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Policy analysis

Effectiveness and design of marine protected areas for migratory species of conservation concern: A case study of post-nesting hawksbill turtles in Brazil

Armando J.B. Santos [a,*], C. Bellini [b], E.A.P. Santos [b], G. Sales [b], R. Ramos [c], D.H.G. Vieira [d], M. A. Marcovaldi [e], Anthony Gillis [f], N. Wildermann [g,h], M. Mills [i], T. Gandra [j], M.M.P.B. Fuentes [a]

[a] Marine Turtle Research, Ecology, and Conservation Group, Department of Earth, Ocean and Atmospheric Science, Florida State University, Tallahassee, FL 32306, USA
[b] Centro TAMAR-ICMBio, Vitória, ES CEP 29050-335, Brazil
[c] ENGEO – Soluções Integradas em Meio Ambiente, Avenida Fernando Ferrari, 1080, sala 404, Mata da Praia, Vitória, ES CEP 29066-380, Brazil
[d] Fundação Projeto TAMAR, Av. Antonio Florêncio, s/ n^o, Praia da Pipa, RN, CEP 59178-000, Brazil
[e] Fundação Projeto Tamar, Rua Rubens Guelli 134/307, Itaigara- Salvador, CEP 41815-135, BA, Brazil
[f] Center for Spatial Analysis, Fish & Wildlife Research Insititute, Florida Fish & Wildlife Conservation Commission, Tallahassee, FL 32399, USA
[g] Texas Sea Grant at Texas A&M University, 4115 TAMU, College Station, TX 77843, USA
[h] Harte Research for Gulf of Mexico Studies, 6300 Ocean Drive, Corpus Christi, TX 78412, USA
[i] Centre for Environmental Policy, Imperial College London, London SW71NE, UK
[j] Federal Institute of Education, Science and Technology of Rio Grande do Sul, Eng. Alfredo Huch, 475 Rio Grande, RS, Brazil

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ABSTRACT

Marine protected areas (MPAs) are among the most widely used strategy to protect marine ecosystems and are typically designed to protect specific habitats rather than a single and/or multiple species. To inform the conservation of species of conservation concern there is the need to assess whether existing and proposed MPA designs provide protection to these species. For this, information on species spatial distribution and exposure to threats is necessary. However, this information if often lacking, particularly for mobile migratory species, such as marine turtles. To highlight the importance of this information when designing MPAs and for assessments of their effectiveness, we identified high use areas of post-nesting hawksbill turtles (*Eretmochelys imbricata*) in Brazil as a case study and assessed the effectiveness of Brazilian MPAs to protect important habitat for this group based on exposure to threats. Most (88%) of high use areas were found to be exposed to threats (78% to artisanal fishery and 76.7% to marine traffic), where 88.1% were not protected by MPAs, for which 86% are exposed to threats. This mismatch is driven by a lack of explicit conservation goals and targets for turtles in MPA management plans, limited spatial information on species' distribution and threats, and a mismatch in the scale of conservation initiatives. To inform future assessments and design of MPAs for species of conservation concern we suggest that managers: clearly state and make their goals and targets tangible, consider ecological scales instead of political boundaries, and use adaptative management as new information become available.

1. Introduction

Marine protected areas (MPAs) are among the most widely used strategy to protect marine ecosystems (Agardy et al., 2011; Peter, 2001) in the face of increasing environmental degradation (Nystrom et al., 2012) and loss of marine biodiversity (Sala and Knowlton, 2006). MPAs are typically designed to achieve specific conservation objectives, often expressed as a proportion of area to be protected, to ensure the representation and persistence of ecological processes and biodiversity features at various temporal and spatial scales (Margules and Pressey, 2000). Typically, MPAs are designed for the protection of ecosystems rather than for a single and/or multiple species, since ecosystem-based approaches provide more benefits to a variety of species (Dryden et al., 2008; Gerber et al., 2003; Lynch et al., 2013; Roberts et al., 2006). However, unless ecosystem-based approaches incorporate targets and ecological information for species of conservation concern, these species

* Corresponding author.
E-mail address: ajs19bf@my.fsu.edu (A.J.B. Santos).

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may not be appropriately protected by MPAs (for examples see Scott et al., 2012; Nel et al., 2013; Rouphael et al., 2013; Schofield et al., 2013b; Cleguer et al., 2015). Inclusion of specific targets for species of conservation concern is particularly important for regions where these species are known to occur and threats are expanding and intensifying (Fuentes et al., 2019).

This is the case for Brazil, where several species of conservation concern utilize the Brazilian coast; e.g., marine mammals (Paludo and Langguth, 2002), fishes (Palmeira et al., 2013), sharks (Lessa et al., 2016), and marine turtles (Almeida et al., 2011; Fuentes et al., 2020). Marine ecosystems in Brazil and associated species currently experience several anthropogenic threats, with medium to medium-high impacts (Halpern et al., 2008, 2012). The outstanding ecological value of the Brazilian marine environment (e.g. more than eight thousand kms of coastline) coupled with the expanding threats to marine biodiversity has prompted the government to implement the Brazilian National System of Protected Areas (SNUC) (Brasil, 2002, 2000). Until 2017, less than 2% of Brazil's marine jurisdiction was under protection (Magris et al., 2013). Despite the creation of four large oceanic MPAs in 2018 increasing the protected area to more than 25%, large gaps remain in the protection of species of conservation concern in the region (Magris and Pressey, 2018; Giglio et al., 2019; Mills et al., 2020).

Hawksbill turtles (*Eretmochelys imbricata*) from the Southwest Atlantic Regional Management Unit (RMU) nest and utilize coastal waters of northern Brazil (Vilaça et al., 2013; Wallace et al., 2010). Hawksbill turtles are listed as Critically Endangered by the International Union for the Conservation of Nature (IUCN) Redbook (Mortimer and Donnelly, 2008) and by the Brazilian Red List of Threatened Species (Marcovaldi et al., 2011a), warranting urgent protection (Wallace et al., 2010). It has been suggested that protection of reproductive female turtles provide the most benefit to the sustainability of marine turtle populations as this life stage has the biggest reproductive value (Heppell et al., 1996; Wallace et al., 2008; Bolten et al., 2011). However, limited information to date exists on the level of protection that nesting hawksbill turtles have in Brazil once they enter the marine environment after nesting (Marcovaldi et al., 2012). A first step to consider marine turtles, in this case hawksbill turtles, into any spatial planning initiative is to obtain information on their spatial-temporal distribution (Fuentes et al., 2019; Gredzens et al., 2014; Hart et al., 2019, 2012; Lascelles et al., 2014a; Schofield et al., 2013b). Two major hawksbill nesting areas have been identified on the coast of Brazil: northern Bahia and southern Rio Grande do Norte states (Marcovaldi et al., 2007; Santos et al., 2019). The turtles nesting at each region represent two genetically distinct subpopulations (Vilaça et al., 2013). Information on the spatial distribution of post-nesting hawksbill turtles has only been identified recently for turtles from the Bahia subpopulation (Marcovaldi et al., 2012).

To inform future management of hawksbill turtles in Brazil, we: 1) identified migratory corridors, internesting and foraging areas of post-nesting hawksbill turtles from the Rio Grande do Norte subpopulation, 2) considered the exposure of high use areas by post-nesting hawksbills to existent threats, 3) assessed the effectiveness of Brazil's existing network of coastal MPAs to protect important habitat for post-nesting hawksbill turtles considering the extent of threats that they are exposed to. As MPAs offer several levels of protection, ranging from full protection, such as "no-take" reserves, to sustainable use, where some extractive activities are allowed (e.g., fishing, under specific regulations) (Magris et al., 2013), our assessments were conducted for each specific MPA protection level in Brazil. Importantly, our approach can be implemented to assess the effectiveness of MPA protection to migratory marine species of conservation concern and our discussions on future considerations can guide the design and implementation of MPAs to protect marine turtles and other highly migratory marine species.

2. Material and methods

2.1. Study site

Our study focused on hawksbill turtles that nest on the southern coastline of Rio Grande do Norte state, Brazil, where we considered four nesting locations from north to south: Centro de Lançamento da Barreira do Inferno (CLBI), a military rocket launch base of the Brazilian Space Agency (−5.91112° S, −35.15677° W; Parnamirim municipality), Malemba beach (−6.15979° S, −35.09810° W; Senador Georgino Avelino municipality), Pipa beach (−6.25713° S, −35.03790° W; Tibau do Sul municipality) and Olho D'água beach (−6.32871° S, −35.03228° W; Baia Formosa municipality) (Fig. 1). Nesting in Rio Grande do Norte state occurs between November and May (Santos et al., 2013).

2.2. Turtle capture and transmitter deployment

Night surveys took place from December through May during the 2014/15 to 2018/19 nesting seasons. Surveys were conducted using a 4 × 4 ATV between 7 pm and 2 am. After laying their eggs, nesting turtles were checked for Inconel tags, if not tagged, they were tagged (Tag Style 681, National Band and Tag) on the trailing edge of each front flipper (Marcovaldi and Marcovaldi, 1999). Curved carapace length (CCL) measurements were taken beginning from the anterior point and extending to the posterior tip of the longest supracaudal scute (Bolten, 1999). Thirty-six post-nesting individuals (CCL from 82 to 102.7 cm; mean 91.9 cm; SD ± 5.4 cm) (Table 1) were selected for platform transmitting terminals (PTT) attachment, and were restrained after they finished nesting, similarly to Hart et al. (2010) to prevent the turtle or research personnel from injuring themselves during the PTT attachment process. To attach the PTT the turtle's carapace was cleaned with scrapers, sanded, and cleaned a second time with isopropyl alcohol. In the 2014/15 nesting season a bi-component epoxy resin (Tubolit MEP-301), mixed by hand, was used for PTT attachment. In the subsequent nesting seasons, a bi-component acrylic adhesive (3 M Scotch-Weld Low Odor Acrylic Adhesive DP8805NS) was applied to the bottom of the PTT and was then pressed to the carapace for three minutes, following the position indicated by the manufacturer. After ten minutes, a bi-component epoxy (Quikrete - High Strength ANCHORING Epoxy No. 8620–31) was applied around the PTT. The entire PTT area was painted with antifouling paint Micron66 to avoid bio-fouling. PTT deployment took between 1.5 and 3 h. Six PTT models were used in our study (Table 1; mass in g; dimensions [length x width x height]): 10 SPOT-293A – 119 g – 72 × 54 × 24 mm, 10 SPOT-375–136 g - 99 × 55 × 21 mm, 7 SPLASH10-F-296A – 195 g - 86 × 85 × 29 mm, 4 SPLASH10-F-334–450 g - 112 × 63 × 62 mm, manufactured by Wildlife Computers (Redmond, WA, USA), and 3 Kiwi-Sat K2G 376D – 240 g - 136 × 44 × 59 mm, 2 Kiwi-Sat K2G 376D – 360 g - 138 × 78 × 50 mm manufactured by Sirtrack (Havelock North, New Zealand).

2.3. Marine turtle tracking and switching state-space modelling (SSM)

Satellite telemetry data was downloaded remotely from the PTT's manufacturers webpage - Wildlife Computers (https://wildlifecomputers.com) or Sirtrack (https://data.sirtrack.com). Additionally, for seven of the 11 SPLASH10 tags, data was downloaded directly from the tag, during the internesting interval, when turtles returned to nest within the same nesting season and were recaptured (Table 1). Further, data was also directly downloaded from two SPLASH10 tags recovered in subsequent nesting seasons, i.e., after one remigration interval (Table 1). Following the download, ARGOS data with location classes (LC) = 3, 2, 1, 0, A and B were retained and LC = Z were excluded (as per Fuentes et al., 2020). The resulting dataset for each PTT was visually inspected to remove locations inland.

A hierarchical switching state-space model (SSM) (Jonsen et al., 2006) was used to generate individual interpolated tracks with an equal

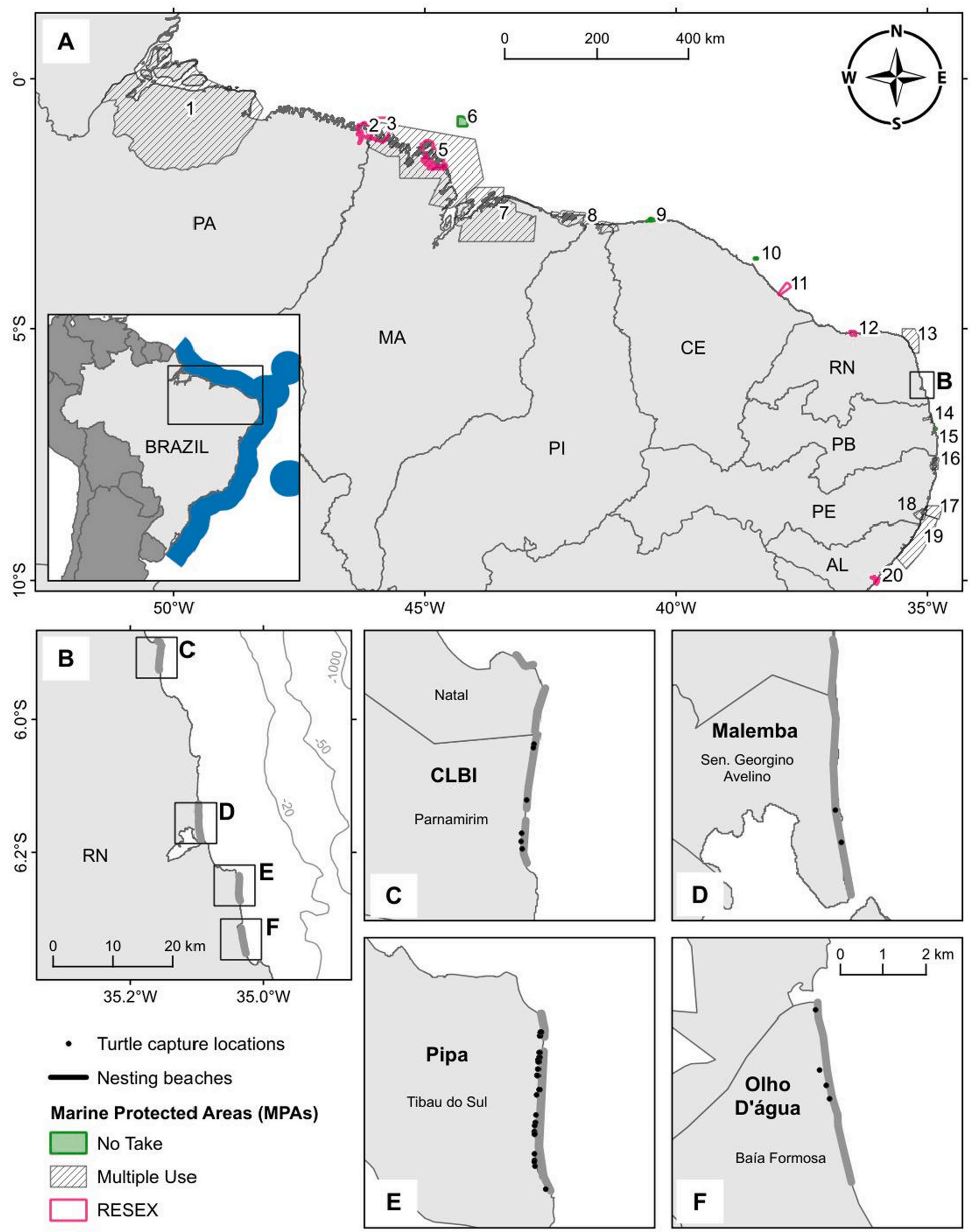

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Fig. 1. Map of the study site showing the three categories of Marine Protected Areas (MPAs): no-take, RESEX and multiple use. (A) North and Northeastern coastline of Brazil, (B) Southern coastline of Rio Grande do Norte (RN) state and the four nesting beaches: (C) CLBI – Centro de Lançamento da Barreira do Inferno, (D) Malemba, (E) Pipa and (F) Olho D'água. Scale bar for C, D and E are the same as in F. Acronyms for states: PA– Pará, MA – Maranhão, PI – Piauí, CE – Ceará, PB – Paraíba, PE – Pernambuco, AL -Alagoas, SE – Sergipe. The numbers are representative of each MPA:1 - APA do Arquipélago do Marajó, 2 - Resex Marinha de Gurupi-Piriá, 3 - Reserva Extrativista Arapiranga-Tromai, 4 - APA Reentrâncias Maranhenses, 5 - Reserva Extrativista de Curupu, 6 - PE Marinho do Parcel de Manuel Luís, 7- APA Upaon-Açu / Miritiba / Alto Preguiça, 8 - APA Delta do Parnaiba, 9 - Parna de Jericoacoara, 10 – Parque Estadual Marinho da Pedra da Risca do Meio, 11 - Reserva Extrativista Prainha do Canto Verde, 12 - RDS Ponta do Tubarao, 13 - APA dos Recifes de Corais, 14 - APA da Barra do Rio Mamanguape, 15 - PE Marinho de Areia Vermelha, 16 - APA de Santa Cruz, 17 - APA Marinha Recifes de Serrambi, 18 - APA de Guadalupe, 19 - APA Costa dos Corais, 20 - Reserva Exrativista Marinha da Lagoa do Jequia.

Table 1
Summary of platform transmitting terminals deployed during the 2014/15–2018/19 nesting seasons on post-nesting hawksbill turtles. CLBI – Centro de Lançamento da Barreira do Inferno. [D] indicates that data download was obtained on the beach when the turtle was recaptured during the internesting interval; [R] indicates that the tag was recovered after one remigration interval, and we were able to recover the stored data. Dates are given as mm/dd/yy.

Turtle ID	Model	CCL (cm)	Deployment location	Deployment date	Transmission Days	ARGOS fixes excluding Z	GPS fixes
2[D]	SPLASH10-F-296A	91.2	Pipa	2/28/15	49	56	90
3	Kiwi-Sat K2G 376D	95	Pipa	2/6/19	332	2061	–
4[D,R]	SPLASH10-F-296A	86.3	Pipa	3/5/15	341	621	215
6	SPOT-375	95.7	Pipa	1/28/18	325	911	–
8[D,R]	SPLASH10-F-296A	86.7	Pipa	2/10/16	527	2370	2808
9	SPLASH10-F-296A	102.7	Pipa	3/11/16	489	1667	1162
10	SPLASH10-F-334	91.7	Pipa	4/8/19	334	665	1275
11	SPOT-293A	93.8	Pipa	3/17/17	258	625	–
13	SPOT-375	85.4	Pipa	2/17/18	566	2962	–
14[D]	SPLASH10-F-296A	88.4	Pipa	1/17/18	257	618	373
15	SPOT-293A	84.5	Pipa	3/7/15	154	412	–
16	SPOT-375	97	Pipa	2/16/18	236	885	–
18	SPOT-375	97.8	CLBI	3/6/18	273	1279	–
21	SPOT-293A	82.8	Pipa	2/10/16	60	235	–
22	Kiwi-Sat K2G 376D	86.3	Pipa	2/25/19	324	2066	–
24	SPOT-375	84.7	Pipa	1/13/19	248	1399	–
25	SPOT-293A	94.5	Pipa	5/2/16	686	1894	–
26	SPOT-293A	89.3	Pipa	2/22/17	101	278	–
27	SPOT-293A	91.2	Pipa	4/13/17	260	309	–
29	SPOT-375	93.3	Pipa	12/20/18	390	2089	–
30	SPOT-375	85.2	Pipa	12/29/18	382	3198	–
31	SPOT-375	91.5	Pipa	4/10/19	280	1827	–
34	SPLASH10-F-334	97.2	Pipa	4/11/19	279	2464	1769
35	Kiwi-Sat K2G 376D	85	Pipa	4/4/19	28	99	–
36	Kiwi-Sat K2G 376D	94.2	Pipa	3/19/19	80	492	–
1	SPLASH10-F-296A	91.2	CLBI	2/25/15	66	124	54
17	SPOT-293A	99.8	CLBI	3/29/15	105	390	–
7	Kiwi-Sat K2G 376D	99.5	CLBI	2/15/19	125	536	–
23	SPOT-293A	99.5	CLBI	2/27/16	78	319	–
33[D]	SPLASH10-F-334	97.5	CLBI	3/15/18	93	785	920
12	SPOT-293A	87	Olho D'água	2/27/15	58	231	–
20	SPOT-375	94	Olho D'água	3/20/18	304	1442	–
28	SPOT-375	93.3	Olho D'água	3/18/18	366	1113	–
32[D]	SPLASH10-F-334	101.5	Olho D'água	3/18/18	192	1186	992
5[D]	SPLASH10-F-296A	82	Malembá	3/18/15	393	1155	138
19	SPOT-293A	92.1	Malembá	2/5/16	151	647	–

time interval of six hours between locations. When available, FastlocGPS locations were converted to LC = 3 and were combined with ARGOS data, as in Wildermann et al. (2019). Behavioral modes were defined as 'area-restricted searching' (ARS) or 'transiting' (Jonsen et al., 2007), with the *bsam* package (Wotherspoon et al., 2017) in R v.3.5.1 (R Core Team, 2018). The unitless output of behavioral state ranged from 1 to 2, where 1 to 1.49 were classified as 'transiting' and 1.50 to 2 as ARS (Fuentes et al., 2020). Only 1.5% of turtle's behavioral state ranged between 1.25 and 1.75, indicating reliable categorization of the assigned states in our study. As we tagged turtles during the nesting season, the behavioral state ARS that occurred immediately after deployment and before 'transiting' corresponded to internesting movement. If 'transiting' occurred and the turtle was detected nesting again and/or returned to the ARS in the vicinity of nesting beach, this movement was still linked to internesting. 'Transiting' was considered migration when it occurred after the last nesting event of the turtle and when the turtle started to move away from the nesting beach. However, when ARS occurred during migration for less than 1.5 days, we considered it a migration state until the turtles reached their foraging areas (the maximum number of consecutive ARS interpolated locations within migration was five, for one individual, in this sense we ignored this stopover and considered it as migration). Similarly, if 'transiting' occurred after arrival at the foraging ground, these movements were considered foraging. This allowed us to identify internesting areas (IN), migratory corridors (MG) and foraging areas (FG) used by post-nesting hawksbill turtles. Of the 36 turtles tracked, five individuals (7, 20, 22, 28 and 34; Table 1) started migration (MG) immediately after nesting and therefore, the IN area for those turtles was not identified.

Three SSMs were fitted with different iterations for diagnostics examination; the model in which Markov chain Monte Carlo (MCMC) parameters converged more appropriately was selected. Best fit model posterior distribution was modeled from two parallel and independent chains of MCMC based on 40,000 iterations after a burn-in of 60,000 samples and thinned by ten to minimize within chain sample autocorrelation. Our models incorporated data until transmitters stopped transmitting or until the time of data synthesis and analysis (8th March 2020). For three individual turtles (3, 11 and 24; Table 1) SSM did not detect “transiting” behavior, therefore we assumed the transition from IN to FG after the last nesting event.

2.4. Space-use by post-nesting hawksbill turtles

To determine high use areas for post-nesting hawksbill turtles we first assessed the raw data to determine if any data gaps occurred. In cases where gaps larger than 4 days occurred, we removed the interpolated locations within this period to avoid over interpolation of locations (Bailey et al., 2008; Fuentes et al., 2020). Filtered data for each turtle and each behavioral state were then normalized by the inverse of its tracking length (Table 1) as per Fuentes et al. (2020). Following this methodology, the R package *trip* (Sumner et al., 2019) was used to create time spent space-use (space-use hereafter) raster cell size of 25 km^2 for each individual turtle and behavior. The normalized space-use rasters were then weighted by the number of individual turtles within each cell for (a) each behavioral state individually and (b) for the whole extent of the tracking of each turtle (i.e., all behaviors together) in ArcGIS 10.7 (ESRI, 2019). For each space-use layer, we categorized the layers in three use classes (low, medium and high) using geometrical interval classification, which is a method specifically designed to accommodate continuous data (ESRI, 2019). To examine temporal scale of post-nesting turtles, we aggregated data from all turtles tracked across different years and plotted behaviors from internesting to foraging areas across time.

2.5. Exposure of use areas to human activity

To assess the distribution and exposure of post-nesting hawksbill use areas to human activities, we considered industrial and artisanal fisheries, marine traffic, mining, ports and oil and gas production fields across our study region, which are known activities to impact marine turtles (Fuentes et al., 2020; Hart et al., 2018; Lutcavage et al., 1996; Wallace et al., 2011). Industrial fisheries space use was based on data from January 2014 to July 2019 obtained by the National Fisheries Satellite Tracking Program (PREPS, www.preps.gov.br), from fishing vessels larger than 15 m, which included vessels using fishing traps ($n = 249$), trawlers ($N = 151$), longline ($N = 68$) and gillnet ($N = 12$). The locations of each vessel were aggregated for each hour and filtered by speed and depth to eliminate navigation and landing positions. Kernel density maps were produced using adehabitatHR R package, for each fishery type using a bandwidth of 0.3 degrees (approximately 33 km) and then reclassified to presence/absence using the last quartile as threshold. Artisanal fishery areas were obtained from reports available at the licensing system from Brazilian environmental protection agency (IBAMA, www.licenciamento.ibama.gov.br) and included information from fisheries (e.g., gill nets, traps, longline, handline, pots, trawl, cast nets, driftnets) operating from a variety of platforms (e.g., small to medium boats, canoe, sailing rafts). For marine traffic data, the heatmap produced from the Automatic Identification System data from 2019 and available at Marine Traffic website (www.marinetraffic.com) was downloaded, and georeferenced using ground control points using QGIS 3.17. Then vectorization on screen was carried out by visual interpretation, where warm colors (red and orange) was used as threshold for high marine traffic polygons. Mining areas were obtained from the National Mining Agency Geographical Information System (https://geo.anm.gov.br/). The active mining process layer was used, limited to “Mining concession” and “Right to request the mining”.

The ports locations were obtained from the Brazilian National Agency for Waterway Transportation and converted for polygons using a 5 km buffer (http://web.antaq.gov.br/portalv3/PNIH.asp). The oil and gas production fields were downloaded from the Brazilian National Agency for Petroleum, Natural Gas and Biofuels (ANP) (http://geo.anp.gov.br/).

Each human activity layer was spatially joined to turtles' space use grids resulting in a presence/absence value for each human activity grid. The percentual overlap area was calculated for each human activity considering the total area for each behavior (all behaviors, FG, MG, and IN) and intensity (high, medium, low). However, for artisanal fisheries, we only considered the spatial extent for which data was available (Fig. S1-A), without inclusion of areas with no data, so the total area for artisanal fisheries was smaller than the other human activities.

2.6. Marine Protected Areas (MPAs)

A composite GIS layer of all marine protected areas (MPAs) in the North and Northeastern Brazilian continental shelf was created with spatial information provided by the Brazilian Ministry of Environment under federal, state and municipal governances. MPAs were categorized based on management intent, according to the International Union for Conservation of Nature (IUCN) criteria; no-take, where only non-extractive activities such as educational and scientific activities are allowed (it includes Ia, Ib and II category), extractive reserves (RESEX), where sustainable use by traditional communities are allowed (VI category), and multiple use, where sustainable use by several groups is promoted (V category) (Table 2; IUCN, 2017). Although no-take zones may occur within RESEX and multiple use MPAs through zonation, information of specific zonation within each MPA was not available, therefore our analyses were conservative and considered the MPA polygon as whole and not the internal zonation. The overlay among turtle's space use, MPAs and human activities layers was made with the Spatial Join tool in QGIS 3.17, using intersection and overlap as geometrical predicates. The percentual area of each human activity layer within MPAs were calculated by spatial overlap using the same grid system used for turtle space use, by category of use (low, medium, and high).

MPAs in Brazil are established by decrees from federal, state or municipal authorities (Brasil, 2000). The official document declares a given area to be included in the Brazilian National System of Protected Areas SNUC (Brasil, 2002, 2000). Creation decrees and management plans for federal MPAs were downloaded from the Chico Mendes Institute for Biodiversity Conservation website (https://www.icmbio.gov.br/portal/) and for state MPAs we obtained their decrees and plans directly from their managing agencies' webpage. When these were not available online, the managing agency was contacted directly by email and a request was made for such information. Management plans were systematically reviewed to determine the representation of marine turtles within each plan. For this we extracted information on the year of plan publication, and whether their goals or targets indicated consideration of marine turtles. A conservation goal was considered as a general statement of what the protected area is attempting to achieve; whereas a target was considered as a quantitative measure of what needs to be accomplished to reach this goal (Cleguer et al., 2015; Knight et al., 2006; Margules and Pressey, 2000). When marine turtles were merely mentioned as a biological feature that occurs within the protected area, it was considered as “feature”. We emphasize that feature is different from a conservation goal since it contains no target action to achieve that goal. Information on whether the plans have been updated since their creation was obtained by contacting their managers.

3. Results

3.1. Internesting, migratory corridors and foraging areas

The IN of post-nesting hawksbill turtles considered in our study extended from December 21st to May 21st, with most (81%) of the internesting behavior starting in February–April (Figs. 2, S2), and lasting in average 34.3 days (4–63 days; $N = 31$; Table S1). During the IN-period, turtles remained near the nesting beaches where they were tagged, with an average maximum distance from the shore of 14.5 km

Table 2
Marine Protected Areas (MPAs) in the North and Northeastern Brazilian continental shelf provided by the Ministry of Environment under federal, state and municipal jurisdictions, which overlap with our study area. RESEX = Extractive Reserve, CE = Ceará state, MA = Maranhão state, PB = Paraíba state, PA = Pará state RN = Rio Grande do Norte state, AL = Alagoas state, PE = Pernambuco state. The numbers accompanying the MPA names relates to Fig. 1.

MPA type	Name of MPA	Creation	State	Jurisdiction	Area (km^2)	Marine turtles as features	Management Plan
No-take	PE Marinho do Parcel de Manuel Luís[6]	1991	MA	State	452.4	No	No
	PE Marinho da Pedra da Risca do Meio[10]	1997	CE	State	33.2	No	No
	PE Marinho de Areia Vermelha[15]	2000	PB	State	2.3	No	No
RESEX	Resex Marinha da Lagoa do Jequiá[20]	2001	AL	Federal	102	No	No
	Resex de Cururupu[5]	2004	MA	Federal	1850	marine turtles	2016
	Resex Prainha do Canto Verde[11]	2009	CE	Federal	298.05	No	No
	Resex Marinha Arapiranga-Tromaí[3]	2018	MA	Federal	1869.10	No	No
Multiple use	APA Reentrâncias Maranhenses[4]	1991	MA	State	26,312.60	No	No
	APA da Barra do Rio Mamanguape[14]	1993	PB	Federal	149.2	*Cm; Cc; Ei*	2014
	APA Costa dos Corais[19]	1997	AL/PE	Federal	4130	*Cm; Ei*	2013
	APA de Guadalupe[18]	1997	PE	State	321.35	No	2011
	APA dos Recifes de Corais[13]	2001	RN	State	1363	Cc; Ei	2011
	APA de Santa Cruz[16]	2008	PE	State	386.96	No	2010
	APA Marinha Recifes de Serrambi[17]	2018	PE	State	84,000.00	No	No

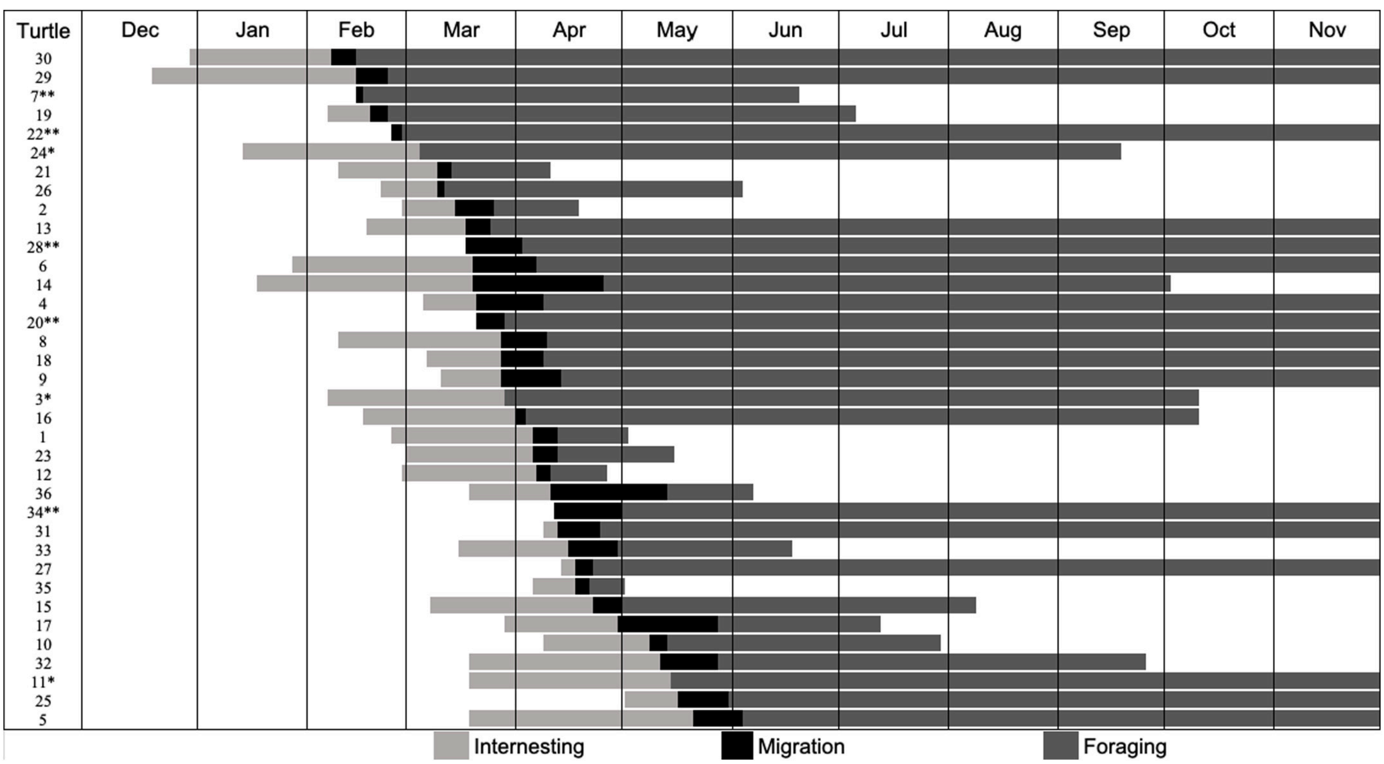

Fig. 2. Internesting, migration and foraging timeline for hawksbill turtles satellite tracked after nesting in the southern coastline of Rio Grande do Norte state, Brazil. For the three individuals with *, no migration was detected and the change from internesting to foraging was assumed after its last detection nesting during beach patrols. **, started migration immediately after tag deployment. Turtles are organized based on the start of their migration (from earlier to later migrations). Only the first year of tracking for each individual is shown.

(8.2–25 km; SD = 5.8 km), concentrated south of Natal and the three southern nesting beaches (Malembá, Pipa and Olho D'água), where 75% of high use area falls within the −20 m isobath (Fig. 3).

Migration occurred from February 8th to June 3rd ($N = 33$), with most turtles (73%) starting MG in March and April (Figs. 2, S2). Migration lasted an average 11.6 days (2–37 days; N = 33; Table 3) with turtles migrating an average of 435 km (32–1608 km; N = 33; Table S1). As long as MG is a directional non-stop movement, the high use cells indicate an overlap among individuals using the same path. As a result, the main cluster of high use cells aligned with the nesting beaches considered by this study and gradually tapered north along the state of Rio Grande do Norte and southwards towards the state of Paraiba (Fig. 4C). The average maximum distance of the main cluster of high use cells from the shore was 26.4 km (11–44 km; SD = 7.8 km), across the −50 m to −20 m isobaths, while southward extends to the edge of continental shelf with the −1000 m isobaths (Fig. 4C). Two smaller and narrower (5–10 km wide) clusters of high use cells were identified in the route of the 20 turtles that migrated north (Fig. 4B, C). The first cluster, within the state of Rio Grande do Norte, extended approximately 55 km north from the main nesting beaches, with average maximum distance of high use cells from the coast of 11 km (6.3–15.9 km; SD = 2.7 km) within the −20 m isobath (Fig. 4C). The second cluster was a narrow corridor extending approximately 160 km from the coasts of Rio Grande do Norte towards Ceará state, with average maximum distance of high use cells from the coast of 30.1 km (16.7–44 km; SD = 7.3 km) between the −20 m and −50 m isobaths (Fig. 4B). For the 13 turtles that migrated south, the main cluster of high use cells extended approximately 100 km south from the nesting beaches following the coast of Rio Grande do

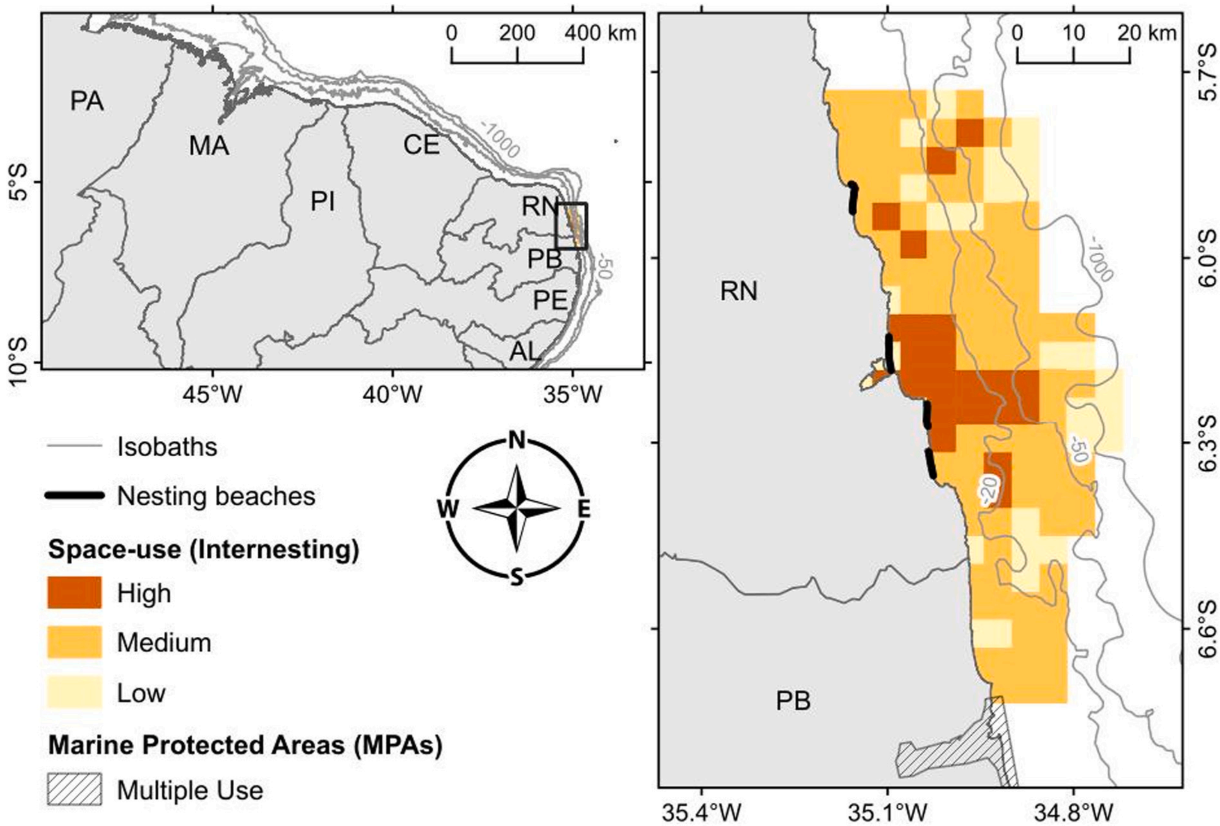

Fig. 3. Space-use during the internesting period (N = 31) of post-nesting hawksbill turtles nesting in Rio Grande do Norte, Brazil between the 2014/15 and 2018/19 nesting seasons. RN – Rio Grande do Norte state, PB – Paraiba state.

Table 3
Space-use frequency by post-nesting hawksbill turtles protected by each type of Marine Protected Area in Brazil during internesting (IN), migration (MG), and foraging (FG) behaviors, as well as across all their tracked period (ALL).

Level of protection		ALL			IN			MG			FG		
		High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low
+	No take (%)	4.8	0.7	0.4	0	0	0	0	0.3	0.1	4.9	0.8	2.6
	RESEX (%)	0	0.7	2.5	0	0	0	0	1.8	2.4	0	0.3	0
	Multiple use (%)	7	14.3	19.5	0	0.3	0	8.4	14.6	23.3	6.2	11.8	7.7
-	Not MPA (%)	88.1	84.3	77.5	100	99.7	100	91.6	83.3	74.2	88.9	87.1	89.7
	Area total (km^2)	5675	30,350	56,150	4800	9125	11,425	6225	42,600	36,650	4050	9125	11,425

Norte state towards Paraiba state (Fig. 4C). Another two clusters of high use cells were found in the south of Paraiba and north of Pernambuco, both extending around 30 km in length and mostly 5 km wide with average maximum distance of high use cells from the shore of 24.5 km (12.2–35 km; SD = 5.7 km) within the isobaths of −50 m (Fig. 4D).

Foraging ground arrivals occurred from February 15th to June 4th (N = 36 turtles) (Fig. 2), where the turtles remained until cessation of transmission for periods that extended up to 1.8 years. Foraging grounds were distributed within the continental shelf along the north and northeastern coast of Brazil (Fig. 5) (Table 2), across Ceará (N = 11), Rio

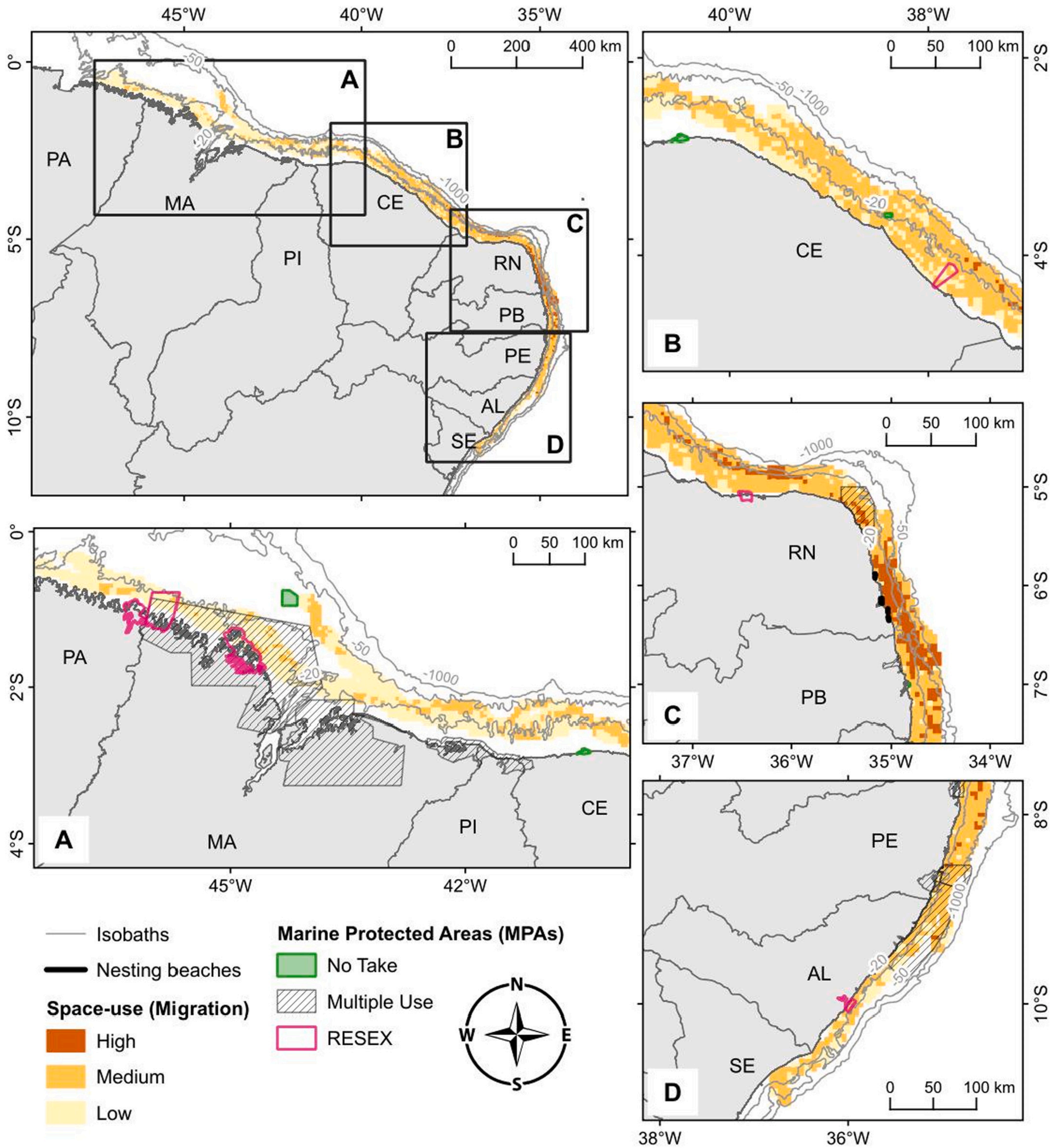

Fig. 4. Space-use during migration (N = 33 turtles) of post-nesting hawksbill turtles nesting in Rio Grande do Norte, Brazil between the 2014/15 and 2018/19 nesting seasons. PA– Pará state, MA – Maranhão state, PI – Piauí state, CE – Ceará state, RN – Rio Grande do Norte state, PB – Paraíba state, PE – Pernambuco, state AL -Alagoas state, SE – Sergipe state.

Grande do Norte ($N = 10$), Paraiba ($N = 5$), Pernambuco (N = 5), Pará ($N = 2$), Maranhão (N = 1), Alagoas (N = 1) and Sergipe (N = 1) states. Three turtles foraged close to the nesting beaches with foraging areas overlapping their internesting areas (ID 3, 11 and 24). The remaining FG areas were located as far as 1608 km north and 616 km south of the nesting beaches (Fig. 5). No overlap on FG areas occurred among individual turtles and the identified high use areas were result of the cumulative residence time. Most high use areas were located between −20 m and −50 m depth (Figs. 5A, 5D), however shallower and deeper high use cells were also observed Fig. 5C, 5E). The average distance to shore from high-use areas was 24.7 km (0–92 km; SD = 18.3 km).

When considering all the behaviors, the high use areas were predominated close to the nesting beaches used by the turtles tagged, also aligning with the migratory corridors and the spatial distribution of the

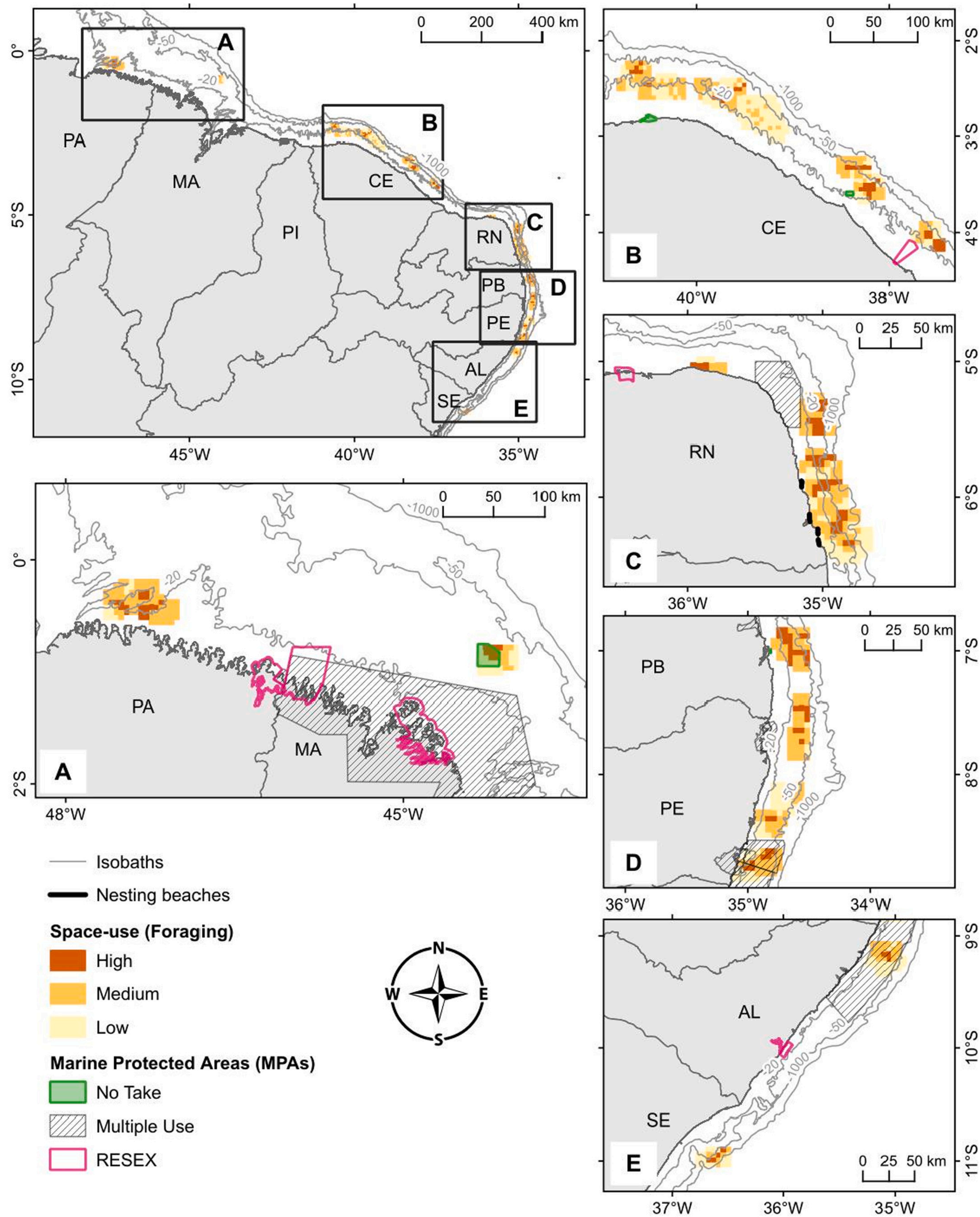

Fig. 5. Space-use at foraging grounds ($N = 36$ turtles) of post-nesting hawksbill turtles nesting in Rio Grande do Norte, Brazil between the 2014/15 and 2018/19 nesting seasons. PA– Pará state, MA – Maranhão state, PI – Piauí state, CE – Ceará state, RN – Rio Grande do Norte state, PB – Paraíba state, PE – Pernambuco, state AL -Alagoas state, SE – Sergipe state.

three resident turtles (ID 3, 24 and 11). The other areas of high use were characterized by smaller clusters, geographically dispersed along the coast of Pará, Maranhão, Ceará, Rio Grande do Norte, Paraiba, Pernambuco, Alagoas and Sergipe states and aligned with to the FG (Fig. 6A-G).

3.2. Exposure of hawksbills turtles to human activities

The majority (88%) of high use areas of post-nesting hawksbill turtles were exposed to human threats, with artisanal fishery being the most prevalent threat in high use areas (78%), followed by marine traffic (76.7%), industrial fisheries (20.7%), ports (1.8%) and mining (0.4%) (Fig. 7; Table S2). Artisanal fisheries were the threat that presented the most overlap with all classes of space use by turtles, varying from 39% of exposure during IN to 87.5% of exposure during FG (Fig. 7; Table S2). Marine traffic was the second activity with the highest overlap rates with space use, ranging from 26.1% of exposure during IN and 80.9% during FG (Fig. 7; Table S2). Industrial fishing was also prevalent in high use areas, with 25.9% of FG being exposed, followed by 20.7% for all behaviors and 7.2% of MG being exposed (Fig. 7; Table S2). High use areas during all behaviors and FG were exposed to mining, 0.4% and 0.6% respectively (Fig. 7; Table S2). No high use area during IN was exposed to ports, however 6% of MG, 1.9% of FG and 1.8% of all behaviors were exposed to ports (Fig. 7; Table S2). Oil and gas production fields overlapped only with high use areas during migration (4%; Fig. 7; Table S2). Importantly, some of the high use areas were exposed to multiple threats, with 14% of areas exposed to three threats and 57% to two threats.

3.3. Representation of hawksbill turtles on MPAs

Fourteen MPAs overlapped with the post-nesting hawksbill turtle space use layer; being three no-take, four RESEX and seven multiple use (Table 2). Most (88.1%) of high use areas by post-nesting hawksbill turtles are not protected by any type of MPA, with only 4.8% of high use areas protected by no-take MPAs and 7% of high use areas are protected by multiple use MPAs (Table 3, Fig. 6). Currently, none of the internesting high use areas by post-nesting hawksbill turtles are protected by MPA (Table 3, Fig. 3). Migration corridors are also poorly protected by MPAs, with only 8.4% of high use areas covered by multiple use areas (Table 3, Fig. 4). Foraging areas, although poorly represented by MPAs, are the behavioral state with most protection (11.1%), with 4.9% of high use areas protected by a single no-take area (Parque Estadual Marinho do Parcel de Manuel Luís) (Table 3, Fig. 5A), and 6.2% of high use areas covered by two multiple use MPAs (Area de Proteção Ambiental Marinha Recifes de Serrambi and Area de Proteção Ambiental Costas dos Corais) (Table 3, Fig. 5F).

Of the 14 MPAs which overlapped with the post-nesting hawksbill turtle space use layer, only six have a management plan (Table 2). Of those MPAs with management plans, four of them indicated that marine turtles are a biological feature within their MPA and of these, three mentioned hawksbill turtles specifically (Table 2). None of the management plans provided quantifiable conservation targets for hawksbill turtles or any other species of marine turtles in their MPA. However, the management plan for APA Recifes de Corais in the state of Rio Grande do Norte, indicated the need of general actions to obtain information on the distribution of endangered species including hawksbill turtles within their MPA, with monitoring efforts being included as a performance indicator, however without specifications on what activities this would involve.

The analysis of the cumulative overlap of threats demonstrates that in the MPAs with high use by the turtles, there are human uses that have the potential to threaten these animals. Among these, artisanal fishing, marine traffic and industrial fishing stand out. The contrast between the activities within the MPAs and outside them was given by the ports, mining and oil exploration fields, which occurred outside the MPAs. A notable contrast between the diversity of threats inside and outside MPA was observed in the Parcel de Manuel Luís Marine State Park, characterized by higher diversity of uses in its surroundings (Fig. S3). About 28% of MPAs within high use areas were exposed to human activities, with artisanal fishery being the most prevalent threat within high use areas of post-nesting hawksbills within MPAs (10.5%) followed by marine traffic (10.1%) (Fig. 7; Table S2). Industrial fisheries were found within MPAs that overlap with high use for FG and all behaviors, with mining, ports and oil and gas being not found within MPAs (Fig. 7; Table S2).

4. Discussion

A spatial mismatch was found between the spatial distribution of post-nesting hawksbill turtles that nest in the state of Rio Grande do Norte and MPAs in Brazil; 88.1% of turtle high use areas are currently not protected by MPAs, and of the areas protected 86% are exposed to threats. This is of concern since hawksbill turtles are a species of conservation concern and currently protected by several international and national conventions (e.g., Inter-American Convention, Convention on International Trade in Endangered Species of Wild Fauna and Flora and the Convention on Migratory Species (Campbell, 2014)). Below we discuss several factors that might drive the spatial mismatch between areas used by post-nesting hawksbills, threats, and the network of MPAs in Brazil. Based on these we suggest how to increase the protection of post-nesting hawksbill turtles in the region.

4.1. Lack of explicit conservation goals and targets

The effectiveness of MPAs requires clear conservation goals and targets to be included in their management plans (Margules and Pressey, 2000; Pressey and Bottrill, 2009). Without clear quantifiable targets MPA performance cannot be assessed and improved (Margules and Pressey, 2000). The explicit statement of quantifiable targets based on scientific methods allows accountability, transparency and conservation progress to be measured (Carwardine et al., 2009; Knight et al., 2006). None of the management plans for the MPAs considered in our study explicitly includes marine turtles as a conservation goal or target, however they were identified in four plans as biological features. Nevertheless, no specific metrics or targeted actions towards their protection was identified in any of these plans except for one MPA: APA Recifes de Corais which aimed to obtain further information on the spatial distribution, population size and structure of endangered species within their MPA.

Although marine turtles are considered an important biological feature at some of the MPAs in Brazil, only terrestrial protected areas are known to be developed specifically to protect marine turtles. For example two no-take protected areas in Brazil were developed to offer special protection to marine turtle nesting beaches (Marcovaldi and Marcovaldi, 1999; Marcovaldi et al., 2011b); Comboios in the state of Espirito Santo, was established in 1984 to protect loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) turtles (Decree N° 90,222); and Santa Isabel in the state of Sergipe was established in 1988 (Decree N° 96,999) to protect olive ridley turtles (*Lepidochelys olivacea*). In theory, the nesting beaches are easier to identify and protect (Mazaris et al., 2017). Nevertheless, marine turtles spend most of their time in-water and protection of critical oceanic habitat is crucial (Hochscheid et al., 2010). Four MPAs, outside of our study region, are known to offer protection to nesting and in water habitat for marine turtles, all of them located in off-shore islands, in which three are no-take, Biological Reserve of Rocas Atoll, Parque Nacional Marinho de Fernando de Noronha, and Parque Nacional Marinho dos Abrolhos. The fourth one is the multiple use MPA Area de Proteção Ambiental de Fernando de Noronha – Rocas – São Pedro e São Paulo.

Defining adequate targets for migratory marine species, such as marine turtles, is challenging (Mazor et al., 2016; Runge et al., 2014),

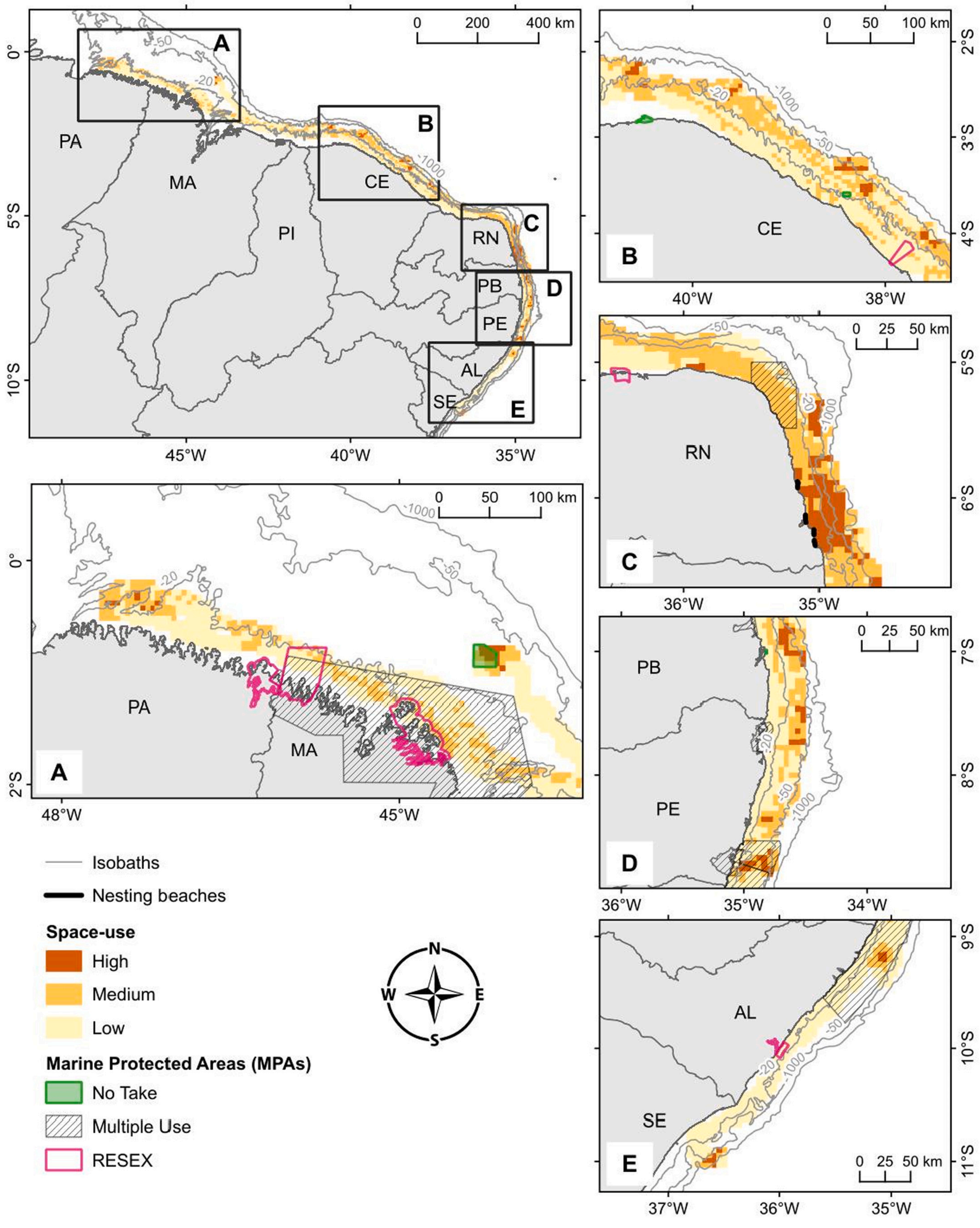

Fig. 6. Space-use of post-nesting hawksbill turtles (N = 36 turtles) nesting in Rio Grande do Norte, Brazil between the 2014/15 and 2018/19 nesting seasons (N = 36 turtles). PA– Pará state, MA – Maranhão state, PI – Piauí state, CE – Ceará state, RN – Rio Grande do Norte state, PB – Paraíba state, PE – Pernambuco, state AL -Alagoas state, SE – Sergipe state.

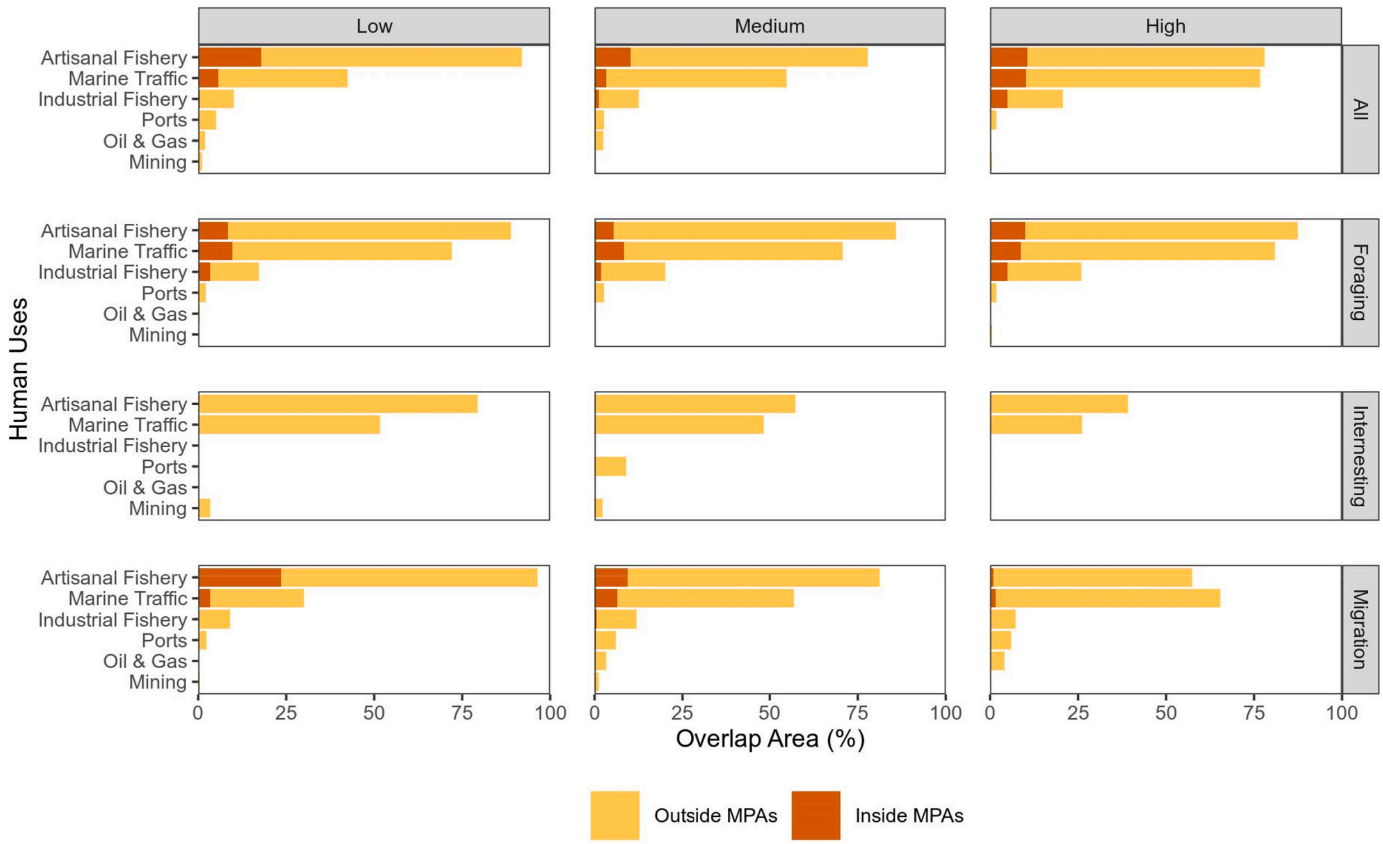

Fig. 7. Percentage of overlap between human activities and post-nesting hawksbill space use during internesting, migration, foraging and all behaviors and an indication of their overlap with MPAs (orange).

with targets for protection often related to protecting a specific proportion of a species distributional range and/or high use areas (for examples see Fuentes et al., 2019; Gerber and Heppell, 2004; Mazaris et al., 2014; Pompa et al., 2011). In the context of marine turtles, the zoning of the Great Barrier Reef Marine Park (GBRMP), is one of the few MPAs in the world which clearly states a quantifiable target for the protection of marine turtle habitat with a minimum of 20% of known foraging habitat for each occurring marine turtle species to be protected (Dryden et al., 2008). If a similar approach from GBRMP was applied in Brazil, to meet the 20% target, an additional 15.2% of the high use areas would need to be protected as no-take areas.

4.2. Limited spatial information on species' distribution and exposure to human activities

Knowledge of the spatial distribution and habitat use of species is paramount to identify key habitats, critical resources and discrete locations for the implementation of MPAs (Bailey et al., 2012; Schofield et al., 2013a; Schofield et al., 2013b; Fuentes et al., 2019). Applicability of such information is highlighted by Hays et al. (2019). However, information on the distribution and habitat use of post-nesting turtles in Brazil is limited and has only recently became available (Almeida et al., 2011; Da Silva et al., 2011; Marcovaldi et al., 2012, 2010; Santos et al., 2019). The only other study to date, apart from this one, tracking post-nesting hawksbill turtles in Brazil provided information on the distribution of nine hawksbill turtles nesting from February to March 2005 and was published in 2012 (Marcovaldi et al., 2012). Thus, no data on the spatial distribution of post-nesting hawksbill turtles existed when 86% MPAs in the region were designed and implemented.

Information on the spatial distribution of marine turtles is often challenging and prohibitively costly to obtain, particularly in developing countries (Antonio Puppim de Oliveira, 2002). In the last two decades, advances and accessibility to telemetry systems (e.g., as radio trackers, satellite transmitters and GPS loggers) (Godley et al., 2008) and in-water surveys has increased knowledge on the spatial distribution and migration pathways of marine turtles (e.g., Fuentes et al., 2020; Gredzens et al., 2014; Hays and Hawkes, 2018; Iverson et al., 2020; Shimada et al., 2016). Indeed, our study represents the largest dataset for post-nesting hawksbill turtles tracked in the Atlantic basin (see Hart et al., 2019 (N = 31); Nivière et al., 2018 (N = 11); Hawkes et al., 2012 (N = 10); Moncada et al., 2012 (N = 10); Marcovaldi et al., 2012 (N = 9); Revuelta et al., 2015 (N = 9); Van Dam et al., 2008 (N = 7); Horrocks et al., 2001 (N = 4); Cuevas et al., 2008 (N = 3); Troëng et al., 2005 (N = 2); Esteban et al., 2015 (N = 2)), with only one study globally to date using a larger number of tracked hawksbill turtles (Pilcher et al., 2014; N = 90). Any study utilizing satellite telemetry data to determine spatial distribution of species should consider the optimal sample size for accurate representation (Shimada et al., 2020). In the case of our study, the overlap between individual use areas of turtles during IN and MG indicates that those areas were likely appropriately delineated. However, the variability in areas used for foraging indicates that more individuals should be tracked in the future for a more fine -scale delineation. Regardless, the relatively large sample size of our study provides a broad indication of the areas used by post-nesting hawksbill turtles in the region, as a first step to identifying their distribution. As our dataset includes five consecutive nesting seasons, which accounts for at least two remigration intervals (Santos et al., 2013), it allowed for possible seasonal variances to be identified. Additional tracking coupled with less expensive approaches such as stable isotope analysis, may help identify foraging grounds for untracked individuals, maximizing the sample size in a much less expensive way (Ceriani et al., 2012; Zbinden et al., 2011).

Since 2014, an effort has been made in Brazil to expand the identification of areas of use by marine species, associated with monitoring requirements for activities with potential impact, such as seismic and ports (Barbosa and Owens, 2020). Indeed, the dataset collected for this study, as well as other programs (Santos et al., 2019) were possible due to such requirements. Thus, MPAs in the region should be revisited to incorporate such information on their management plans and to reassess whether species of conservation concern can be better protected by expanding existing or adding other protected areas. For example, a new multiple use MPA (APA dos Parrachos de Pirangi) is being proposed to protect a reef formation close to the nesting beaches considered in our study (Fig. S4). Implementation of this MPA would add 22% of protection to high use areas of post-nesting hawksbill turtles from Rio Grande do Norte state considering all behaviors together or 65% of high use areas during the internesting.

Unfortunately, management plans in Brazil are very rarely updated, and as a result new information is not often incorporated to MPAs after they have been designed and implemented (Gerhardinger et al., 2011; Magris et al., 2013; Mills et al., 2020). In the context of marine turtles, it is crucial that as information becomes available, especially those related to their distribution, habitat use and threats, that it is considered into management plans through an adaptive management approach. In particular, conservation planning approaches that consider delineation of movements and high use areas by species of conservation concern are very useful for the prioritization of areas for protection (for examples see Mazor et al., 2016; Fuentes et al., 2019).

However, information on species distribution is just a first step towards their conservation, to efficiently protect species, knowledge of the spatial-temporal extent of their exposure to threats is necessary (Dawson et al., 2017; Fuentes et al., 2020; Witt et al., 2011). Hawksbill turtles in Brazil are known to be impacted by a variety of threats (Marcovaldi et al., 2014; Marcovaldi et al., 2011a; Marcovaldi et al., 2011a; Montero et al., 2018). In particular, it has been suggested that small scale coastal fisheries might be a threat to post-nesting hawksbill turtles (Marcovaldi et al., 2006; Lima et al., 2010), with our study indicating that there is a large overlap between high use areas of post-nesting hawksbills and artisanal fishery. Indeed, more than 85% of hawksbill turtles stranded in the coasts of Rio Grande do Norte and Ceara states, approximately between 150 and 400 km north from the nesting beaches considered in this study, showed signs of interactions with fishing gears (Farias et al., 2019). Thus, efforts to minimize interactions between fisheries, and the other activities that overlap with areas of high use by post-nesting hawksbills should be considered in the region. Importantly, there is still the need to quantify the impact of those activities to the stability of this hawksbill subpopulation and determine the most effective mitigation strategies to reduce threats to the population (Dawson et al., 2017; Fuentes et al., 2020; Maxwell et al., 2011; Witt et al., 2011). Indeed, knowledge of the overlap between human activities and the spatial extent of species of conservation concern is expanding, however little is known on the long-term impacts of these threats to population stability (Fuentes et al., 2020; Lascelles et al., 2014b). Thus, future work should focus on quantifying the overall mortality and impact from known human stressors and couple these assessments with population models to determine which human activities are of most concern (Bolten et al., 2011). Trend assessments for the hawksbill subpopulation studied here indicates that nest numbers are found to be stable, although only data from eight nesting seasons were used on the assessments hindering robust conclusions (Santos et al., 2013). Nevertheless, to avoid future declines to hawksbill turtles in the region, continued management and protection is necessary both on land and in-water (Marcovaldi et al., 2011a), particularly in areas of high use, which would benefit from robust quantifiable information of age and sex specific mortality.

4.3. Mismatch of spatial scale

Post-nesting hawksbill turtles from Rio Grande do Norte state were found to migrate over 1600 km north and 600 km south of the nesting beaches where they were tagged, with foraging sites distributed across nine states. Similarly, post-nesting hawksbill turtles tracked from Bahia also crossed several states (Marcovaldi et al., 2012), with information from flipper tags confirming their broad range (Santos et al., 2019). Thus, management and protection measures need to be implemented at scales compatible to their distribution and require coordination and cooperation from Brazilian authorities at local, state and federal levels. However, MPAs in Brazil are designed and managed at the provincial scale, where inter-state connections are rare, and without integration with other geopolitical units (Gerhardinger et al., 2018; Vieira et al., 2019). Importantly, as hawksbill turtles are highly migratory consideration should also be given to maximize connectivity between protected areas (Beger et al., 2015), which can be informed by identifying migratory corridors (Iverson et al., 2020; Mazor et al., 2016; Pendoley et al., 2014; Stokes et al., 2015). Our study identified specific migratory corridors that link movements from hawksbill's nesting to foraging areas, these areas should be incorporated into future conservation prioritization efforts in the region.

4.4. Increasing the protection of post-nesting hawksbill turtles in Brazil and insights into the design of marine protected areas for migratory marine species

Valuable information on the spatial-temporal distribution and exposure of human activities to post-nesting hawksbill turtles in the north and northeast of Brazil was provided by our study. It is clear from our analysis and other studies (Marcovaldi et al., 2010; Marcovaldi et al., 2012) that coastal areas adjacent to nesting beaches are of high importance for post-nesting marine turtles, making them ideal candidates for protection. Indeed, in Australia, a buffer of 5 km around marine turtle nesting beaches was implemented for the protection of internesting habitat (Dobbs, 2007; Dryden et al., 2008) and nesting females. In our study site, internesting habitat extends up to 14.5 km from the shore, as a result a 5 km buffer may not be sufficient, as it would represent only 9% all high use areas of post-nesting hawksbill turtles and 48% of IN high use areas. Importantly, due to the seasonal use of these areas they do not need to be protected year-round and can be seasonally protected. Protecting key habitat where individuals aggregate for certain period of time may be a valid option to reduce pressures on marine turtles while reducing disturbance to other users of the area (Grantham et al., 2008; Seminoff et al., 2008; Shillinger et al., 2008). In locations where species of conservation concern overlap with human activities, seasonal closures are believed to be considered more acceptable to impacted stakeholders (Allen and Singh, 2016). Indeed, seasonal restrictions are already commonplace in Brazil to protect nesting turtles. Seasonal restriction exists in shrimp trawling efforts in Sergipe state to protect olive ridley turtles during their internesting season (Silva et al., 2010), as well as in Espirito Santo state to protect nesting leatherback and loggerhead turtles (Diario Oficial da Uniao, 2018). Additionally, a normative instruction was published in 2011 by the federal government, establishing periodic restriction for oil and gas exploration and production activities during marine turtle nesting season in four regions in Brazil, which reflect the main nesting areas for loggerhead, leatherback, olive ridley and hawksbill turtles, including our study site (IBAMA, 2011). These periodic restrictions include restriction of activities such as installation of pipelines and geotechnical surveys within a buffer of 5.4 km from shore, protecting 52% of IN high use areas. For seismic surveys and drilling of oil wells the restrictions are up to 27 km from shore, encompassing the whole IN high use areas of post nesting hawksbills tagged in our study. The seasonal protection promoted by this normative instruction also comprises 41% of FG high use areas and 54% of all high use areas.

To expand protection of the post-nesting hawksbill turtles in Brazil and the appeal to implement future MPAs, information from this study on high use areas of post-nesting hawksbill turtles and human activities should be combined with information on the spatial-temporal distribution of other species of conservation concern to inform areas of high priority for multiple species (Pendoley et al., 2014; Magris et al., 2016; Asaad et al., 2018). Post-nesting hawksbill turtles from turtles tagged in Bahia (Marcovaldi et al., 2012), as well as other marine turtle species, such as loggerheads (Marcovaldi et al., 2010) and olive ridleys turtles (Da Silva et al., 2011; Santos et al., 2019) were also found to forage off the coasts of Rio Grande do Norte, Ceará and Pará states. Compilation of information on the use of these species in the region with a threat assessment may help identify areas which would benefit the most from protection to sustain marine turtle populations.

Importantly, identification of areas that will benefit the most from protection is just a first step towards conservation of species such as hawksbill turtles. In Brazil, increased compliance and enforcement of MPA regulations is a major problem because of managers' inability to survey the region, due to problems such as institutional instability and lack of infrastructure and resources (Gerhardinger et al., 2011). Strengthening the capacity of managers to monitor MPAs is needed to ensure compliance to regulations and therefore achievement of their goals. Additionally, consideration of the level of protection provided by the existent network of MPAs is needed, since we found that high use areas within MPAs are still exposed to fisheries and marine traffic. Valuable guidance is provided by Mills et al. (2020) on best practices to improve the effectiveness of the Brazilian MPA network. Conservation of charismatic species of conservation concern, such as hawksbill turtles, would undoubtedly benefit from community engagement through awareness and educational campaigns (Day and Dobbs, 2013; da Silva et al., 2016).

4.5. Conclusion

The results and insights provided here can directly inform MPA planning and design not only in Brazil but also elsewhere. To avoid spatial mismatch of future MPAs with important areas for species of conservation concern, managers should ensure that they: (1) clearly state and make their conservation goals and targets tangible (Margules and Pressey, 2000), (2) use the best available information on the target species and precautionary principle, considering expert opinions in cases where such information is missing (Fernandes et al., 2005), (3) consider ecological scales instead of political boundaries (Beger et al., 2015), (4) involve all impacted stakeholders for improved compliance and acceptability (Arias et al., 2014), and (5) use adaptative management as new information become available (Fuentes et al., 2016; Nickols et al., 2019).

CRediT authorship contribution statement

Armando J.B. Santos: Conceptualization, Data curation, Writing – original draft, Investigation. **C. Bellini:** Investigation. **E.A.P. Santos:** Writing – review & editing. **G. Sales:** Writing – review & editing. **R. Ramos:** Writing – review & editing. **D.H.G. Vieira:** Investigation. **M.A. Marcovaldi:** Funding acquisition. **Anthony Gillis:** Formal analysis, Writing – review & editing. **N. Wildermann:** Software, Formal analysis, Writing – review & editing. **M. Mills:** Writing – review & editing. **T. Gandra:** Formal analysis, Writing – review & editing. **M.M.P.B. Fuentes:** Conceptualization, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2021.109229.

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