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Potential Grey Reef Shark (*Carcharhinus amblyrhynchos*) Nursery on Seamounts Southwest of Guam[1]

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Abstract— The grey reef shark, *Carcharhinus amblyrhynchos*, is a coastal-pelagic schooling shark often associated with deeper areas near coral reefs, atoll passes and lagoons with strong tidal flow. Currently listed as "near threatened" by the UCIN, grey reef sharks, as with many other shark species, are considered to be in rapid decline. Here I report observations of high-density aggregations of young grey reef sharks at a small and relatively shallow continental seamount South-West of the Marianas island of Guam. Juvenile grey reef sharks were found to be 9.3 and 5.6 times higher in abundance on the observed sea mount compared to the surrounding seamounts over successive years. Grey reef shark pupping grounds have not previously been reported in the Marianas archipelago potentially identifying this locality as a rare suitable habitat for grey sharks to reproduce. A discussion of the physical characteristics of the sea-mount and a comparison between these observations and the established criteria for shark nurseries is presented.

Introduction

The grey reef shark, *Carcharhinus amblyrhynchos* (Bleeker, 1856), is a nearshore reef-associated shark species that is widely distributed throughout the Indo-West Pacific and Central Pacific Ocean (Compagno 2002, Heupel et al. 2010). Listed by the IUCN as "near threatened" due to overfishing and reef degradation, recent population estimates suggest that grey reef shark numbers are rapidly declining and believed to be lower than 14% of 1970s levels (Pauly, Christensen et al. 1998, Jackson, Kirby et al. 2001, Myers & Worm 2003, 2005, Graham Nicholas et al. 2010, Dulvy, Fowler et al. 2014). While *C. amblyrhynchos* utilize seamounts (Barnett et al. 2012), little is known about the early life stages of grey reef sharks or their use of "shark nurseries" or seamounts as a potential rearing habitat. Three criteria have been suggested to describe shark nurseries. Specifically, juvenile animals must be more abundant in a defined location than in adjacent areas and must utilize or return to the specific habitat for extended periods. Lastly, the habitat must be used consistently over successive years (Heupel et al. 2007).

Documented here are several encounters with particularly high-density schools of young grey reef sharks favoring a relatively small and shallow seamount locally named "Baby Banks", which lays South-West of the Marianas island of Guam. How the observations presented here align with the established criteria for shark nurseries, a physical description of the locality and the implications for fisheries conservation in the Marianas Islands are discussed.

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Materials and Methods

On 09 March 2018 and again on 03 and 17 March 2019, observations were made via snorkeling and freediving to observe and count sharks in three relatively shallow seamounts, which are a part of a series of seamounts locally termed "The Southern Banks" approximately 22-47 km Southwest of Guam (Fig 1). The observation sites comprised of a series of seamounts in the Southern Marianas archipelago that rise from depths of over 2000 m to the subsurface of depths of 25 m, 36 m and 7 m for Galvez bank, Baby bank and Santa-Rosa reef respectively. The intermediate is location known locally as "Baby Banks" is technically part of the southern region of Galvez Bank, but is separated by a 4.6 km wide, 625 m deep-water channel.

The abundance of juvenile grey reef sharks (*Carcharhinus amblyrhynchos*) at each of three banks was compared to document the proportionally high abundance of juveniles observed at "Baby Banks". Animal counts, size and aspects of shark behavior were documented by visual counts and with digital video by freediving observers. The size of juvenile sharks was estimated when specimens approached a floating measurement device of known size, which was then used to calibrate the still images taken from the video using ImageJ software. Visual counts of sharks at each location were made over an approximately 1-5-min encounter during the "curious" (Compagno 2002) phase of the initial contact. Due to the depth of water, visual clarity and aggregation behavior of the sharks around the floating measurement device, the entire school of sharks were recorded on 10-20 second video clips which were later analyzed. To reduce the probability of recounts of individual animals, still frames from the videos were taken two seconds apart during sections of the video that captured all or most of the school of sharks. The videos were then viewed in slow motion until each of the animals in the successive still frames could be accounted for (see online content with article here: http://micronesica.org/volumes/2019).

Transects were conducted during a flooding tide by free-divers while floating along with the current on the most North and Eastern aspects of each of the banks (transect bars Fig 1). Approximately a 1.2-knot current was moving in an East to West direction with the exception of North Santa Rosa bank which the prevailing current was traveling in a NE to SW direction during the transect. At the beginning of the transects on each of the three banks, free-divers entered the water in depths of approximately 3-400 m and floated with the current into shallower water over the banks. Therefore, the transect was conducted from deep water into shallower water and began when divers could see the bottom in approximately 40m depth. These observations were conducted in approximately equal transects of 2200 meters in length over a depth of 40 to 7 m deep. While free-divers were making observations, they were live-boated and the transect path, current velocity, and depth were recorded by the boat GPS and depth sounder. Water depth (m) was recorded using Garmin Echomap 54dv echo sounder. Reported depths were confirmed from NOAA Office of Coast Survey using the WGS84 chart datum and the surface area above 40 m depth in m^2 was measured using ImageJ software from the NOAA nautical charts. To calculate juvenile shark density on each of the banks, the 40-meter isobath was chosen to determine surface area. This was because no juvenile sharks were observed swimming high in the water column within the visual range of the free-divers in water deeper than 40 m. This depth was also the approximate bounding depth of visibility for the free-divers and the topography of the banks is such that the depth drops off precipitously below approximately 40 m.

Results and Discussion

On 09 March 2018, Juvenile *C. amblyrhynchos* sharks were 9.3 and 5.6 times higher in abundance on Baby Banks (28 animals) than on the two surrounding banks, Galvez (3 animals) and Santa Rosa (5 animals) respectively. On 03 and 17 March 2019, juvenile *C. amblyrhynchos* sharks were again observed in higher abundance on Baby banks (16 and 14 animals on 03 and 17 March respectively) compared to 4 and 6 animals on Galvez and 4 and 3 animals on Santa Rosa Banks respectively for each of the observation dates. The 2019 observations were from similar transects to that observed on the three banks in 2018 (Fig 1). These sightings were of aggregations of animals during peak daylight hours, which has been previously reported for *C. amblyrhynchos* (Taylor 1993). During these encounters, the animals stayed within sight of the divers for between 1-5-minutes during the approximately 60-minute transects. In all observations except one, the shark aggregations occurred close to the North or East aspect of the bank when the free-divers floated into water less than 40 m deep where the sharks would disperse after a short time. The observation made on Baby Bank on 09 March 2018, the sharks remained with the divers until the depth profile began to drop off as the divers were carried into deep water with the current, an approximate encounter time of 40 min.

During the 09 March 2018 Baby Banks encounter, two specimens of *C. amblyrhynchos* from the aggregation approached particularly close to the divers, and their size was measured using calibrated still images. They were approximately 87 cm and 85 cm in total length. This suggests that these animals are young-of-the-year and likely birthed in close proximity to the site of aggregation (Robbins 2006, Smart et al. 2016, Bradley et al. 2017). From video and free-divers observations, the aggregation of 28 animals was composed of similar sized sharks with the exception of one animal, which was approximately twice the size of the rest of the cohort. Further, a direct personal observation on one animal of a partially closed, but still evident umbilical scar indicated this animal had developed beyond the neonate stage but was still considered young-of-the-year (Kinney & Simpfendorfer 2009, Oh et al. 2017). During the same sampling day 09 March 18, one shark was measured from the school of 5 animals on Santa Rosa bank and found to be approximately 75 cm.

At Baby Banks on 03 March 2019, two of the 16 juvenile sharks observed were measured using calibrated images. They were approximately 72 cm and 71 cm in length. Two weeks later at Baby Banks, an animal 69 cm in length was measured from the observed school of 14 juvenile sharks. While particular growth rates vary between populations, these observed sizes correlate with either young-of-the-year or juvenile animals from other populations in the Pacific (Robbins 2006, Bradley et al. 2017). As seen in the previous year on Baby Banks, individuals in the schools were of similar size, indicating these again were likely the young-of-the-year in this location (Kinney & Simpfendorfer 2009, Oh et al. 2017).

Heupel and others (Heupel et al. 2007) suggest three criteria are required to demonstrate a shark nursery: (1) juveniles must occur in greater abundance than in other areas, (2) sharks must stay or return for extended periods, and (3) the habitat is used repeatedly across years. The observations presented here of the behavior of juvenile grey reef sharks utilizing the habitat at Baby Banks conform to these three criteria. First, observations suggest that juvenile grey reef shark abundances on Baby Banks were between 9.3 and 2.8 times higher than adjacent habitats during three separate observations. Second, juvenile animals were observed in the same location for at least two weeks in duration. The successive observations from March 3 and 17 2019 indicate that juvenile sharks are utilizing the Baby Banks habitat for an extended period which satisfies the Heupel's 2nd criterion.

Third, juvenile grey reef sharks have been observed to use Baby Banks in higher abundance on successive years as demonstrated by repeated observations at the same locations in March 2018 and 2019.

While this evidence supports the idea that Baby Banks is a grey reef shark pupping grounds which likely corresponds to the ideal biotic and abiotic factors for *C. amblyrhynchos* rearing areas, alternatives to these conclusions might also be supported. First, Baby Banks smaller surface area may simply present a habitat that concentrates juvenile sharks into a smaller space and presents unique qualities such as increased prey availability, fisheries predation/scavenging or reduced predation risk. Baby Banks along with the other locations are known to be utilized as recreational bottom fishing locations and shark predation and scavenging of fisheries catch has been reported (Guam DAWR personal communication). However, reported fishing pressure at each of the three banks does not correlate with surface area or juvenile shark abundance. Fisheries pressure at each bank has been recorded 346, 31 and 75 times between 1982-2018 for Galvez, Baby and Santa Rosa Banks respectively. This reported fishing pressure does not support the idea that juvenile shark aggregations are due to juvenile grey sharks aggregating at Baby Banks due to bottom sport fisheries predation or scavenging (DAWR unreported data). Second, in all observations, the sharks directly approached the divers. At remote and pristine locations, sharks often approach divers (Bradley 2017). Because of this behaviour, I may have overestimated juvenile shark abundance and therefore density on this small bank. Both sharks being attracted to divers and the effect of this behaviour in accurately estimating both abundance and density has been called into question (Bradley 2017), however, estimates from trained divers have reported reliable measures (Ward-Paige et al. 2010). The small size of Baby Bank is such that a large proportion of the bank was surveyed during each transect. For example, two of the three transects passed entirely over the bank. It's possible that all of the juvenile sharks on baby banks were aggregating to the divers which would then give an accurate estimate of abundance and density on this bank.

Third, we may have unintentionally observed a "hotspot" for grey reef shark daily aggregations, which may be only temporary. Further, we were not able to observe if any juvenile animals remained deeper than 40 m outside of the shallower regions of the banks. While possible, this alternative is less likely given the three separate observations in the same location over a two-year time period.

Fourth, it's possible that we observed a different cohort of sharks at Baby Banks on 3 March 2019 (16 animals) than we did two weeks later on 17 March 2019 (14 animals). However, it is also possible that these were the same individuals and that this would indicated some degree of site fidelity to this habitat. If we observed different schools of animals, it may be erroneous to describe that Baby Banks is a shark nursery rather than a well-used "aggregation hotspot". The non-invasive methods used here cannot identify individuals, so tagging experiments would be needed to confirm residency times and site fidelity of individuals utilizing this specific location.

These observations conform to descriptions of how sharks utilize other described nurseries in that for most shark species, only neonates and young juveniles generally occupy the nursery area, while larger and more mature juveniles move away from these locations (Kinney & Simpfendorfer 2009). As described, the Baby Banks observations only contained juvenile sharks within the schools (with one exception). While larger grey sharks were observed, they were sighted in deep water on the fore-reef and up-current of the shallower banks.

While *C. amblyrhynchos* parturition in the Northern Hemisphere is thought to take place from March to July, the growth curves suggested by Bradley et al. (2017) indicate these animals are likely at the young-of-the-year stage suggesting parturition must have preceded or is ongoing during March at this location in 2018 and 2019.

Despite well-documented growth and reproduction biology of *C. amblyrhynchos*, little understanding exists of the distribution and or physical description of what constitutes optimal nursery conditions for grey reef sharks. The physical characteristics of Baby Banks resembled Galvez and Santa Rosa banks in both water current velocity (1-1.3kts), water temperature (28.3-29.1 ^{o}C), and bottom surface topography being composed of a rocky substrate with sparse coral cover and intermittent sandy patches. Baby Banks differed from the other banks in that it is both the deepest and has the smallest surface area of the banks examined. Specifically, Baby Banks has the shallowest

depth below chart datum of 36.0 m with a surface area of approximately 8720 m^2 above the 40 m depth contour (Fig 1). Galvez banks have a shallower depth of 27 m with the largest total surface area of 24594 m^2, while Santa Rosa Reef being the shallowest of the three sites with a depth of just 7 m below chart datum and an intermediate surface area of 21971 m^2 above the 40 m contour. One limiting factor for shark populations, other than prey and predator abundance, is the number of rearing areas with adequate habitat (Springer 1967, Jackson et al. 2001). Knowing the location, biotic and abiotic factors of the rearing areas is imperative to ensure adequate protection for these species and to evaluate possible human impacts in these areas (Myers & Worm 2003, 2005, Skomal 2007, Dulvy et al. 2014, Oh et al. 2017). The protection of sharks at essential fish habitat including seamounts should be an integral component of conservation plans (Pauly et al. 1998, Myers & Worm 2003, 2005, Heupel et al. 2007, Skomal 2007, Kinney & Simpfendorfer 2009, Chapman et al. 2015, Oh et al. 2017). While sharks are protected in the Northern Marians Islands where the fin trade is limited by legislation, the banks historically and currently are legally exploited for local recreational and market fishing (Allen & Bartram 2008) and most intentional food fishery or bycatch of sharks goes largely unreported.

The Southern Banks are isolated from the nearest reef of equal depth in all directions for over 220 Km except to the North, which lays the Island of Guam and the Northern Mariana Islands. Given that Guam is the human population center of Micronesia, yet has the second lowest fish biomass of 23 Pacific Island Nations due to heavy fisheries exploitation (Houk et al. 2018), Baby Banks may be a rare suitable habitat in the region for grey sharks to reproduce. Managing both juvenile and adult sharks with expansive ranges has typically focused on strategies that attempt to provide protection for younger age classes, particularly neonates and young juveniles (Kinney & Simpfendorfer 2009, Chapman et al. 2015, Oh et al. 2017). Therefore, knowledge on the spatial ecology of sharks at critical habitats such as seamounts is essential for the implementation of management and conservation plans (Heupel et al. 2010, Barnett et al. 2012, Chapman et al. 2015, Osgood 2015).

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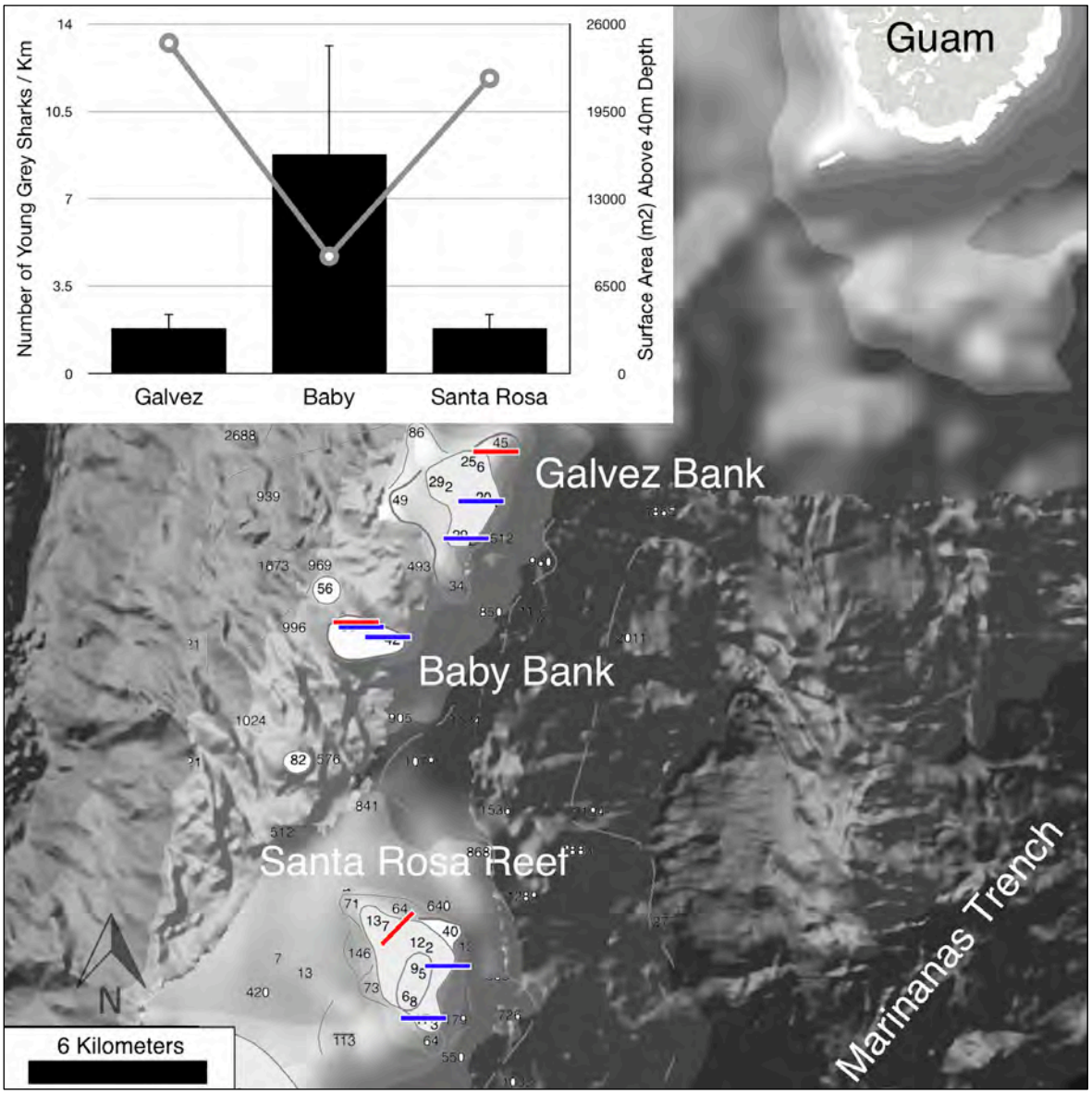

Figure 1. Location of Marianas sea mounts examined from most Northerly to Southerly respectively: Galvez Bank, Baby Bank, and Santa Rosa Reef in relation to Guam. Depths indicated are in meters. Red bars indicate locations of transects conducted in March 2018, blue bars, March 2019. Inset: Relative abundance of sighted *C. amblyrhynchos* per kilometer of transect for each bank (bars) and approximate surface area of each bank above the 40-meter depth contour (line). Depths using WGS84 chart datum from the NOAA nautical charts.

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