Diel variability in the activity patterns of two endemic Brazilian reef fish species

Variabilidad diaria en los patrones de actividad de dos especies endémicas de peces de arrecife de Brasil

Variabilité diurne des schémas d'activité de deux espèces endémiques de poissons de récifs du Brésil

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EXTENDED ABSTRACT

The diel cycle is one of the key environmental factors that drives reef fish activity patterns and spatial occupation. Diel movements and habitat shifts within coral reef seascapes are often related to foraging and anti-predator strategies. Many reef fishes display greater movement distances during foraging periods and more limited movements while resting or sheltering from predators. For most reef fish species, activity patterns tend to be either diurnal, nocturnal, or crepuscular. However, intra-specific variability in diel patterns may be driven by many factors including ontogeny, changes in environmental conditions and biological factors such as predation risk, foraging, and competition (Rooker et al. 2018). In the present study, we used acoustic telemetry to investigate the diel variability in the activity patterns of two poorly known endemic Brazilian reef fish species, the gray parrotfish *Sparisoma axillare* (Labridae) and the Brazilian snapper *Lutjanus alexandrei* (Lutjanidae). Both *S. axillare* and *L. alexandrei* are important resources for the artisanal fisheries in Northeast Brazil and appear to display activity patterns similar to congeners from each family, with contrasting diurnal and nocturnal foraging patterns, respectively. The study was conducted within a no-take zone, where positive effects of protection such as the increase in fish size and density have been reported for both species (Lippi et al. 2022). The knowledge on species diel patterns may have important implications for management and conservation of species and ecosystems, including the design of marine protected areas and marine spatial planning.

The monitored area is located on the Tamandaré coral reef complex off Pernambuco state coast, in the Northeast Brazil, and include the reef formations inside and around a 2.7 km² well-enforced no-take zone (NTZ). From December 2016 to October 2017, 16 *S. axillare* and 9 *L. alexandrei* were passively monitored by an array of 17 VR2W acoustic receivers. Fish were internally tagged with V9-4L (*S. axillare*) and V8-4L (*L. alexandrei*) acoustic transmitters. All tagged *S. axillare* were initial phase females with a mean size of 26.5 ± 2.3 cm TL. *Lutjanus alexandrei* sex was not determined and mean size 22.5 ± 2.3 cm TL. For all individuals, the tag-to-body relationship never exceeded 2% (0.83 to 1.95%) of fish total weight.

The Fast Fourier Transformation analysis revealed a primary 24h rhythmicity on hourly detections for 80% (13 out of 16) of *S. axillare* and 90% (8 out of 9) of *L. alexandrei* individuals. Detections were then divided into diurnal and nocturnal periods, and four diel activity pattern indicators were calculated for each fish: number of hourly detections, movement rate ($m.h^{-1}$), home range and spatial evenness (Seven *S. axillare* were excluded from analysis due to the low number of detections during nighttime). Mixed-design ANOVAs (between-subject factor "Species" and within-subjects factor "Daily phases") of each activity pattern indicator found significant differences between diurnal and nocturnal phases for movement rate ($F=45.4$, $P<0.001$), home range ($F=6.58$, $P=0.02$) and spatial evenness ($F=5.78$, $P=0.03$). Tukey HSD tests showed that such differences were due to significantly higher values obtained during daytime for *S. axillare*, whereas no differences were observed for *L. alexandrei*. No diel variability on number of hourly detections was observed for either species. For *S. axillare*, PCA followed by a hierarchical clustering arranged the individuals' diurnal and nocturnal activity patterns in two distinct and temporally homogeneous groups: a high activity-diurnal group and a low activity-nocturnal group (Figure 1-A). The first two axes of the PCA explained nearly 89% of the total variation. PC1 was characterized by an increase on movement rate, home range and spatial evenness values (positive loadings and similar magnitudes) from the low activity-nocturnal group (lower scores) towards the high activity-diurnal group (higher scores). *Sparisoma axillare* also showed high

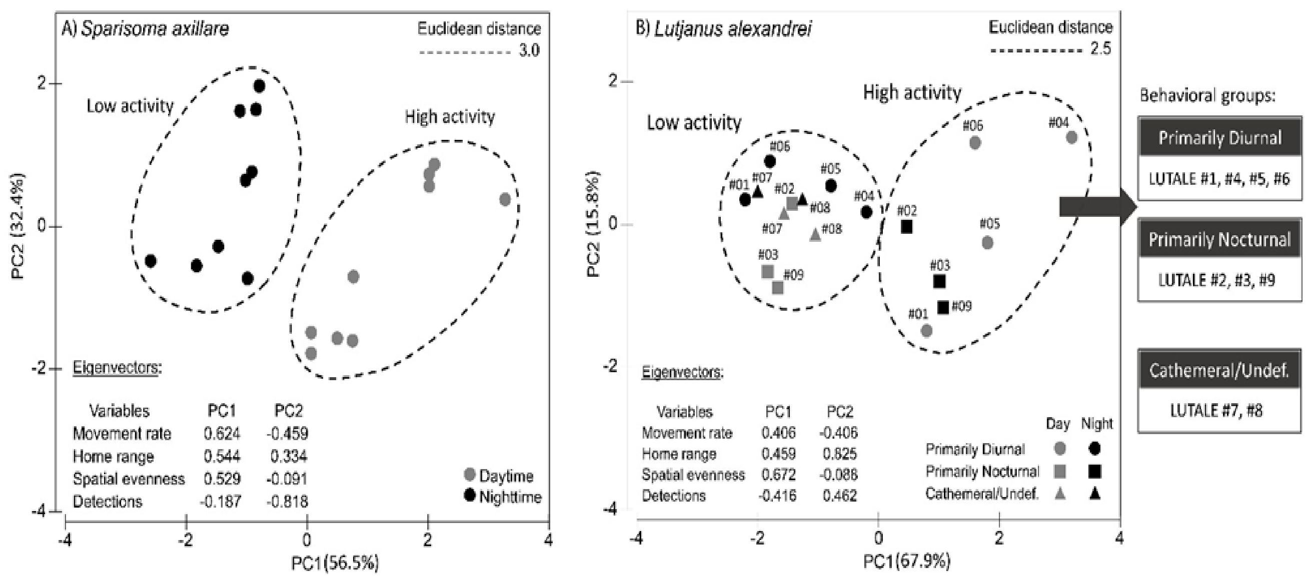

Figure 1. Principal Component Analysis (PCA) of the diurnal (grey shapes) and nocturnal (black shapes) activity patterns of A) *Sparisoma axillare* and B) *Lutjanus alexandrei*, based on the number of detections (h^{-1}), movement rate ($m.h^{-1}$), home range (km²) and spatial evenness values. Overlaid contour lines from hierarchical cluster analysis indicates the formation of two clearly distinct groups: a Low Activity and a High Activity group. For L. alexandrei, three behavioral groups of fish could also be inferred: Primarily Diurnal (circles), Primarily Nocturnal (squares) and Cathemeral/Undefined (triangles).

spatial fidelity to their nocturnal resting areas, since for a given individual, approximately 90% of the detections during nighttime were recorded by only one receiver.

For *L. alexandrei*, the PCA indicated an individual-level heterogeneity on the diel behavior for most fish (Figure 1-B). A primarily diurnal or nocturnal behavior could be observed for 7 individuals (LUTALE #1, #2, #3, #4, #5, #6, #9) by having their respective day and night activity patterns plotted far apart from each other and on opposite sides along the PC1. Also, hierarchical clustering revealed two distinct, but temporally mixed groups (i.e., diurnal and nocturnal activity patterns within the same cluster). The High Activity group comprised the daily phases when individuals had higher home range, movement rate and spatial evenness values. In this group were included the diurnal activity pattern of LUTALE #1, #4, #5 and #6 and the nocturnal activity pattern of LUTALE #2, #3, #9. In contrast, the Low Activity group was composed by the respective periods of reduced activity for the abovementioned individuals. *Lutjanus alexandrei* individuals were then classified into three distinct behavioural groups: Primarily Diurnal (composed by LUTALE #1, #4, #5 and #6), Primarily Nocturnal (LUTALE #2, #3, #9) and Cathemeral/Undefined (LUTALE #7 and #8).

A mixed diel behavior was observed for the tagged *L. alexandrei*, with co-occurring groups of individuals displaying contrasting diel patterns. The present study was performed within a marine NTZ where the density of *L. alexandrei* is locally high. Thus, increased intra-specific competition might also have promoted an individual-level diversification of the diel activity patterns in order to reduce the competition among conspecifics. No significant differences were observed in fish size between Primarily Diurnal and Primarily Nocturnal groups, what might suggest that the observed opposite diel patterns represented individual variations not related to fish ontogeny. Moreover, the fact that individuals with opposite diel patterns co-occurred both spatially (i.e., overlapping home ranges) and temporally (i.e., overlapping detection periods) also suggest that these contrasting patterns are not related to environmental factors or to differences on detection probability. A clear diurnal pattern for *S. axillare* was demonstrated, whereas an intra-population diel variability was observed for *L. alexandrei*, indicating that biological factors may interact to determine individual fish behavior. Further studies such as fine-scale acoustic telemetry and diet analysis are necessary to fully understand the differences in resources used between *L. alexandrei* behavioral groups.

KEYWORDS: Acoustic telemetry, Diel periodicity, Movement, Parrotfish, Snapper

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