Acoustic Patterns of Black Grouper, *Mycteroperca bonaci*, Spawning Aggregations in South Florida and Puerto Rico

Patrones Acusticos de la Agregación de Desove del Mero Negro, *Mycteroperca bonaci*, en Puerto Rico y el sur de Florida

Modèles Acoustiques de Mérou Noir, *Mycteroperca bonaci,* Concentrations de Reproducteurs dans Puerto Rico et la Sud de la Florida

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EXTENDED ABSTRACT

Black grouper, *Mycteroperca bonaci*, are protogynous hermaphrodites that reproduce seasonally in transient fish spawning aggregations (FSA) (Brule et al. 2003). A common component of shallow, benthic habitats, they exhibit high vulnerability to overexploitation due to their natural history. Now classified as Near Threatened by the IUCN Red List with a predicted 30% population loss across their range (Ferreira et al. 2008), they grow slow, mature late, and display high female to male sex ratios (Crabtree and Bullock 1998). Along the Puerto Rican coast black grouper are now only found associated with deeper topographic features along the shelf edge and offshore geological formations, potentially as a consequence of past removal from near shore habitats by local fishing pressure. In order to develop a sustainable fishery, a more thorough understanding of their reproductive behavior is essential, due to their particular vulnerability during spawning aggregations. Traditional methods however are not adequate to acquire the in-depth knowledge needed due to the deeper and more complex environments that local FSAs are formed.

Two potential black grouper FSAs have been identified offshore of the western coast of Puerto Rico, at the Bajo de Sico seamount and the shelf edge of Mona Island based on their increased concentrations of individuals combined with observations of courtship behavior, including male "white head" coloration. The male courtship associated sound (CAS) was recorded *in situ* by divers at the Mona Island FSA. A subsequent analysis of CAS patterns proved the practicality of quantifying CAS patterns to reveal spawning activities utilizing passive acoustics (Sharer et al. 2014).

Utilizing the passive acoustics methodology, the spatio-temporal patterns of black grouper spawning aggregations were modeled at three FSAs within the western Atlantic. Digital spectrogram recorders (DSG) were set at the two Puerto Rico sites and Riley's Hump in Florida's Dry Tortugas during the formation of the FSAs. The DSGs recorded on a fixed schedule from late December through May. At Bajo de Sico, recordings were also analyzed from a second site (55), where black grouper CAS were also detected. Audio recordings were transformed to visible spectrograms and every recording was inspected visually to quantify CAS. Recordings were time stamped allowing a temporal recreation of black grouper CAS activity. CAS numbers were compared with solar, lunar, and daily periodicities to determine seasonal, monthly, and daily patterns, respectively. Patterns were then compared across sites. A morphometric analysis was conducted at each site to compare general geomorphology of FSA locations.

Black grouper CAS activity exhibited similar patterns at Bajo de Sico, Mona Island, and Riley's Hump. FSA formation occurs during the winter and spring months when water temperature is lowest. Increased CAS activity occurred from January to April at Bajo de Sico and Mona Island. Months of peak activity varied between sites, however. At Mona Island CAS patterns are very consistent (Figure 1). Mean CASs/day increased through January and peaked in February all three years, before beginning a slow decrease in March and April (ANOVA, $p < 0.05$). March of 2013 showed the only irregularity, with an unexpectedly low amount of identified CASs and with no peak day associated with the lunar periodicity. Bajo de Sico site 55 monthly patterns closely mirrored those at Mona Island, with CASs increasing through January and February, then peaking in March before beginning their decline. The main site at Bajo de Sico exhibited earlier activity. Mean monthly CAS/day peaked in January for both seasons followed by a steady decline through April (ANOVA, $p < 0.05$, both years). Riley's Hump showed increased activity later in the season from March through May with a maximum in April.

CAS activity correlated with lunar periodicities with high predictability across all sites. Specifically at Riley's Hump and Mona Island, monthly peaks occurred mostly 8 to 13 days after the full moon, with only one exception. The majority, 56%, of the peaks occurred exactly 10 days after the full moon (DAFM). The broader peak CAS period was observed between 9 - 12 DAFM (ANOVA, Fisher LSD, $p < 0.05$). All peaks across all sites and years occurred in the last quarter of the lunar periodicity, between the last quarter moon and new moon. Both sites at Bajo de Sico displayed more variation, peaking between 6 - 14 DAFM. The only site containing significant days before the last quarter moon, both years peaking 6 DAFM, was the main site at Bajo de Sico

CAS patterns are highly correlated with solar periodicity. CASs peaked during the two-hour block before/during sunset at all sites (Figure 2). The three likely spawning sites displayed at least two hours of significant CAS increase between the 1600-1900 hours. Riley's Hump and Bajo de Sico peaked in the 1600 - 1700 hours while Mona peaked in the

1700 - 1900 hours (ANOVA, LSD Fisher, $p < 0.05$).

The geomorphology surrounding DSG locations at the FSAs is comparable to morphometric parameters described for multispecies FSAs in Belize and Cuba (Kobara and Heyman 2010). The FASs form near convex promontories between 25 - 35 m depths along the shelf edge, and within 50 m of deep water.

Spatio-temporal patterns are predictive across the surveyed sites. Though some local variations exist, CAS activity correlates strongly with seasonal, lunar and solar periodicities. CAS frequency peaks during sunset hours between the last quarter and new moons. Variations in peak months need to be considered for localized regulations and enforcement, but should be based on generalized aggregation behaviors described above. Utilizing geomorphology parameters and passive acoustics methodologies, black grouper FSAs can be more effectively identified, modeled and subsequently managed throughout their range.

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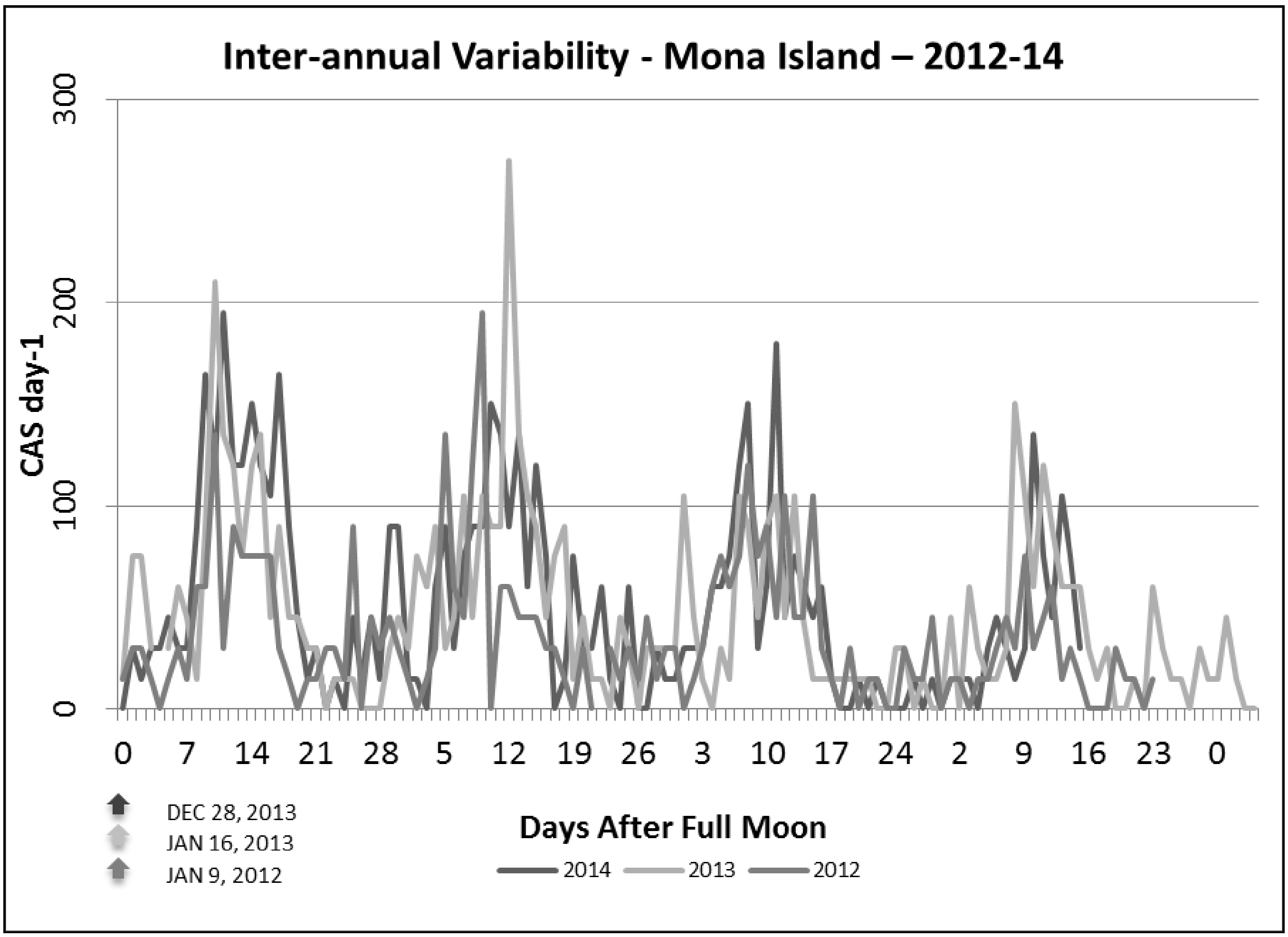

Figure 1. Total courtship associated calls (CA) per day during spawning period at aggregation site at Mona Island for three consecutive years. Graphs begin on the full moon before initial peak of season, which occurred all three seasons in January. Arrows indicate specific calendar date of the initial full moon for each season.

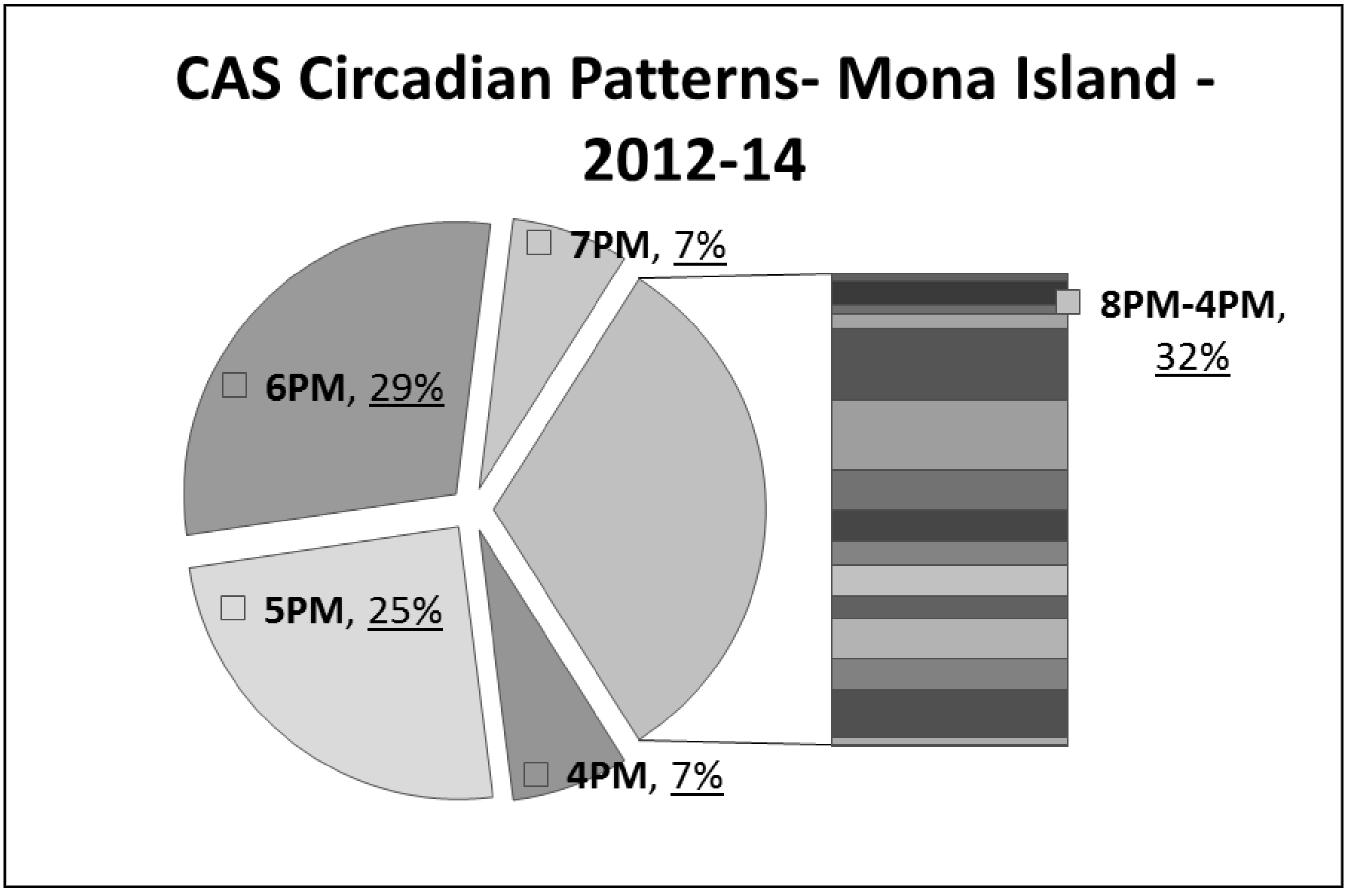

Figure 2. Daily patterns of courtship associated sounds (CAS) during all days of increased CAS activity during the three spawning seasons of Mycteroperca bonaci at Mona Island. CAS are calculated per hour block and summed for all periods of increased activity and years from 2012 to 2014. Hours are in local time. Percentages are percent of all calls for specific hour block. Sunset was between 5:45PM and 6:45PM during entire period.