^*)(Table 1). From equations (2) and

(3), the 95% confidence limits for *N*, estimated from the variance (v^*) of N^*, are given to provide estimates of maximum aggregation size (Table 1).

Given the similarity in these abundance estimates generated from the two sites, it might be concluded that they are similar in area. However, as diving operations were not made at the sites during the sampling and tagging periods due to logistical constraints, there are no estimates of density of red hinds at the two sites during the spawning periods which could be compared. It should be recalled that both sites are seasonally closed to all fishing during the spawning period (May – August) and thus receive the same protection.

Table 1. Petersen Index estimates of red hind aggregation size and maximum aggregation size (using the 95% confidence interval) at two sites on the Bermuda reef platform.

Aggregation site	Year	Aggregation size (N*)	Maximum aggregation size (95% CI)
NE1	1993-94	639	926
SW1	1997-98	712	1,153
SW1	1998-99	664	1,074

DISCUSSION

Before comparing the aggregation size estimates obtained in this study with the estimates for red hinds from locations in the Caribbean, it is useful to evaluate the assumptions upon which the Peterson method is based in estimating population size (*N*), if N^* is to be a suitable estimate of *N*:

The population is closed (N is constant) — The spawning aggregations depart from this assumption in several ways:

i) An estimate of mortality from the tagging process itself was not obtained because fish were not retained for observation after tagging. Thus, additional mortality may have occurred as a result of the tagging process (e.g. infection of wounds around the tag site). There may also have been increased vulnerability to predation as a result of tagging although initial diving observations at the time of release did not detect any. Thus, more tagged fish may have been removed through incidental mortality than estimated (n_1 is too high), with the net result of overestimating the aggregation size.

ii) Fishing mortality during the period between samples will remove fish from the population. In addition, recruitment probably occurred between the two sampling periods as fish attaining maturity joined the aggregation. Seber (1982) states that when both recruitment and mortality occur, N^* will overestimate both the initial and final population size.

All fish have the same probability of being caught in the first sample — Two potential sources of bias could affect the composition of the first sample; the area sampled and the catchability of the fish. Given that the spawning aggregation sites were very limited in area (1-1.5 hectares) and the research vessel was not static in relation to the anchor site, it is probable that all portions of the aggregation site were fished. As catchability often varies with the size of the fish, a variety of hook sizes and bait types were used to reduce bias through gear selectivity. Studies on a red hind aggregation in southwest Puerto Rico demonstrated that hook and line fishing provided an adequate sampling technique both for sex ratio and size distribution within the aggregation, as determined by spearfishing (Shapiro et al. 1993).

The second sample is a simple random sample — Two sources of bias need to be considered here; thorough mixing of the tagged and unmarked fish between the sampling periods and the effect of tagging on catchability. Our data strongly indicate that the aggregations dispersed and reformed between sampling years thus resulting in thorough mixing of the tagged and untagged fish. Multiple recaptures of red hinds were common at both sites providing circumstantial evidence that catchability was not significantly affected by tagging.

There is no tag loss between samples — During the early stages of the study, tag obliteration was recorded and thus complete loss of the visible portion of the tag probably also occurred. However, all specimens were double-tagged from 1994 onward thus limiting the impact of this factor.

All tags are reported on recovery in the second sample — The only vessel authorised to fish at the aggregation sites during the spawning season was our research vessel. As the aggregation sites are both located in seasonally protected areas, we believe that poaching by other vessels was unlikely and all recaptures in the second sample were probably reported.

Given the above considerations, we believe that our estimates are reasonable first approximations of red hind aggregation size in Bermuda.

There are three studies of red hind spawning aggregation size from the Caribbean with which to compare our estimates. The first study was conducted in Puerto Rico by diver survey and the estimate of the size of the red hind aggregation, based on a peak density of 7.6 fish/100 m², was 745 fish (Shapiro et al. 1993). This value is very similar to our values. The second study, which was conducted in St. Thomas, U.S. Virgin Islands, yielded a mean density estimate of 4.7 fish/100 m² (Beets and Friedlander 1998) but did not provide an estimate of the aggregation size. However, this density estimate was obtained two days after peak spawning and so is undoubtedly an underestimate as red hinds appear to leave the aggregation site shortly after spawning (Shapiro et al. 1993). As there is some uncertainty concerning the actual area of the aggregation site in St. Thomas, we are unable to estimate aggregation size. Given the area of the aggregation site and density values, a simple extrapolation will produce an estimate of aggregation size. The population response of red hind to the permanent closure of this same aggregation site in St. Thomas (Red Hind Marine Conservation District) was evaluated by Nemeth (2005). He determined that the area of the red hind aggregation was considerably larger than our Bermuda estimates (1 - 1.5 hectares) and that the density of red hinds increased from 11.2 fish/100 m² in January 2000 to 24.0 fish/100 m² in 2003. As a consequence of these higher values, Nemeth (2005) estimated that the spawning population size ranged from about 26,000 to 84,000 fish. These are extraordinarily high values when compared to the other studies outlined here and may demonstrate the dramatic impact of a permanent closure of an aggregation site on the population.

The technique of mark / recapture has much potential for assessing aggregation size, particularly if simple experiments to assess tagging mortality and tag loss rates are conducted to reduce the tendency for overestimation of *N*. This technique can be a useful compliment to other methods of estimating aggregation abundance particularly when on site abundance estimation is challenging.

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