Spatio-temporal Patterns of Red Hind, *Epinephelus guttatus*, Spawning Aggregations Off the West Coast of Puerto Rico: Evidence from Monitoring Courtship Associated Sounds

Los Patrones Espaciales ytemporales en las Agregaciones Reproductivas del Mero Cabrilla, *Epinephelus guttatus*, de la Costa Oeste de Puerto Rico: La Evidencia del Monitoreo de los Sonidos Asociados al Cortejo

Les Patrons Spatiotemporels dans les Agrégations de Reproduction des Mérou Couronné, *Epinephelus guttatus*, Côte Ouest de Puerto Rico: Preuves de la Surveillance de les Sons Associé pour la Fréquentation

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EXTENDED ABSTRACT

Introduction

The red hind is the most important commercial grouper in Puerto Rico (Matos-Caraballo 2002) and is characterized by the formation of spawning aggregations at known sites and times (Nemeth et al. 2007, Shapiro et al. 1993, Sadovy et al. 1994). This behavior make the species highly vulnerable because fishers can target the aggregations, bringing intense fishing effort over a small area; as a consequence several aggregations are known to have collapsed or suffered large decreases in abundance (Beets and Friedlander 1999, Marshak and Appeldoorn 2008). This same behavior, however, offers the unique possibility of easily assessing the status of the spawning stock, if the aggregation locations are known. Quantitative surveys of spawning stock offer the potential to directly assess stock health and monitor stock decline/recovery (Beets and Friedlander 1999, Nemeth 2005). However, such surveys need to be timed to the occurrence of fish at the sites, and they are subject to understanding the factors driving aggregation behavior. Passive acoustic monitoring of species-specific courtship associated sounds (CASs) is a convenient way of determining the temporal pattern of reproductive activities, as call counts and sound levels are related to the abundance of fish within a specific aggregation (Appeldoorn et al. 2013, Mann et al. 2010, Rowell et al. 2012).

We used passive acoustic monitoring of red hind CASs to determine the temporal patterns of aggregation formation at Abrir la Sierra (ALS) over multiple years and for single years at two additional sites off the west coast of Puerto Rico. The purpose of this study was to study the variations in the temporal dynamics of red hind spawning across space and time, with the goal of developing a better predictive capacity for when red hind aggregate and potentially understanding what may drive observed differences.

Methods

Following the methods of Mann et al. (2010) and Rowell et al. (2012), a digital spectrogram long-term acoustic recorder (DSG; Loggerhead Instruments) was deployed within the seasonal closed area of ALS for the 2008 and 2011-2014 spawning seasons (defined January year), while at Buoy 4 and the Tourmaline Reef seasonal closed area single deployments were made for the 2012 and 2014 spawning seasons, respectively (Figure 1). The DSGs were programed to record acoustic signals for 20 seconds every 5 minutes. Audio files were extracted and converted into WAV files. Sound pressure levels in the 100 to 200 Hz frequency band (band levels) were used as an indicator of red hind sound production.

Patterns of aggregation activity, as indicated by the rise and fall of sound intensity, were compared among years and sites relative to moon phase, and the number and relative size of peaks were compared to the predictive model of Nemeth et al. (2007) developed for the red hind aggregation at the Hind Bank, South of St. Thomas, USVI, where peak densities occur on the full moon. Peak densities at ALS occur approximately 8 - 10 days after full moon (Mann et al. 2010, Rowell et al. 2012). For this study, date of the full moon was defined as the day in which full moon occurred during the night, local time. Thus, for example, if full moon occurred at 02:00 the date ascribed was the previous day. The Nemeth model predicts that if the full moon occurs between January 1 - 11, there will be two spawning peaks, one each for January and February. If the moon is between January 12 - 20 there will be one January spawning peak, and if the moon is between January 21 - 31 there will be two spawning peaks – one in December and one if January.

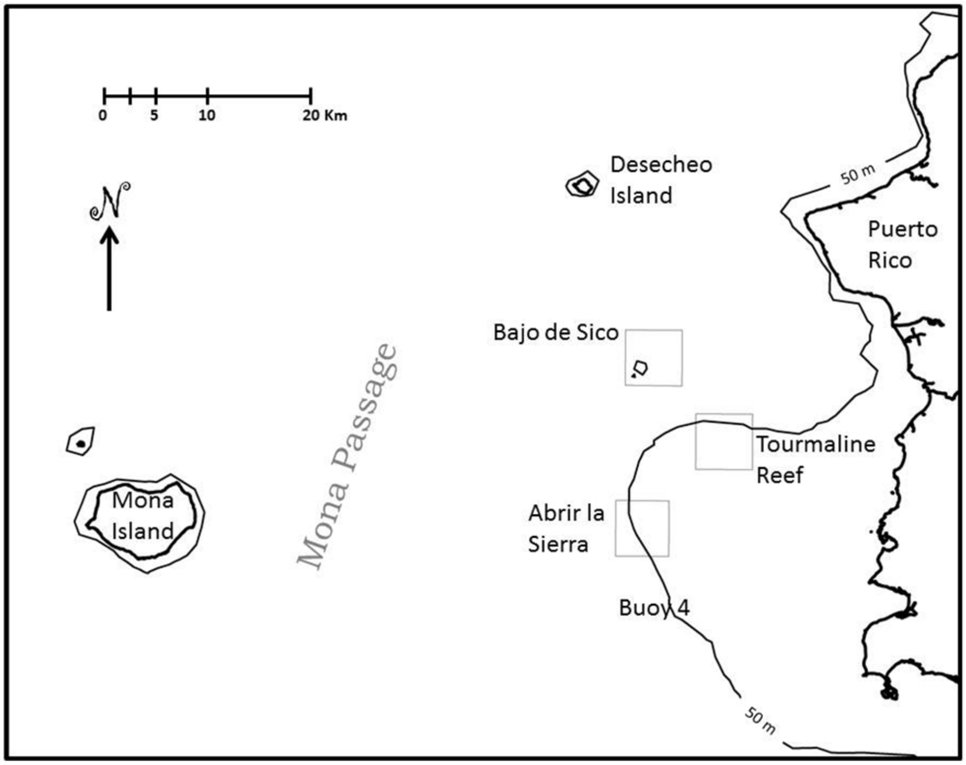

Figure 1. Location of monitored red hind spawning sites off the west coast of Puerto Rico. Grey boxes indicate seasonally closed areas.

Results

For all years, peaks in the production of red hind CASs followed that previously reported, occurring 8 - 10 days after full moon. In general, the number and strength of the major peaks each year followed the pattern of aggregation formation predicted by Nemeth et al. (2007) (Table 1). The only difference is the expected months of aggregation when the full moon occurs late in the month. Since aggregations at ALS peak approximately 10 days after full moon, when the full moon is late in the month the timing of the expected peaks flips to January and February, instead of December and January. Furthermore, the record of CASs was able to discern additional minor peaks not predicted by the model.

In addition to the peaks in CAS production associated with known spawning times, there were additional peaks evident that occurred prior to the largest peak. In 2011, for example this phenomenon was observed as a simple peak (see Figure 2 of Rowell et al. 2012). The timing of this peak was 2 weeks prior to the main peak. However, in 2007 (see Fig. 5A of Mann et al. 2010), 2013, 2014 to varying degrees this initial build up extended until the main peak.

In 2012, the pattern of peak sound production at Buoy 4, 9 km to the south, occurred in synchrony with that of ALS. Yet, at Tourmaline Reef, 12 km to the northeast, peak sound production in 2014 occurred seven days prior to that at ALS.

Discussion

The observed patterns of red hind CAS production are variable and highly complex over space and time. Yet, some consistent trends are apparent. At ALS, the pattern of peak sound production is consistent across all years in terms of its peak timing 8 - 10 days after full moon. Addi-

Table 1. Annual pattern of peak production of red hind courtship associated sounds relative to the date of the January full moon (FM), plus predictions based on the model of Nemeth et al. (2007).

Year	January FM	Predicted Peaks	Observed Peaks
2007	3	2 Peaks (Jan, Feb)	2 even peaks (Jan16, Feb13)
2012	8	2 Peaks (Jan, Feb)	2 even peaks (Jan 16, Feb16)
2014	15	1 Peak (Jan)	1 large peak (Jan 26), 2 small peaks (Dec 29, Feb 25)
2011	19	1 Peak (Jan)	1 large peak (Jan 31-Feb 1)
2013	26	2 Peaks (Dec, Jan)	1 large peak (Feb 5), 1 small peaks (Jan 9), 1 minor peak (Mar 7)

tionally, the number and relative size of peaks observed appears to follow the model of Nemeth et al. (2007), suggesting:

i) That this model has general applicability, subject to variability in the timing of the peaks within the lunar cycle, and
ii) There are some underlying factors that control s these patterns, which if elucidated would greatly add to our predictive capacity for both red hind and potentially other aggregation groupers.

The additional peaks in call production are more enigmatic. No field sampling was done during these events, so it is unknown if actual spawning occurs at this time. The apparent two-week offset from the known spawning peak suggests that there could be additional spawning occurring on the same lunar cycle of tidal currents. However, the extension of these peaks into the known spawning time suggests that perhaps these peaks represent a false spawning peak, with fish then staying on site until the normal spawning time.

The correspondence in peak sound production between ALS and Buoy 4 is expected, given their close proximity and shared orientation of the shelf. However, the mismatch between ALS and Tourmaline Reef was not expected. The one-week offset indicates that spawning would occur in different parts of the lunar cycle of tidal currents. This could perhaps be explained by differences in their respective orientations relative to the shelf, with ALS on the western edge, and Tourmaline Reef on the northern edge. Of interest, the periodicity at Tourmaline Reef is the same observed at Mona Island, 62 km to the west (Mann et al. 2010).

Resolution of the variations in red hind CAS activity observed over space and time will require coupled long-term monitoring of call behavior, density, spawning, currents, and other key environmental factors, especially temperature.

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