Ocean and Coastal Research

ORIGINAL ARTICLE

http://doi.org/10.1590/2675-2824071.22089altc
ISSN 2675-2824

New data on abundance of lemon shark *Negaprion brevirostris* (Poey, 1868) at Lama Bay, Rocas Atoll, Brazil

Ana Laura Tribst Corrêa[1], Dráusio Pinheiro Véras[2], June Ferraz Dias[3]

[1] Centro de Biologia Marinha da Universidade de São Paulo. Rodovia Doutor Manoel Hipólito do Rego, km 131.5, 11612-109 São Sebastião, SP, Brazil.
[2] Universidade Federal Rural de Pernambuco, Unidade Acadêmica de Serra Talhada, Avenida Gregório Ferraz Nogueira, 56909535, Serra Talhada, PE, Brazil.
[3] Laboratório de Ecologia da Reprodução e do Recrutamento de Organismos Marinhos, Departamento de Oceanografia Biológica, Instituto Oceanográfico, Universidade de São Paulo, Praça do Oceanográfico, 191, Cidade Universitária, 05508120, São Paulo, SP, Brazil

* Corresponding author: ana.laura.correa@alumni.usp.br

Abstract

The abundance and movement patterns of lemon sharks (*Negaprion brevirostris*) at Lama Bay, Biological Reserve Rocas Atoll, were reassessed by visual census. We considered tides and daylight periods to plan our observations during two expeditions in 2015. Using daily visual counts, the mean abundance of individuals was 29 in austral summer (maximum 35) and 31 in winter (maximum 41). The results indicated that the local lemon shark population might have recovered after 18 years of a substantial drop in mean abundance. In addition, the movement pattern of the species corroborated previous studies related to their fidelity to the birthplace. These results justify the need of continuous monitoring of lemon sharks over the course of time at Rocas Atoll using non-lethal and non-invasive techniques.

Keywords: Conservation, Population ecology, Marine protected area, Visual census, Endangered.

INTRODUCTION

Anthropogenic actions such as overfishing, by-catch mortality, pollution, habitat destruction, and climate change are threats to marine ecosystems (Dulvy et al., 2008, 2021; Simpfendorfer et al., 2011). As a direct consequence, fish populations from deep sea, coral reefs, and coastal regions are declining (Jones et al., 2004; Baker et al., 2009, Dulvy et al., 2021). However, it is unknown whether decreases occur in isolated populations or if they might cause widespread extinction across all populations of a species (Dulvy et al., 2014).

As an important component of the ecosystem, sharks influence the structure and the functionality of marine communities (Camhi et al., 2008). Major populations of oceanic predators, such as large sharks, are impacted by anthropogenic threats due to their low fecundity, low growth rates, late sexual maturation, and reproductive aggregations (Baum et al., 2003; Hammerschlag and Sulikowski, 2011; Worm et al., 2013; Barreto et al., 2017). Furthermore, there are limitations and challenges in data availability to investigate population decays, extinction threats, and potential consequences for marine ecosystems (Worm et al., 2013; Ward-Paige and

Submitted: 05/07/2022
Approved: 07/05/2023

Associate Editor: Francesc Maynou

Worm, 2017). Thus, the investigation of threats and the development of tools for shark population research are essential (Dulvy et al., 2017).

The lemon shark, *Negaprion brevirostris* (Poey, 1868), inhabits tropical waters on continental shelves and oceanic islands in Western Atlantic, Eastern Atlantic, and Eastern Pacific Oceans (Compagno, 1984; Ebert et al., 2013). Juvenile individuals have philopatric behavior to their birthplace and they commonly use it as nursery and growth areas (Morrissey and Gruber, 1993; Freitas et al., 2006; Garla et al., 2009). Even though adult individuals have a pelagic phase, which hinders studies (White et al., 2014), some adult female lemon sharks also have natal philopatry, which means they return to give birth at the same location where they were born (Feldheim et al., 2014; Brooks et al., 2016; Smukall et al., 2019). Therefore, the conservation of this important species is possible with the protection of its key habitats (Tavares et al., 2016).

According to the IUCN (2021), *N. brevirostris* is classified as a vulnerable species worldwide. In Brazil, however, this species is classified as endangered (Ministério do Meio Ambiente, 2022). The country ranks as the first importer and 11th producer of shark meat in the world (Barreto et al., 2017), assuming an important role in the global shark trade (Rangel et al., 2021), which may justify the endangered classification.

Lemon sharks are found in the Marine Protected Area (MPA) of Rocas Atoll (Oliveira et al., 2011), the unique atoll in South Atlantic and a Ramsar site since 11th December of 2015 (http://www.ramsar.org). This MPA is a no-take marine reserve established on July 5th of 1979. Despite being an area of integral conservation of biodiversity, scientific and educational activities are allowed under permission of the ICMBio (Instituto Chico Mendes de Biodiversidade) (Granville et al., 2012).

Marine protected areas are important for helping shark species worldwide (Knip et al., 2012; Goetze and Fullwood, 2013; Speed et al., 2016). Freitas et al. (2009) reported a clear decline in lemon shark abundance at Rocas Atoll, but the knowledge about the current status of this species is limited. In this context, this study aims to estimate lemon shark abundance, particularly at the nursery/growth area of Lama Bay, in different seasons and tides using a non-invasive method. This approach provides new data on abundance of newborn and juvenile lemon shark local populations and a comparison with previous data. Finally, seasonal differences in movement patterns of this species were identified at Lama Bay.

METHODS

Rocas Atoll (3°52'S; 33°48'W) (Figure 1) is located at 269.5 km east from Natal city, Northeast coast of Brazil (Granville et al., 2012), in the South Atlantic Ocean. It is located in the mid-Atlantic ridge and rises 4,000 m from the ocean floor (Kikuchi and Leão, 1997). This atoll presents two sand islands, Farol Island (FI) and Cemitério Island (CI), which are influenced by marine and terrestrial biota, waves, currents, and winds (Soares et al., 2011). Farol Island, where Lama Bay lies, spans approximately 700 m in length and 300 m in width (Pereira et al., 2010). This bay is an elongated tidal creek, exhibits low hydrodynamics, and is influenced by the tidal regime, which makes it covered by water only during high tide (Pereira et al., 2010).

Two field trips to Rocas Atoll were conducted in 2015, 23 days in austral summer (January/February) and 22 days in austral winter (June/July). Data were obtained using visual census from a natural elevated point in Farol Island, between Lama Bay and Barretinha (Figure 1). Lama bay was divided in three zones: entrance (E), middle (M), and inner bay (I). Each zone measured 30×30 m and prominent landmarks were used for orientation.

The tidal table from Fernando de Noronha Santo Antonio Bay (PE) (DHN, 2015) was used to plan observations. Thus, the time of data collection occurred at the third hour before and at the third hour after high tide. Considering the two types of tidal currents (flood and ebb) and the three zones (E, M, and I), six visual counts were conducted per day. During some days it was not possible to perform all six observations due to tidal time and variation in sunlight period.

The parameters recorded by visual census were abundance, by individual counting, and life cycle stage, by visual evaluation of individual total length (TL). To avoid double counting, the abundance was determined as the maximum number of individuals in each zone at the same time. TL was considered as a measure from the tip of the snout to the end of the upper lobe of caudal fin. TL measurements obtained by visual census are not usually considered accurate but were suitable for this study. According to their length, lemon sharks were divided in four life cycle stages: newborn (less than 65 cm), juvenile (between 65 and 150 cm), sub-adults (between 150 and 220 cm), and adults (more than 220 cm) (Agra, 2009).

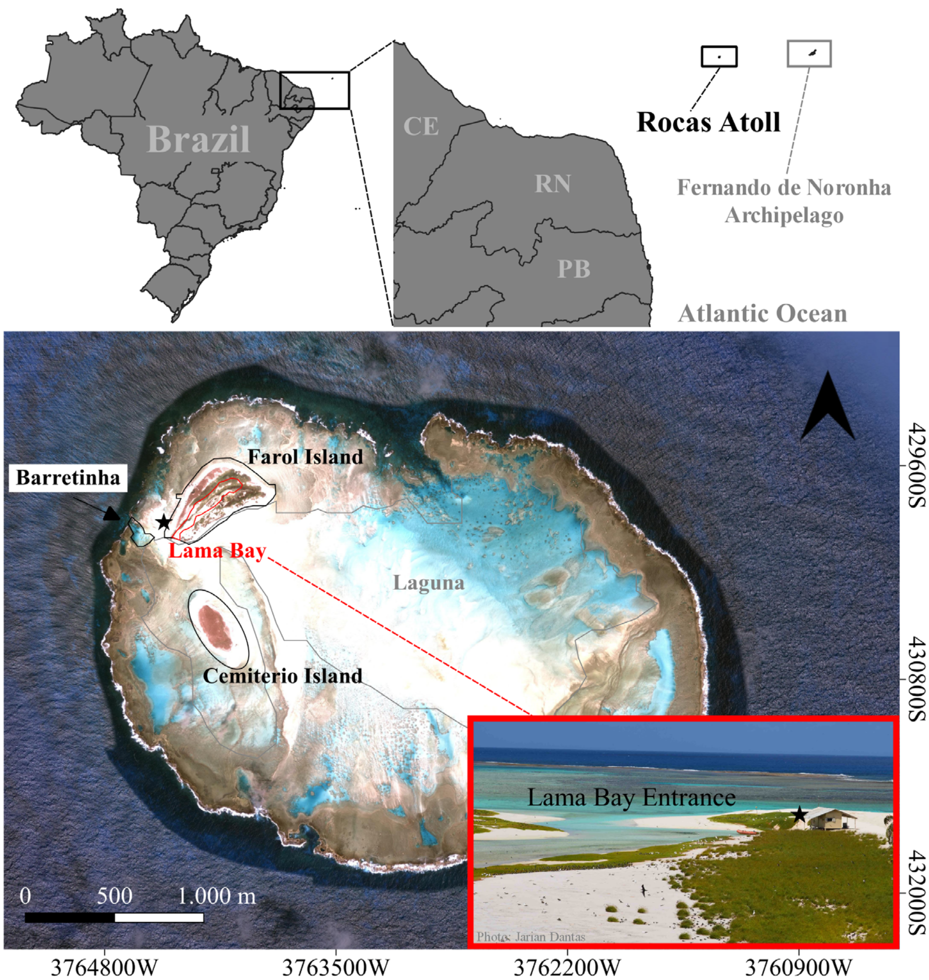

Figure 1. Rocas Atoll. In the map: Lama Bay (red), Barretinha, Farol Island, Cemitério Island and Laguna. Black star = land point. Detail of the Lama Bay entrance. QGIS, 2023.

Statistical analyses were performed with Past version 4.03 (Hammer et al., 2001). Chi-square test (χ^2) was used to verify the difference between the number of observations between flood and ebb tidal currents in the same day, assuming 1:1. The mean number of individuals obtained by each season was tested by analysis of variance using a non-parametric test (Kruskal-Wallis, considering statistically significant differences for $p < 0.05$). Shark abundance (total, newborn, and juveniles) was compared by season (austral summer or austral winter), tidal current (flood or ebb), and tide (spring or neap).

RESULTS

A total of 2,306 sightings were recorded in 2015, with 1,168 during austral summer and 1,138 during austral winter. Tidal current and abundance (± standard deviation) of lemon sharks per day rejected the hypothesis of different number of sightings according to tide since only two days exhibited significant differences between the number of individuals sighted at flood and ebb currents (d.f. = 1, $\chi 2$ =3.841, p=0.95).

During the austral summer trip, a total of 40 visual censuses were conducted, with 21 at flood current and 19 at ebb current, amounting to 240 visual counts. Mean abundance of lemon sharks was 29.20 (± 5.04) per day, ranging from a minimum of 12 to a maximum of 35 specimens, and variance of 25.39. On the other hand, 37 visual censuses were conducted during the austral winter trip, 19 at flood current and 18 at ebb current, amounting to 222 visual counts. Mean abundance of lemon sharks was 30.76 (±6.04) per day ranging from a minimum of 16 to a maximum of 41, and variance of 36.52 (Figure 2).

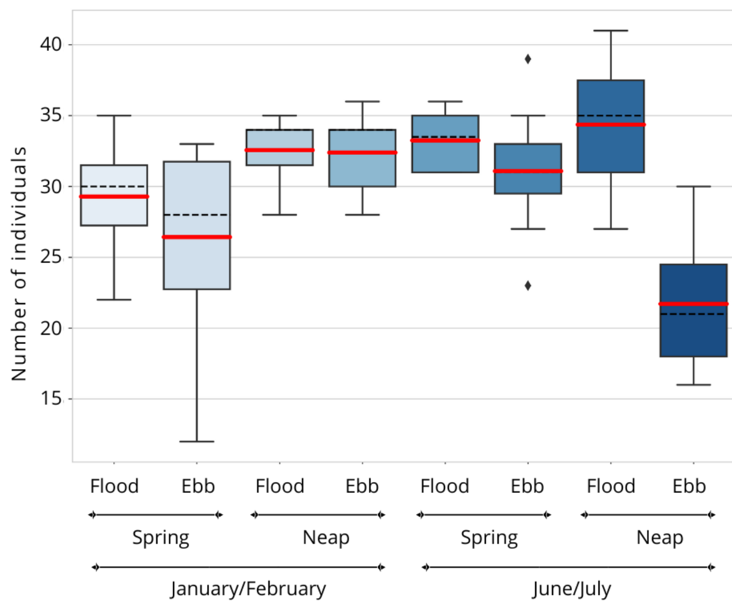

Figure 2. Median of the number of N. brevirostris across tides, the interquartile range, range and maximum and minimum values, from both field trip, at Lama Bay, Rocas Atoll. Austral summer field trip (January/February 2015): flood and ebb currents at spring tide; and flood and ebb currents at neap tide. Austral winter field trip (June/July 2015): flood and ebb currents at spring tide and flood and ebb currents at neap tide. Mean number of individuals presented in red.

Kruskal-Wallis test was used to compare the mean between two seasons, showing that there were no significant differences between the mean values of total shark abundance between the two field trips (p=0.1564). Nevertheless, there were significant differences in abundance of newborns (p=1.11 x 10^{-15}) and juveniles (p=3.12 x 10^{-14}) between the seasons.

The analysis of variance regarding shark abundance considered the sum of data from two field trips. There were significant differences in the mean total abundance of individuals between flood and ebb currents (p=0.002716). However, there were no significant differences in mean abundance of newborns (p=0.5733) and juveniles (p=0.236) between flood and ebb currents. Additionally, there were no significant differences in abundance of newborns (p=0.6937) and juveniles (p=0.05372), and no significant differences in total abundance (p=0.2141) between spring and neap tides.

Lemon shark abundance in different tides showed the highest average in neap tide in both austral summer and winter (Table 1). Maximum number of individuals per day was in neap tide in both seasons. There were significant differences among data from observations in spring and neap tide in the first field trip (p=0.01172), but not in the second field trip (p=0.3686).

Table 1. Mean lemon shark abundance (± standard deviation; maximum), in flood and ebb currents of spring and neap tides in both austral summer (January/February 2015) and winter (June/July 2015) field trip at Rocas Atoll. Bold numbers showed the highest average of each field trip.

Tide	Spring		Neap	
Tidal currents	Flood	Ebb	Flood	Ebb
Austral summer	29.28 (± 3.15; 35)	26.43 (± 6.52; 33)	**32.57** (± 2.57; 35)	32.40 (± 3.28; 36)
Austral winter	33.25 (± 2.05; 36)	31.09 (± 4.18; 39)	**34.36** (± 4.43; 41)	21.71 (± 4.96; 30)

Mean lemon shark abundance was higher at flood of spring and neap tides compared to ebb current in both field trips. At flood current, low standard deviation values showed that the number of individuals sighted was numerically close to average. However, the standard deviation values of ebb current were higher, which means that the number of sharks sighted fluctuated throughout the day (Table 1).

The behavior of lemon sharks was similar concerning both tide and season. Newborn and juvenile lemon sharks enter and leave the bay following flood and ebb currents, respectively. It was observed that some sharks leave the bay before all water has flowed out taking three different ways: to Laguna (Southeast), to Barretinha (Southwest of Lama Bay), or around Cemitério Island (South). However, some sharks stayed in the mouth of Lama Bay, often in neap, when tide amplitude was lower.

Concerning life cycle stages, lemon shark sightings during the two field trips were quite different: newborns and juveniles were observed in the first field trip (Figure 3), whereas only juveniles were sighted in the second field trip (Figure 4), some reaching 1 m TL. Moreover, two sub-adults (180 cm) were observed out of the bay on different days during summer expedition, but they were not considered for overall analysis.

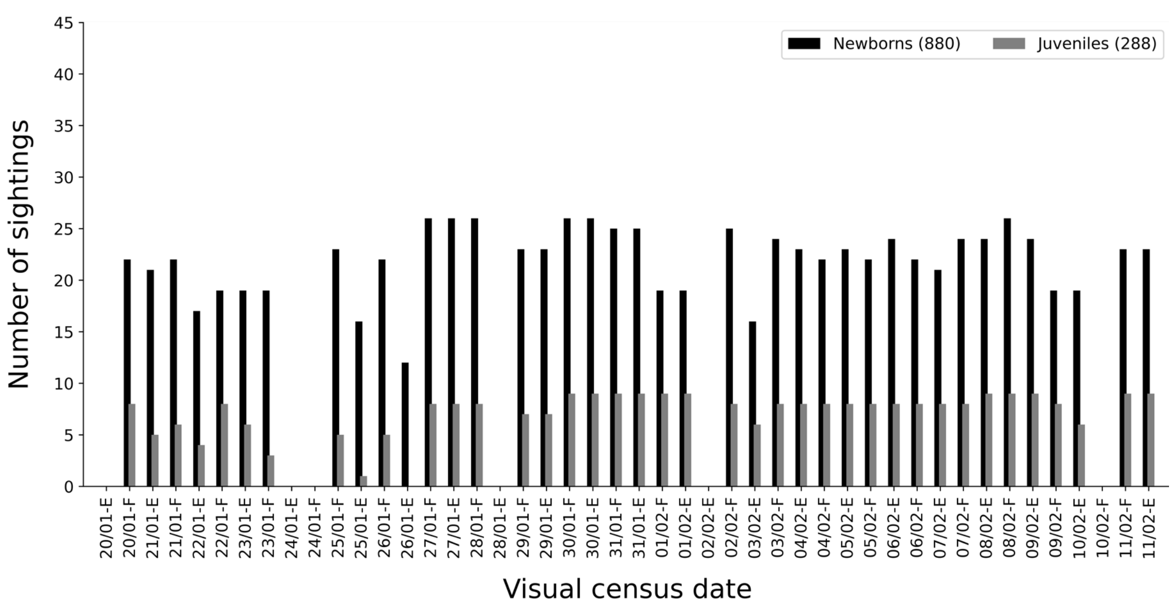

Figure 3. Number of sightings of lemon sharks (*N. brevirostris*) per life cycle stage (newborn and juveniles) sighted on the austral summer (January/February 2015) at Lama Bay, Rocas Atoll (F = flood; E = ebb).

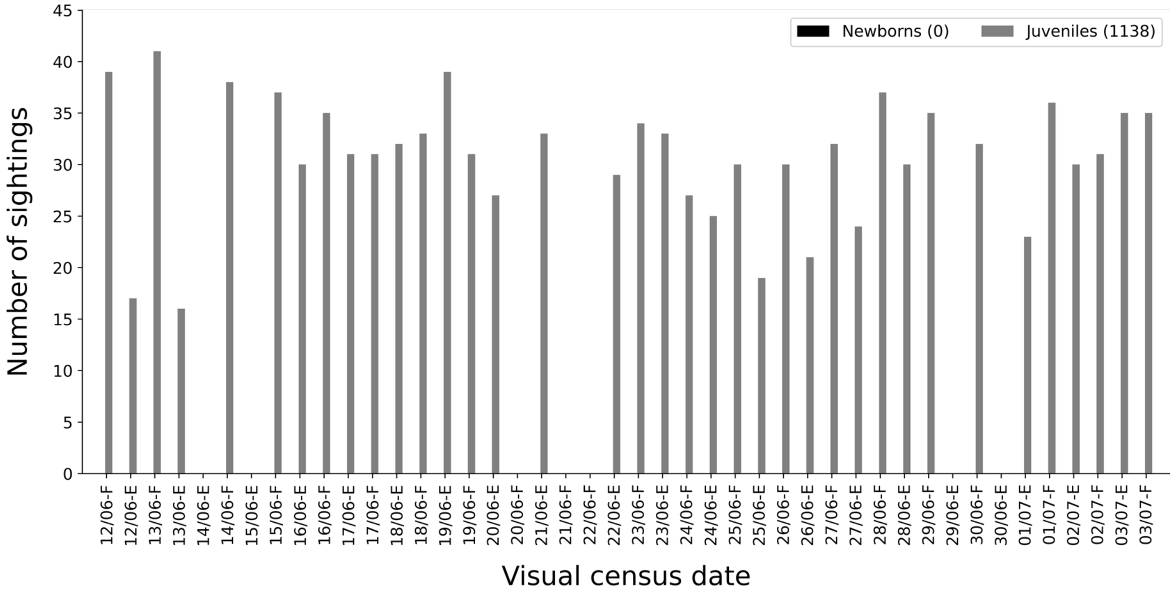

Figure 4. Number of sightings of lemon sharks (*N. brevirostris*) per life cycle stage (newborn and juveniles) sighted on the austral winter (June/July 2015) at Lama Bay, Rocas Atoll (F = flood; E = ebb).

DISCUSSION

Non-invasive methods of observation from land points and underwater images are important tools for conservation of biodiversity. These methods are being adopted to investigate the ecology and behavior of elasmobranchs as a cheap and simple technique (Castro and Rosa, 2005; Agra, 2009; Rada, 2010). Thus, this study's proposed technique, based on visual census from emerged fixed points, reinforces that non-invasive methods can be effective alternatives and can be applied for continuous monitoring with a group of trained people.

From captures with gillnets and longlines to tag individuals with rototags (a plastic mark for tag-recapture studies) and transmitters, several studies have reported declines on lemon shark abundance at Rocas Atoll (Freitas et al., 2006, 2009; Wetherbee et al., 2007). Additionally, Freitas et al. (2009) observed juvenile lemon sharks in Lama Bay for six years (from 1998 to 2003) in seven expeditions of 20 days each. Using visual census, they reported a decrease in mean numbers of individuals from 64 in March 1998 to 58 in March 1999; from 41 in March 2000 to 11 in August 2002; and stable values of 15, 15, and 14 individuals in March, May, and October 2003, respectively. Similarly, a fluctuation in numbers of juvenile lemon shark populations through years was reported in Bimini nursery (White et al., 2014).

Our observations resulted in a mean number of 29 individuals per day (maximum 35) in January/February and 30 (maximum 41) in June/July, approximately twice the number of sharks observed since 2003. Considering the information added by this study and the previous data, we could verify a great variation in the number of lemon sharks, with a higher decline from 1998 to 2003, and an increase reported in 2015 from 14 to 29-30 individuals. Although the methods adopted in both studies were not the same and despite a temporal lag of registered data, there was a consistent increase in the average number of individuals observed in this period.

Freitas et al. (2009) attributed different causes that may explain the decrease in the number of juvenile lemon sharks sighted at Lama Bay: high mortality due to previous tag research; natural fluctuation in number of reproductive females and, consequently, a low birth rate; and, finally, even though Rocas Atoll is a Biological Reserve, illegal fishery activities around the area, could influence the resident fauna.

Since this site is a full protection marine area since 1979, fishing practices have been prohibited for a long time. In addition, shark finning has been prohibited in Brazil since November 2012 by "Instrução Normativa Interministerial MPA/MMA number 14." However, as Brown and Gruber (1988) and Feldheim et al. (2001) pointed out, adult lemon sharks exhibit a nomadic movement pattern, doing incursions in deep water and, sometimes, migrations. This is the reason why they could be captured off the MPA, reducing females and births due to direct adult catches.

Our results showed an increasing abundance trend that may provide insights concerning the recovery potential of lemon shark populations. Data from a non-exhaustive literature-based study present cases of elasmobranch population increase (Ward-Paige et al., 2012). According to that study, the main causes listed for population recovery were the reduction of fishing mortality by traditional fishery management and incidental by-catch, along with shark finning prohibition. In addition, ecosystem-based strategies, such as the creation of shark sanctuaries and restoration of their natural habitat, nature-based education, and species-specific policies of conservation may have contributed to the positive results (Ward-Paige et al., 2012; Ward-Paige and Worm, 2017).

According to Costa et al. (2016), the tides play an important role in driving the circulation at Rocas Atoll and the waves drive morphological changes on the reef islands. Additionally, the extreme tidal flux results in an exposed shallow area during low tide (Gherardi and Bosence, 1999; Silva et al., 2002). As a consequence, the tidal regime and local depth influence the movement patterns and the behavior of juvenile lemon sharks at Lama Bay (Wetherbee et al., 2007). This area is described as an unusual refuge area for growth and feeding for this species due to absence of mangroves or seagrass habitats (Freitas et al., 2006). According to Agra (2009), there was segregation by size in the lemon shark population at Rocas Atoll: juveniles were more frequent in closed shallow waters far from the ocean connection.

In this study, we corroborate that the behavior of juvenile lemon sharks follows the strong tidal currents. We observed that some sharks left the bay before all water flowed out, taking different ways: to Laguna, Barretinha, and around Cemitério Island. Some sharks stayed in the mouth of Lama Bay, often in neap tide, when the tide amplitude was lower. These movements could explain the differences in the number of lemon shark sightings at flood and ebb currents, the highest average in neap tide comparable with spring, and the maximum number of sharks per day in neap tide in both seasons. During high tide, this current flows in ocean-atoll direction and during low tide it flows in opposite direction, allowing sharks to move in and out of Lama Bay, which is considered a primary and secondary nursery area (Oliveira et al., 2011).

Previous studies of lemon shark at Rocas Atoll reported that their copula and birth probably occurred at the beginning of the year, leading to a gestation period ranging from 10 to 12 months. This finding is based on the co-occurrence of newborn, juvenile, and adult females with bite marks in December, February, and March (Oliveira et al., 2011). The results of our study corroborate the previous results since newborn and juveniles were sighted in the first field trip (January/February), whereas only juveniles were seen in the second trip (June/July), four months later. Parturition of lemon sharks was observed from November to April at Fernando de Noronha Archipelago (Garla et al., 2009), with mating behavior during the austral summer (Clapis-Garla et al., 2022). In Rocas Atoll, Freitas et al. (2006) observed lemon sharks' births from February to May.

Based on data collected in this study associated with the previous information in the area, it is possible to indicate that the birth of the individuals was between December 2014 and February 2015. Furthermore, by visual census, all the newborns from the first field trip (January-February) already had attained their juvenile period in the second field trip (June-July) since the estimated growth rate of this species is 24.7 cm year^{-1} (±3.4) in total length (Freitas et al., 2006).

Our results showed no significant difference in abundance of lemon sharks between summer and winter and it was not observed a pattern associated with spring and neap tides. Therefore, studies on other parameters are necessary to clarify the influence of hydrography in the demography of *N. brevirostris*.

The proxies based on records of population abundance from research surveys must use standardized observations to obtain consistent long-time results. Although movement patterns were directly influenced by tide and depth, other variables may influence biotic interactions. Continuous monitoring studies are fundamental to verify how different parameters could influence movement patterns. Currently, management plans for lemon sharks are inexistent in Brazil. In this context, this study and future research should provide knowledge to develop conservation plans for lemon shark preservation.

CONCLUSION

The estimate of lemon shark abundance at Lama Bay, Rocas Atoll, in 2015 during austral summer and winter suggests a possible population recovery based on the previous reported data. The consistency of observations between two periods in this study reinforces and qualifies the non-invasive method as an alternative tool to understand population dynamics that is independent of fisheries data. Our results reported newborns and juveniles in January/February, but only juveniles in June/July, suggesting birth of lemon sharks during the summer and their growth afterwards, which is compatible with estimated growth rates. No tidal pattern and abundance relationship was identified. As a sharp decline in the abundance of this species was detected in previous publications, new studies are needed to understand the causes of its numerical fluctuation.

ACKNOWLEDGMENTS

This study was conducted according to Brazilian legislation, including authorization to assess the Rocas Atoll Biological Reserve and to observe organisms (ICMBio n. 48415-1). Many thanks to Maurizélia de Brito Silva (ICMBio), who allowed the project in the Reserve, to Paulo Guilherme Vasconcelos de Oliveira, Fabio Hissa Vieira Hazin (*in memorian*), Frederico Osório, Jarian Dantas, Gabriela Camargo, and Isis Cabral for the support. We also thank Prof. Michel Mahiques and OCR reviewers for suggestions.

AUTHOR CONTRIBUTIONS

A.L.T.C.: Conceptualization; Investigation; Data collection; Data analysis and interpretation; Writing - original draft, review, and editing.

J.F.D.: Supervision; Conceptualization; Data analysis and interpretation; Critical revision; Writing - review & editing.

D.P.V.: Conceptualization; Data analysis and interpretation; Critical revision; Writing - review & editing.

REFERENCES

Agra, G. 2009. *Organização social de elasmobrânquios na reserva biológica do Atol das Rocas, Brasil* (mathesis). Departamento de Oceanografia, Universidade Federal de Pernambuco, Recife.

Baker, K. D., Devine, J. A. & Haedrich, R. L. 2009. Deep-sea fishes in Canada's Atlantic: population declines and predicted recovery times. *Environmental Biology of Fishes*, *85*(1), 79–88. DOI: https://doi.org/10.1007/s10641-009-9465-8

Barreto, R. R., Bornatowski, H., Motta, F. S., Santander-Neto, J., Vianna, G. M. S. & Lessa, R. 2017. Rethinking use and trade of pelagic sharks from Brazil. *Marine Policy*, *85*, 114–122. DOI: https://doi.org/10.1016/j.marpol.2017.08.016

Baum, J. K., Myers, R. A., Kehler, D. G., Worm, B., Harley, S. J. & Doherty, P. A. 2003. Collapse and Conservation of Shark Populations in the Northwest Atlantic. *Science*, *299*(5605), 389–392. DOI: https://doi.org/10.1126/science.1079777

Brooks, J. L., Guttridge, T. L., Franks, B. R., Grubbs, R. D., Chapman, D. D., Gruber, S. H., Dibattista, J. D. & Feldheim, K. A. 2016. Using genetic inference to re-evaluate the minimum longevity of the lemon shark *Negaprion brevirostris*. *Journal of Fish Biology*, *88*(5), 2067–2074. DOI: https://doi.org/10.1111/jfb.12943

Brown, C. A. & Gruber, S. H. 1988. Age Assessment of the Lemon Shark, Negaprion brevirostris, Using Tetracycline Validated Vertebral Centra. *Copeia*, *1988*(3), 747. DOI: https://doi.org/10.2307/1445397

Camhi, M. D., Pikitch, E. K. & Babcock, E. A. (eds.). 2008. *Sharks of the Open Ocean*. Oxford: Wiley. DOI: https://doi.org/10.1002/9781444302516

Castro, A. L. F. & Rosa, R. S. 2005. Use of natural marks on population estimates of the nurse shark,Ginglymostoma cirratum, at Atol das Rocas Biological Reserve, Brazil. *Environmental Biology of Fishes*, *72*(2), 213–221. DOI: https://doi.org/10.1007/s10641-004-1479-7

Clapis-Garla, R., Veras, L.-B. & Garrone-Neto, D. 2022. Mating behavior of the lemon shark, Negaprion brevirostris (Carcharhiniformes: Carcharhinidae), as revealed by citizen science in the Equatorial Atlantic Ocean. *Revista de Biología Tropical*, *70*(1).

Compagno, L. J. V. 1984. *Sharks of the world. An annotatedand illustrated catalogue of sharksspecies known to date.* (Vol. 4). Rome: FAO.

Costa, M. B., Macedo, E. C., Valle-Levinson, A. & Siegle, E. 2016. Wave and tidal flushing in a near-equatorial mesotidal atoll. *Coral Reefs*, *36*(1), 277–291. DOI: https://doi.org/10.1007/s00338-016-1525-x

Dulvy, N. K., Baum, J. K., Clarke, S., Compagno, L. J. V., Cortés, E., Domingo, A., Fordham, S., Fowler, S., Francis, M. P., Gibson, C., Martínez, J., Musick, J. A., Soldo, A., Stevens, J. D. & Valenti, S. 2008. You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *18*(5), 459–482. DOI: https://doi.org/10.1002/aqc.975

Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., Harrison, L. R., Carlson, J. K., Davidson, L. N., Fordham, S. V., Francis, M. P., Pollock, C. M., Simpfendorfer, C. A., Burgess, G. H., Carpenter, K. E., Compagno, L. J., Ebert, D. A., Gibson, C., Heupel, M. R., Livingstone, S. R., Sanciangco, J. C., Stevens, J. D., Valenti, S. & White, W. T. 2014. Extinction risk and conservation of the world's sharks and rays. *ELife*, *3*. DOI: https://doi.org/10.7554/elife.00590

Dulvy, N. K., Simpfendorfer, C. A., Davidson, L. N. K., Fordham, S. V., Bräutigam, A., Sant, G. & Welch, D. J. 2017. Challenges and Priorities in Shark and Ray Conservation. *Current Biology*, *27*(11), R565–R572. DOI: https://doi.org/10.1016/j.cub.2017.04.038

Ebert, D. A., Fowler, S. L. & Compagno, L. J. 2013. *Sharks of the world: a fully illustrated guide*. Princeton: Wild Nature Press.

Feldheim, K. A., Gruber, S. H. & Ashley, M. V. 2001. Population genetic structure of the lemon shark (Negaprion brevirostris) in the western Atlantic: DNA microsatellite variation. *Molecular Ecology*, *10*(2), 295–303. DOI: https://doi.org/10.1046/j.1365-294x.2001.01182.x

Feldheim, K. A., Gruber, S. H., DiBattista, J. D., Babcock, E. A., Kessel, S. T., Hendry, A. P., Pikitch, E. K., Ashley, M. V. & Chapman, D. D. 2014. Two decades of genetic profiling yields first evidence of natal philopatry and long-term fidelity to parturition sites in sharks. *Molecular Ecology*, *23*(1), 110–117. DOI: https://doi.org/10.1111/mec.12583

Freitas, R. H. A. de, Rosa, R. S., Wetherbee, B. M. & Gruber, S. H. 2009. Population size and survivorship for juvenile lemon sharks (Negaprion brevirostris) on their nursery grounds at a marine protected area in Brazil. *Neotropical Ichthyology*, *7*(2), 205–212. DOI: https://doi.org/10.1590/s1679-62252009000200011

Freitas, R. H. A., Rosa, R. S., Gruber, S. H. & Wetherbee, B. M. 2006. Early growth and juvenile population structure of lemon sharks Negaprion brevirostris in the Atol das Rocas Biological Reserve, off north-east Brazil. *Journal of Fish Biology*, *68*(5), 1319–1332. DOI: https://doi.org/10.1111/j.0022-1112.2006.00999.x

Garla, R. C., Garcia, J., Veras, L. B. & Lopes, N. P. 2009. Fernando de Noronha as an insular nursery area for lemon sharks, Negaprion brevirostris, and nurse sharks, Ginglymostoma cirratum, in the equatorial western Atlantic Ocean. *Marine Biodiversity Records*, *2*. DOI: https://doi.org/10.1017/s1755267209000670

Gherardi, D. F. M. & Bosence, D. W. J. 1999. Modeling of the Ecological Succession of Encrusting Organisms in Recent Coralline-Algal Frameworks from Atol Das Rocas, Brazil. *PALAIOS*, *14*(2), 145. DOI: https://doi.org/10.2307/3515370

Goetze, J. S. & Fullwood, L. A. F. 2013. Fiji's largest marine reserve benefits reef sharks. *Coral Reefs*, *32*(1), 121–125. DOI: https://doi.org/10.1007/s00338-012-0970-4

Granville, M., Matheus, Z. & Grossman, A. 2012. Atol das Rocas 3º51´S 33º48´W. Brasil, Bei Comunicação.

Hammer, P. D., O., Harper, D. A. T. &. Ryan, Harper, D. A. T. & Ryan, P. D. 2001. PAST: Paleontological Statistics Software Package for Education. *Palaeontologia Electronica*, *4*(1).

Hammerschlag, N. & Sulikowski, J. 2011. Killing for conservation: the need for alternatives to lethal sampling of apex predatory sharks. *Endangered Species Research*, *14*(2), 135–140. DOI: https://doi.org/10.3354/esr00354

Jones, G. P., McCormick, M. I., Srinivasan, M. & Eagle, J. V. 2004. Coral decline threatens fish biodiversity in marine reserves. *Proceedings of the National Academy of Sciences*, *101*(21), 8251–8253. DOI: https://doi.org/10.1073/pnas.0401277101

Kikuchi, R. K. P. & Leão, M. A. N. 1997. Rocas (Southwestern Equatorial Atlantic, Brazil): an atoll built primarily by coralline algae. *In*: *Proceedings of the 8th International Coral Reef Symposium* (Vol. 1, pp. 731–736). Balboa.

Knip, D. M., Heupel, M. R. & Simpfendorfer, C. A. 2012. To roam or to home: site fidelity in a tropical coastal shark. *Marine Biology*, *159*(8), 1647–1657. DOI: https://doi.org/10.1007/s00227-012-1950-5

Ministério do Meio Ambiente. Portaria MMA n. 148, de 7 de junho de 2022 (2022).

Morrissey, J. F. & Gruber, S. H. 1993. Habitat selection by juvenile lemon sharks,Negaprion brevirostris. *Environmental Biology of Fishes*, *38*(4), 311–319. DOI: https://doi.org/10.1007/bf00007524

Oliveira, P. G. V. ., Hazin, F. H. V., Carvalho, F. C., Veras, D. P., Silva, M. B., Oliveira, D. S. & Pinheiro, P. B. 2011. Population Structure and Growth of Young Lemon Shark, Negaprion brevirostris(Poey, 1868), at the Atol das Rocas Biological Reserve, Brazil. *Journal of Integrated Coastal Zone Management*, *11*(4), 389–395.

Pereira, N. S., Manso, V. A. V., Silva, A. M. C. & Silva, M. B. 2010. Geomorphological Mapping and Morphodynamic of Rocas atoll, South Atlantic. *Journal of Integrated Coastal Zone Management*, *10*(3), 331–345. DOI: https://doi.org/10.5894/rgci209

Rada, D. de P. 2010. *Interações sociais, uso do habitat e estruturapopulacional do tubarão-limão , Negaprion brevirostris (Poey, 1868), no Arquipélago de Fernando de Noronha (PE)* (mathesis). Departamento de Zoologia, Universidade Federal da Paraíba, João Pessoa. Retrieved from https://repositorio.ufpb.br/jspui/bitstream/tede/8220/2/arquivo total.pdf

Rangel, B. S., Barreto, R., Gil, N., Mar, A. D. & Castro, C. 2021. Brazil can protect sharks worldwide. *Science*, *373*(6555), 633–633. DOI: https://doi.org/10.1126/science.abj9634

Silva, M. B., Campos, C. E. C. & Targino, S. G. 2002. Atol das Rocas: primeira unidade de conservação marinha do Brasil e único atol do Atlântico sul. *Gerenciamento Costeiro Integrado*, *2*, 27–28.

Simpfendorfer, C. A., Heupel, M. R., White, W. T. & Dulvy, N. K. 2011. The importance of research and public opinion to conservation management of sharks and rays: a synthesis. *Marine and Freshwater Research*, *62*(6), 518–527. DOI: https://doi.org/10.1071/mf11086

Smukall, M. J., Kessel, S. T., Franks, B. R., Feldheim, K. A., Guttridge, T. L. & Gruber, S. H. 2019. No apparent negative tagging effects after 13 years at liberty for lemon shark, *Negaprion brevirostris* implanted with acoustic transmitter. *Journal of Fish Biology*, *94*(1), 173–174. DOI: https://doi.org/10.1111/jfb.13856

Soares, M. de O., Lemos, V. B. & Kikuchi, R. K. P. de. 2011. Aspectos biogeomorfológicos do Atol das Rocas, Atlântico Sul Equatorial. *Revista Brasileira de Geociências*, *41*(1), 85–94. DOI: https://doi.org/10.25249/0375-7536.20114118594

Speed, C. W., Meekan, M. G., Field, I. C., McMahon, C. R., Harcourt, R. G., Stevens, J. D., Babcock, R. C., Pillans, R. D. & Bradshaw, C. J. A. 2016. Reef shark movements relative to a coastal marine protected area. *Regional Studies in Marine Science*, *3*, 58–66. DOI: https://doi.org/10.1016/j.rsma.2015.05.002

Tavares, M., R. ,. Rodriguez, J. P. &. Morales, Rodriguez, J. P. & Morales, M. 2016. Nursery area and size structure of the lemon shark population, Negaprion brevirostris (Poey, 1868), in Los Roques Archipelago National Park, Venezuela. *Universitas Scientiarum*, *21*, 33–52.

Ward-Paige, C. A., Keith, D. M., Worm, B. & Lotze, H. K. 2012. Recovery potential and conservation options for elasmobranchs. *Journal of Fish Biology*, *80*(5), 1844–1869. DOI: https://doi.org/10.1111/j.1095-8649.2012.03246.x

Ward-Paige, C. A. & Worm, B. 2017. Global evaluation of shark sanctuaries. *Global Environmental Change*, *47*, 174–189. DOI: https://doi.org/10.1016/j.gloenvcha.2017.09.005

Wetherbee, B. M., Gruber, S. H. & Rosa, R. S. 2007. Movement patterns of juvenile lemon sharks Negaprion brevirostris within Atol das Rocas, Brazil: a nursery characterized by tidal extremes. *Marine Ecology Progress Series*, *343*, 283–293. DOI: https://doi.org/10.3354/meps06920

White, E. R., Nagy, J. D. & Gruber, S. H. 2014. Modeling the population dynamics of lemon sharks. *Biology Direct*, *9*(1), 23. DOI: https://doi.org/10.1186/1745-6150-9-23

Worm, B., Davis, B., Kettemer, L., Ward-Paige, C. A., Chapman, D., Heithaus, M. R., Kessel, S. T. & Gruber, S. H. 2013. Global catches, exploitation rates, and rebuilding options for sharks. *Marine Policy*, *40*, 194–204. DOI: https://doi.org/10.1016/j.marpol.2012.12.034