UNIVERSIDADE FEDERAL DE ALAGOAS
INSTITUTO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos

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AVALIAÇÃO DAS AMEAÇAS À TARTARUGA-VERDE (*Chelonia mydas*) EM AMBIENTE RECIFAL

MACEIÓ - ALAGOAS
Fevereiro/2023

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Dissertação/Tese apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde. Universidade Federal de Alagoas, como requisito para obtenção do título de Mestre/Doutor em CIÊNCIAS BIOLÓGICAS, área de concentração em Conservação da Biodiversidade Tropical.

Orientador(a): Prof. Dr. Robson Guimarães dos Santos

MACEIÓ - ALAGOAS
Fevereiro/2023

Catalogação na fonte
Universidade Federal de Alagoas
Biblioteca Central
Divisão de Tratamento Técnico Bibliotecária
Responsável: Betânia Almeida dos Santos – CRB-4 - 1542

O48a Oliveira, Priscilla Monteiro de.
Avaliação das ameaças à tartaruga-verde (Chelonia mydas) em ambiente recifal / Priscilla Monteiro de Oliveira. – 2023.
66 f. : il. color.

Orientador: Robson Guimarães dos Santos.
Dissertação (Mestrado em Ciências Biológicas) – Universidade Federal de Alagoas. Instituto de Ciências Biológicas e da Saúde. Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos. Maceió, 2023.

Bibliografia: f. 17-21.

1. Tartaruga-verde – conservação – habitat . 2. Tartaruga-verde – captura acidental . 3. Àreas marinhas – urbanização. 4. Zona costeira – poluição. I. Título.

CDU: 574.2

Folha de aprovação

Priscilla Monteiro de Oliveira

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Dissertação apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde da Universidade Federal de Alagoas, como requisito para obtenção do título de Mestre em CIÊNCIAS BIOLÓGICAS na área da Biodiversidade.

Dissertação aprovada em 23 de fevereiro de 2023.

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ROBSON GUIMARAES DOS SANTOS
Data: 23/02/2023 14:29:26-0300
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Data: 23/02/2023 17:06:03-0300
Verifique em https://verificador.iti.br

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MACEIÓ - AL
Fevereiro/2023

AGRADECIMENTOS

Agradeço primeiramente à Deus.

Agradeço à minha família, mesmo passando por tempos difíceis, mesmo sofrendo cada uma à sua maneira, ainda se colocaram à disposição para me apoiar. Também agradeço, pois, souberam estar presentes quando foi necessário e souberam sair de perto, quando ficou perigoso para eles.

Agradeço ao meu companheiro Felipe, que teve participação direta na confecção dessa dissertação. Agradeço a paciência que ele teve comigo, e todas as frases de motivação em meio ao desespero. Suas contribuições não serão esquecidas, e espero poder retribuir.

Agradeço imensamente à minha psicóloga Sílvia. Entendo que ela estava fazendo seu trabalho, mas de uma maneira tão graciosa e acolhedora, que fez muita diferença.

Agradeço aos meus companheiros de laboratório. Desde os que coletaram e analisam boa parte dos dados utilizados neste trabalho, até os que participaram de discussões, auxílio com artigos, ou mesmo palavras de suporte.

Agradeço ao Instituto BIOTA de Conservação, que cedeu gentilmente as tartarugas utilizadas aqui, e que também fazem um trabalho essencial de preservação no estado.

Finalmente, agradeço ao meu orientador, Robson Guimarães dos Santos, pela compreensão, apoio e incentivo ao longo desses três anos, e seus altos e baixos.

RESUMO

As alterações antrópicas afetam profundamente a dinâmica costeira e a manutenção dos ecossistemas. Essas alterações e o crescimento da população humana são conhecidos por serem as origens de muitas ameaças às tartarugas verdes (*Chelonia mydas*), um megaherbívoro marinho de vida longa. Aqui, buscou-se entender a distribuição espacial de *C. mydas* na mais extensa unidade de conservação marinha federal brasileira - a Área de Proteção Ambiental Costa dos Corais (APACC) - e como ela está associada a diversas ameaças: pesca, fibropapilomatose, ingestão de lixo e empobrecimento da dieta. Para isso, foram utilizadas imagens aéreas obtidas por drones de pesquisa para identificar a localização das tartarugas, e um banco de dados de tartarugas encalhadas com informações sobre: presença/ausência e severidade de fibropapilomatose, quantidade de plástico ingerido e identificação de itens alimentares ingeridos. Também foram utilizados dados de lixo nas praias e cobertura bentônica da APACC. Foram investigas as relações entre os locais de maior agregação de *C. mydas* e os itens considerados como ameaças diretas ou cumulativas, buscando definir "*hotspots*" para conservação da espécie a nível local. Os resultados demonstram que *C. mydas* apresenta uma distribuição heterogênea ao longo da costa, com áreas de alta concentração. As regiões central e sul da APACC são os locais de maior densidade de tartarugas. Por fim, destacam-se as cidades de Maceió e Japaratinga como áreas prioritárias para a intensificação das ações conservacionistas, por apresentarem altos níveis de múltiplas ameaças e alta densidade de tartarugas.

PALAVRAS-CHAVE

Áreas Marinhas Protegidas; Urbanização; Zona costeira; Impactos antropogênicos; Poluição plástica; captura acidental.

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1 APRESENTAÇÃO

Com distribuição global tropical e subtropical, *Chelonia mydas* é uma das 7 espécies de tartarugas marinhas existentes. Categorizada como ameaçada de extinção (IUCN, 2014), essa espécie se diferencia das outras por possuir hábitos costeiros e dieta majoritariamente herbívora. Esses atributos fazem com que a espécie execute o papel ecológico de megaherbívoro, importante para controlar o crescimento de gramas marinhas e algas, que competem diretamente com os corais. Neste trabalho, será apresentada a distribuição de *Chelonia mydas* ao longo de 95 km da Área de Proteção Costa dos Corais (Alagoas - BR), assim como locais de maior incidência de encalhes.

Atualmente, as principais ameaças reportadas para a espécie têm sido a pesca, deposição de lixo nas praias e degradação do ambiente marinho através do aumento de doenças infecciosas e diminuição da qualidade alimentar (Santos *et al.,*2010; Melo *et al.,* 2010; Bastos *et al.,* 2022). Portanto, os dados oriundos deste trabalho, referentes à essas ameaças citadas serão associadas à ocorrência de indivíduos da espécie, buscando definir as áreas de maior pressão antrópica para *C. mydas*. Aqui, buscamos definir os graus de interação antrópica com as tartarugas. Utilizamos os dados de cabanas de pesca distribuídas ao longo da costa como um *proxy* para medir a intensidade da atividade pesqueira. Para deposição de lixo, coletamos resíduos antrópicos ao longo da faixa de areia e comparamos com lixo encontrado no trato gastrointestinal de indivíduos encalhados. E finalmente, para avaliar a urbanização, utilizamos os dados de luz noturna, relacionando-o a fibropapilomatose e empobrecimento da dieta (número de gêneros ingeridos).

Este estudo buscou fornecer dados relevantes à tomada de decisão em uma importante área protegida, mas não se limita diretamente a ele. Os dados aqui fornecidos poderão ser utilizados para melhor compreensão das relações entre *C. mydas* e possíveis ameaças às suas populações, ao longo de toda a costa brasileira. Esperamos que nosso mapeamento de ameaças resultantes de diferentes bancos de dados possa ser útil para planejar a intensificação das atividades de monitoramento de tartarugas, e educação ambiental.

2 REVISÃO DE LITERATURA

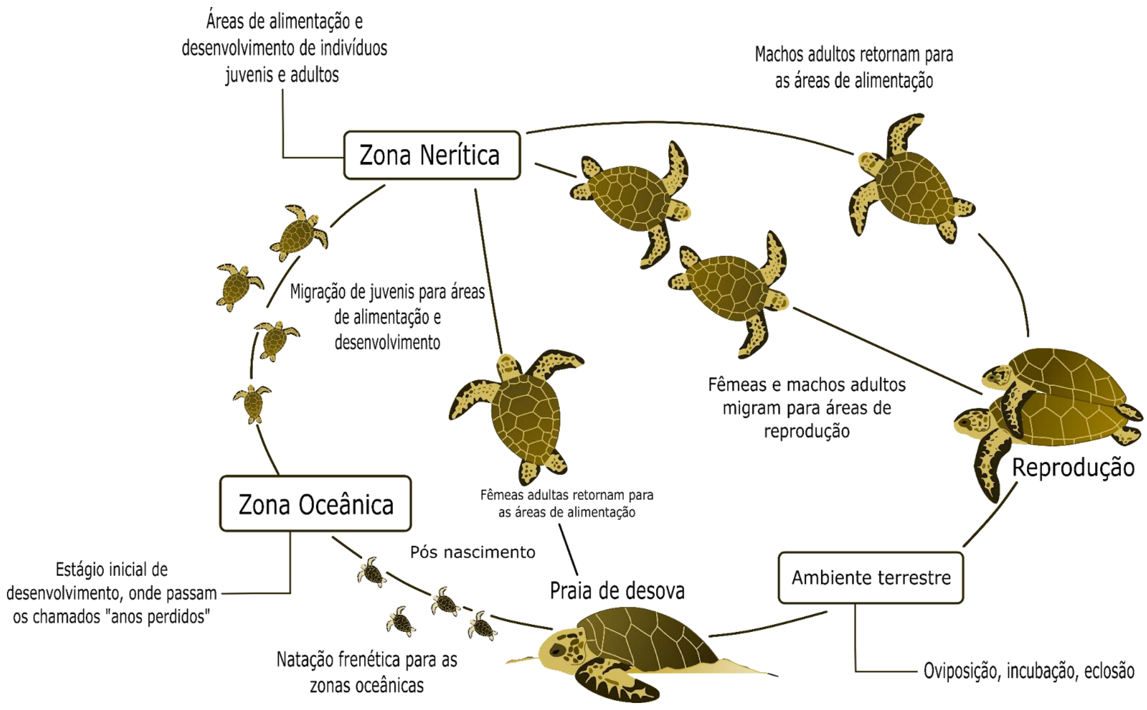
2.1 Tartarugas-verdes: Ciclo de vida

As tartarugas marinhas apresentam um ciclo de vida longo e com várias mudanças de hábitat, uma vez que usam inúmeros ambientes para o seu desenvolvimento (PERES; MAGRIS; RIBEIRO, 2011). Apesar de serem animais marinhos, é no ambiente terrestre que colocam seus ovos (HIRTH, 1997). Nesse propósito, as tartarugas seguem até a praia para desovar e garantir o melhor local para o nascimento de seus filhotes. Logo após o nascimento, os filhotes seguem para o alto mar em busca de alimento e de proteção. Na fase juvenil, quando atingem tamanhos de comprimento curvilíneo da carapaça (CCC) entre 20 e 35 cm, retornam para a zona nerítica (BJORNDAL & BOLTEN, 1988). Esse grupo atinge a idade adulta entre 20 e 30 anos e permanece em locais de alimentação até a reprodução (HIRTH, 1997). Nessa fase da vida as tartarugas marinhas migram até as praias onde nasceram para fazer a desova, possibilitando um local adequado para o nascimento dos filhotes (LOPES *et al.,* 2021).

Existem sete espécies de tartarugas marinhas em escala mundial pertencentes a duas famílias – as famílias *Cheloniidae* e *Dermochelyidae* – das quais cinco são encontradas em mares brasileiros. A família *Cheloniidae* agrupa quatro espécies: tartaruga-cabeçuda (*Caretta caretta*), tartaruga-oliva (*Lepidochelys olivacea),* tartaruga-de-pente (*Eretmochelys imbricata*) e a tartaruga-verde (*Chelonia mydas*). Já a família *Dermochelyidae* possui uma única espécie, a tartaruga-de-couro (*Dermochelys coriacea).* Salienta-se que as tartarugas marinhas pertencem à mais antiga linhagem de répteis vivos, tendo aparecido inicialmente no período jurássico (MÁRQUEZ, 1990; LOPES *et al.,* 2021).

A tartaruga-verde (*Chelonia mydas*) foi descrita por Linneaus no ano de 1758 o qual a denominou de "*Testudo mydas".* Anos mais tarde, o nome genérico *Chelonia* foi introduzido por Brongniart (1800) (FORMIA, 2002). Trata-se de uma das espécies mais comuns no litoral brasileiro e faz parte da lista de espécies ameaçadas de extinção em escala mundial (SEMINOFF *et* al., 2015; LOPES *et al.,* 2021). A tartaruga-verde, bem como as demais tartarugas marinhas, exibem um ciclo de vida bastante complexo em sua movimentação (Figura R1), no qual realizam extensas migrações por *habitats* que se distanciam centenas ou milhares de quilômetros. Esse grupo de répteis tem alta longevidade (MÁRQUEZ, 1990; BONDIOLI, 2009), sendo os estudos de marcação e recaptura uma atividade informativa para o avanço da compreensão sobre esses répteis. Dados valiosos para obter informações a respeito do ciclo de vida, das migrações reprodutivas, do crescimento lento e da maturação sexual tardia (BALASZ, 1999).

Figura R1: ciclo de vida das tartarugas marinhas.



Fonte: Ingredy da Silva, adaptado de Miler et al, 1996.

A espécie não recebeu o nome comum de tartaruga-verde em razão da coloração do seu corpo ou de sua carapaça, mas por causa da tonalidade esverdeada de sua gordura (WYNEKEN, 2001). O plastrão possui uma coloração que varia entre branco ou amarelo claro e a pele comumente é cinza ou marrom, exibindo uma auréola mais clara margeando as escamas e um tom amarelo muito claro na porção ventral das nadadeiras, conforme mostra a Figura R2 (WYNEKEN, 2001).

Figura R2: *Chelonia mydas* nas fases filhote, juvenil e adulta.

Fonte: www.seaturtle.org

A literatura abarca muito conhecimento a respeito dos hábitos alimentares, desenvolvimento e comportamento durante a etapa oceânica da ontogenia desses animais (BJORNDAL, 1997; PERES; NARO-MACIEL *et al.,* 2008; MAGRIS; RIBEIRO, 2011; SANTOS *et al.,* 2015). Contudo, estudos realizados com amostras extraídas dos escudos da carapaça de filhotes demonstraram que durante essa fase da vida as tartarugas-verdes possuem hábitos alimentares onívoros – essa alimentação tem duração média de três a cinco anos (REICH, 2007). Já durante a fase juvenil são encontradas com frequência próximas à costa, em recifes, baías e regiões estuarinas, caracterizadas pela forte presença de algas, alimentos preferenciais dessa espécie (SANTOS *et al.,* 2015). Além disso, essas áreas são conhecidas por serem áreas propícias para a proteção contra os possíveis predadores desses indivíduos (BONDIOLI, 2009).

Ao se espalharem pelas áreas de alimentação pode haver em uma única área animais apresentando estoques genéticos distintos (PERES; MAGRIS; RIBEIRO, 2011). Esse fator foi comprovado por estudos genéticos realizados na costa brasileira que indicaram a presença de haplótipos da Ilha da Trindade, Ilha de Ascensão, Atol das Rocas, México, África, Costa Rica e Suriname (NARO-MACIEL *et al.,* 2008).

2.2 O papel ecológico de megaherbívoro marinho

Chelonia mydas é uma das espécies marinhas de distribuição circunglobal, caracterizada como um animal marinho altamente migratório com movimentos sazonais (LOPES *et al.,* 2021). É um dos poucos megaherbívoros – herbívoros que possuem massa corporal acima de 10 kg – marinhos existentes (BASTOS et al., 2022). Esses animais têm a capacidade de impactar as comunidades de gramas marinhas, modificando a composição e os níveis de produtividade das espécies de angiospermas (BAKKER *et al*., 2016).

Os adultos de *C. mydas* costumam apresentar hábito herbívoro, alimentando-se de algas verdes, vermelhas e marrons e grama marinha de inúmeras espécies disponíveis em áreas conhecidas como áreas de alimentação, que podem ocasionalmente ser frequentadas por animais adultos e subadultos, tanto machos quanto fêmeas (BJORDAL, 1997). Na costa brasileira, uma região localizada no sudoeste do Oceano Atlântico, com uma área pequena de gramas marinhas, e impacto antrópico moderado a alto, as tartarugas-verdes costumam se alimentar sobretudo de macroalgas (SANTOS *et al.,* 2015; COPERTINHO *et al.,* 2015).

Os impactos ambientais e a ação humana ocasionam implicações na disponibilidade de recursos alimentares para as tartarugas-verdes (SANTOS *et al.,* 2015). Em ambientes expostos a poluição por efluentes domésticos e industriais, as espécies mais vulneráveis que fazem parte da dieta da tartaruga-verde irão desaparecer com o tempo e as mais tolerantes, como as algas verdes, terão mais espaço nessas áreas (FERREIRA, 2018). Estudos indicam que em áreas mais urbanizadas a riqueza de espécies marinhas é menor em relação a áreas não urbanizadas, ressaltando o efeito negativo da poluição (PORTUGAL *et al*., 2016). Desse modo, mesmo que esses animais tenham preferências alimentares a composição da dieta irá sofrer efeitos decorrentes do nível de urbanização da área de forrageamento o que irá desencadear problemas à saúde da espécie com restrições nutricionais (SANTOS *et al.,* 2015; COPERTINHO *et al.,* 2015).

2.3 Ação antropogênica: impactos no *habitat* de tartarugas-verde

A degradação ambiental e a poluição são exemplos de ameaça a esses animais. Artefatos como restos de redes de pesca, isopor e plástico afetam diretamente a espécie durante todo o seu ciclo vital (BONDIOLI, 2009). Quando filhotes, por exemplo, podem ficar enredados em materiais flutuantes – a chamada pesca-fantasma – no decorrer das zonas de convergências (BUGONI *et al*., 2001). Os indivíduos podem se alimentar de restos de plásticos que se parecem com algas e gramas marinhas. Todos esses fatores podem desencadear consequências graves a vida desses animais, como a obliteração do trato digestório, a alimentação em menor quantidade em decorrência da sensação de saciedade e, até mesmo a origem de fecalomas produzidos por meio da compactação do lixo consumido (BUGONI *et al*., 2001; POLI *et al,* 2015; SANTOS *et al,* 2020).

A ocupação de áreas costeiras também pode comprometer praias de desova, pois a presença humana pode impedir as fêmeas de construírem seus ninhos. A presença de animais domésticos e de animais exóticos também podem causar impedimento por serem possíveis predadores de fêmeas, filhotes e ovos. A iluminação é outro elemento prejudicial, pois pode causar desorientação de fêmeas e de filhotes que são atraídos para o lado oposto ao mar e, assim, podem acabar morrendo por desidratação e exaustão (LORNE and SALMON, 2007).

A captura incidental em ampla escala é, atualmente, a principal responsável pelos maiores índices de mortalidade de tartarugas marinhas em todo o mundo (LOTZE *et al*., 2006; WALLACE *et al*., 2011). Compreende-se por captura incidental, a captura de animais que não são os reais alvos de determinado tipo de pesca, sendo as aves e tartarugas vítimas frequentes dessa captura. O arrasto e o espinhel – petrechos utilizados para a captura de camarões e peixes de alto valor comercial – são os principais causadores das capturas incidentais e mortes desses animais (SALES, 2008).

Analisar a relação entre a degradação da região costeira com os parâmetros de saúde dessa espécie oportuniza, além da proposição de estratégias para sua conservação como megaherbívoro marinho, o uso dos dados sobre as tartarugas como indicadores da qualidade ambiental dos *habitats* costeiros. Nesse caminho, podem ser verificados os impactos provocados pelos contaminantes e efluentes domésticos, a modificação da comunidade bentônica – organismos que vivem no substrato de ambientes aquáticos – entre outros (FERREIRA, 2018).

Em estudo realizado nas regiões costeiras com a presença de tartarugas-verdes, mais precisamente áreas localizadas nos estados de Pernambuco, Bahia, Espírito Santo e São Paulo, foi possível avaliar a ingestão de resíduos antropogênicos no trato gastrointestinal em 193 tartarugas, das quais 120 ingeriram lixo – o que equivale a 62,2% da amostra – e, ao todo, foram encontrados 3695 itens que haviam sido consumidos pelos indivíduos. Ademais, o estudo constatou que a frequência de ingestão de resíduos antrópicos manteve-se alta independentemente do nível de urbanização do local (FERREIRA, 2018).

2.4 Os reflexos dos impactos ambientais em regiões costeiras urbanizadas

As tartarugas marinhas possuem uma incidência de interações antrópicas que atingem direta ou indiretamente suas populações, podendo abranger o consumo de detritos antrópicos, impactos das mudanças climáticas no ambiente marinho, degradação e poluição de habitats de nidificação e forrageamento, colisão em embarcações, e emaranhamento por redes de pesca (BASTOS et al., 2022). No entanto, especificamente para *Chelonia mydas*, os efeitos da ingestão e exposição a polunetes atingem diretamente a fisiologia do animal, danificando o sistema digestório e, em decorrência disso, enfraquecendo os demais sistemas (MELO *et al.,* 2010).

O uso de regiões costeiras pelo homem é crescente e, com isso, os impactos provocados no ambiente costeiro – terrestre, estuarino ou marinho – afetam inúmeras espécies marinhas (CLAUSEN & YORK, 2007; CREEL, 2003; LOTZE *et al*., 2006). A degradação ambiental influencia no valor nutricional das principais algas ingeridas pela tartaruga-verde. Isso porque em áreas urbanizadas essa espécie adota uma dieta mais rica em proteínas, lipídios e carboidratos e menor em carotenóides, ou seja, com redução de pigmentos fotossintéticos e fotoprotetores provenientes das algas e plantas (esses elementos são precursores da vitamina A e envolvidos no transporte de oxigênio em animais) (BASTOS *et al.,* 2022).

Os altos níveis de ficobiliproteínas e proteínas em áreas urbanizadas pode ser resultante da poluição orgânica, bem como da acumulação de nitrogênio nas águas costeiras. Ressalta-se que os compostos de nitrogênio dissipados na água são uma ameaça para os vertebrados em razão da sua toxicidade e implicações negativas sobre o sistema imunológico. Estudos evidenciam que a composição química das algas aliada a fibropapilomatose – tumores decorrentes de um herpesvírus nas tartarugas-verdes – estão intimamente relacionados com as alterações ambientais ocasionadas pela urbanização (BASTOS *et al.,* 2022).

2.5 Fibropapilomatose: uma ameaça a sobrevivência das tartarugas marinhas

Doenças e parasitas são ameaças naturais das tartarugas marinhas. Dentre as doenças, ressalta-se a fibropapilomatose (FP), doença em que ocorre o crescimento de tumores tanto internos quanto externos e de tamanho variável, de causa viral e atrelada a fatores negativos como poluição e aquecimento das águas (FOLEY, 2005). A FP é um importante apontador do estado de saúde das tartarugas, uma vez que é uma patologia neoplásica, ligada a um herpesvírus, de escalas epizoóticas recentes, achadas em tartarugas que estão associadas a áreas costeiras degradadas (BORYSENKO & LEWIS, 1979; SANTOS *et al*., 2010).

Os tumores característicos da doença podem aparecer na pele, nadadeiras, tecidos perioculares, carapaça e plastrão – quando desenvolvidos de modo externo – e em órgãos internos como fígado, pulmões, baço, trato gastrointestinal, rins e gônadas (AGUIRRE; LUTZ, 2004). O crescimento dos tumores em locais distintos, podem comprometer desempenhos essenciais à sobrevivência destes animais, como a alimentação e deslocamento e, quando acometem os olhos, podem causar impactos à visão, incluindo cegueira (BONDIOLI, 2009). Além disso, a FP é multifatorial, podendo sofrer influência de mudanças de temperatura da água, poluentes ambientais ou, ainda, de biotoxinas. Apesar da falta de precisão para determinar os fatores causadores da doença nas tartarugas, sabe-se que esta pode estar diretamente associada à qualidade ambiental, apresentando-se em populações com baixa imunidade causada por poluição ambiental (BORYSENKO & LEWIS, 1979; BONDIOLI, 2009; SANTOS *et al*., 2010).

A dieta comprometida de tartarugas marinhas em áreas costeiras impactadas oportuniza uma maior ocorrência dessa patologia, conforme indicam estudos (SANTOS *et al.,* 2010). Isso porque além dos prejuízos para crescimento e maturação sexual desses animais, a restrição de itens na dieta também pode ocasionar déficit no sistema imunológico, uma vez que algumas algas que deveriam fazer parte da dieta desses indivíduos geram metabólitos secundários que possuem efeito antitumoral e antiviral. Logo, uma vez sem esses itens na dieta, as tartarugas podem tornar-se mais propícias para o aparecimento de doenças como a FP (SANTOS *et al.,* 2010; SPOSATO, 2014).

2.6 Área de Proteção Ambiental Costa dos Corais – APACC

Para reduzir o impacto de ameaças à biodiversidade são propostas as Áreas de Proteção Marinha (APM), fundamentais para programas mais amplos de conservação do patrimônio marinho e o sistema de suporte à vida. As APMs são importantes também para garantir que os recursos marinhos vivos sejam usados de forma sustentável ecologicamente e, se bem-sucedidas, ajudar a reconstruir a produtividade dos oceanos. Para minimizar os impactos das ameaças às tartarugas verdes em APMs, portanto, faz-se necessário identificar a distribuição das ameaças, seu nível de interação com as tartarugas e assim, planejar estratégias de conservação adequadas às condições locais de gerenciamento, levando em consideração as áreas usadas para forrageamento e alimentação (MCCLENACHAN *et al*., 2006; LOTZE *et al*., 2006; HALPERN *et al*., 2008; SCOTT *et al*., 2012; CHRISTIANEN *et al*., 2014; FUENTES *et al*., 2019).

Inúmeros são os empenhos de conservação para que as populações de tartarugas-verdes mostrem sinais de recuperação, incluindo as populações que habitam áreas costeiras brasileiras. Nesse sentido, o acúmulo de informações locais a respeito da ecologia da espécie auxilia os gestores das unidades de conservação na tomada de decisões, e nas estratégias e ações voltadas para a conservação (MAIDA; FERREIRA, 2003).

No Brasil, a maior unidade de conservação da área costeira é a Área de Proteção Ambiental Costa dos Corais (APACC) que tem 135 km de costa e mais de 4000 mil hectares entre áreas terrestres e marinhas (SOBRAL, 2020). O objetivo primordial da APACC e razão pela qual foi criada é proteger seus amplos recifes rasos que estão dispostos paralelamente a linha da costa e são usados como abrigo e como área de alimentação para muitas espécies marinhas (ICMBio, 2021). Na superfície desses recifes podem ser encontrados algas calcárias, corais, zooantídeos e inúmeras macroalgas, itens importantes para a qualidade da alimentação de muitas espécies marinhas (MAIDA; FERREIRA, 2003). Os ecossistemas marinhos presentes na APACC dão abrigo e alimento para diversos organismos, abrangendo inclusive espécies da megafauna marinha, como golfinhos, peixe-boi e tartarugas marinhas, por exemplo (SOBRAL, 2020).

Importa destacar que rios também estão presentes na extensão da APACC e são considerados como uma das fontes essenciais para carregar sedimentos e nutrientes para regiões recifais do mar (PEREIRA, 2013; ICMBio, 2021). Salienta-se que essa carga aumenta consideravelmente durante os períodos chuvosos ao longo do ano (SILVA *et al*., 2022). Por meio do carreamento, os rios viabilizam a cobertura bentônica dos recifes e, em virtude disso, na disponibilidade de alimentos para espécies como as tartarugas-verdes que, por sua vez, fazem uso dos recifes como área de alimentação. Todavia, informações a respeito dos fatores que cercam a ecologia alimentar das tartarugas-verdes na APACC ainda são insuficientes (SOBRAL, 2020). Assim como dados populacionais, que ainda são escassos para as populações costeiras, sendo prejudiciais para o planejamento de estratégias eficientes na conservação desses animais (MAZARIS *et al*, 2006).

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3. EVALUATING THREATS TO GREEN TURTLES (*Chelonia mydas*) ON COASTAL REEF HABITATS

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ABSTRACT

Anthropogenic changes profoundly affect coastal dynamics and the maintenance of ecosystems. These changes coupled with human population growth are known to be the origins of many threats to green sea turtles (*Chelonia mydas*), a long-lived marine megaherbivore. Here, we sought to understand the spatial distribution of *C. mydas* in the most extensive Brazilian federal marine conservation unit - the Costa dos Corais Environmental Protection Area (APACC) - and how it is associated with various threats: fishing, fibropapillomatosis, ingestion of garbage and impoverishment of the diet. For this, aerial images obtained by research drones were used to identify the location of the turtles, and a database of stranded turtles with information on: presence/absence and severity of fibropapillomatosis, amount of plastic ingested and identification of ingested food items. Data on litter on beaches and benthic coverage from the APACC were also used. The relationships between the places with the highest aggregation of *C. mydas* and the items considered as direct or cumulative threats were investigated, seeking to define *"hotspots"* for the conservation of the species at the local level. The results demonstrate that *C. mydas* has a heterogeneous distribution along the coast, with areas of high concentration. The central and southern regions of the APACC are the places with the highest density of turtles. Finally, the cities of Maceió and Japaratinga stand out as priority areas for the intensification of conservation actions, as they present high levels of multiple threats and high density of turtles.

KEYWORDS: Marine Protected Areas; Urbanization; Coastal zone; Anthropogenic impacts; Plastic pollution; By-catch; ALAN.

3.1 INTRODUCTION

Coastal ecosystems are among the most productive and biodiverse systems of the world (Ngoile & Horrill, 1993; Birch & Reyes, 2018). Historically, anthropogenic alterations profoundly affected coastal dynamics and compromised their capacity to deliver many ecosystem services though it is still an important source of food to humans and habitat for a range of species (Agardy, 2005). One of the most common vertebrate species in the coastal ecosystems is the green turtle (*Chelonia mydas*), a long-living marine megaherbivore that plays an important ecological role by controlling the populations of marine grasslands and algae that compete directly with corals (Arthur & Balazs, 2008; Goatley et al., 2012).

Although *C. mydas* populations had a dramatic recovery in the last decades (HIRTH, 1997; Broderick et al., 2006), the species is still listed as endangered and threats to their survival are common (Seminoff 2004). Such threats range from intentional capture to the increasing degradation of coastal environments, which often leads to the occurrence of diseases, litter ingestion and diet impoverishment (Bastos et al., 2022; Creel, 2003; Lotze et al., 2006; Wallace et al., 2011). The intensification of human-turtle interactions has also increased accidental or bycatch fishing (when animals often drown following entanglement in fishing nets), which also became a major threat to turtles (Mancini et al., 2012; Bastos et al., 2022). Although by-catch has a high impact on turtle deaths, artisanal fishing can also have a great impact, especially when fishing areas and sea turtle foraging areas overlap, a common scenario in coastal environments (Mancini et al., 2012; Musick & Limpus, 1997; Santos et al., 2015).

Among the many threats that *C.* mydas faces during the different stages of life, we can cite the ingestion of insufficient quantities of food and nutrients associated with the exposure to pollutants. This threat is known to induce immunosuppression and increase susceptibility to diseases in turtles (Borysenko & Lewis, 1979; Santos et al., 2010). It may favor the occurrence of fibropapillomatosis (FP), a debilitating disease characterized by the presence of tumors caused by a herpesvirus (Van Houtan et al., 2010; Herbst, 1994;

Herbst & Klein, 1995). FP occurrence has recently been proposed as an indicator of turtles' health (Santos et al., 2010).

As another threat, commonly associated with human occupation, plastic ingestion is one of the most recent (though extremely widespread) threats to turtles (Schuyler et al., 2013). Plastic ingestion may lead to a false feeling of satiety and a consequent nutrient impairment, as well as exposure to chemicals present in the plastic (Santos *et al., 2020*). These impacts are known to negatively affect turtles' fitness, often causing their death and it has been suggested that plastic ingestion can lead to population decline (Bugoni; Krause; Petry, 2001; Marn *et al*., 2020).

The urbanization and population growth in coastal areas are known to be the major factor causing the destruction of natural habitats (Clausen & York, 2007; Creel, 2003; Lotze et al., 2006). Due to the decline in environmental quality and biodiversity loss, it is necessary to carry out conservation actions to maintain ecosystems' services and functions (Cicin-Sain, 2005; Eger et al., 2021). Here, we hypothesize that the distribution of *C. mydas* responds to environmental degradation and intensity of threats within a large tropical marine protected area. To test this hypothesis, we modeled the spatial distribution of *C. mydas* with a range of threats existing in the area, such as fishing, plastic ingestion rates, fibropapillomatosis and dietary impoverishment.

3. 2 METHODOLOGY

3. 2.1 Study area

The Costa dos Corais Environmental Protection Area (APACC) is the largest federal coastal protected area in Brazil. The Protected Area is in the northeastern portion of the country and comprises approximately 120 km of coastline along 12 cities with an approximately human population density of 336.05 inhabitants/km².

The APACC is characterized by an extensive reef formation and beaches with different levels of human occupation. To define the different activities that are allowed in each APACC environment, its management plan establishes different zones within its territory, with different degrees of human intervention, aiming to incorporate conservation into fisheries and tourism in a sustainable way (ICMBio, 2021). The population that lives in its surroundings develops a series of legalized economic activities directly linked to coastal ecosystems, such as artisanal fishing, collection of crustaceans and molluscs, and tourism (Steiner et al., 2006). The area delimited for this study is located between the city of Maragogi (-8.91399 and -35.15233) and a portion of the city of Maceió (-9.5472 and -35.6165), corresponding to the 95 km of the APACC belonging to the state of Alagoas (Figure 1).

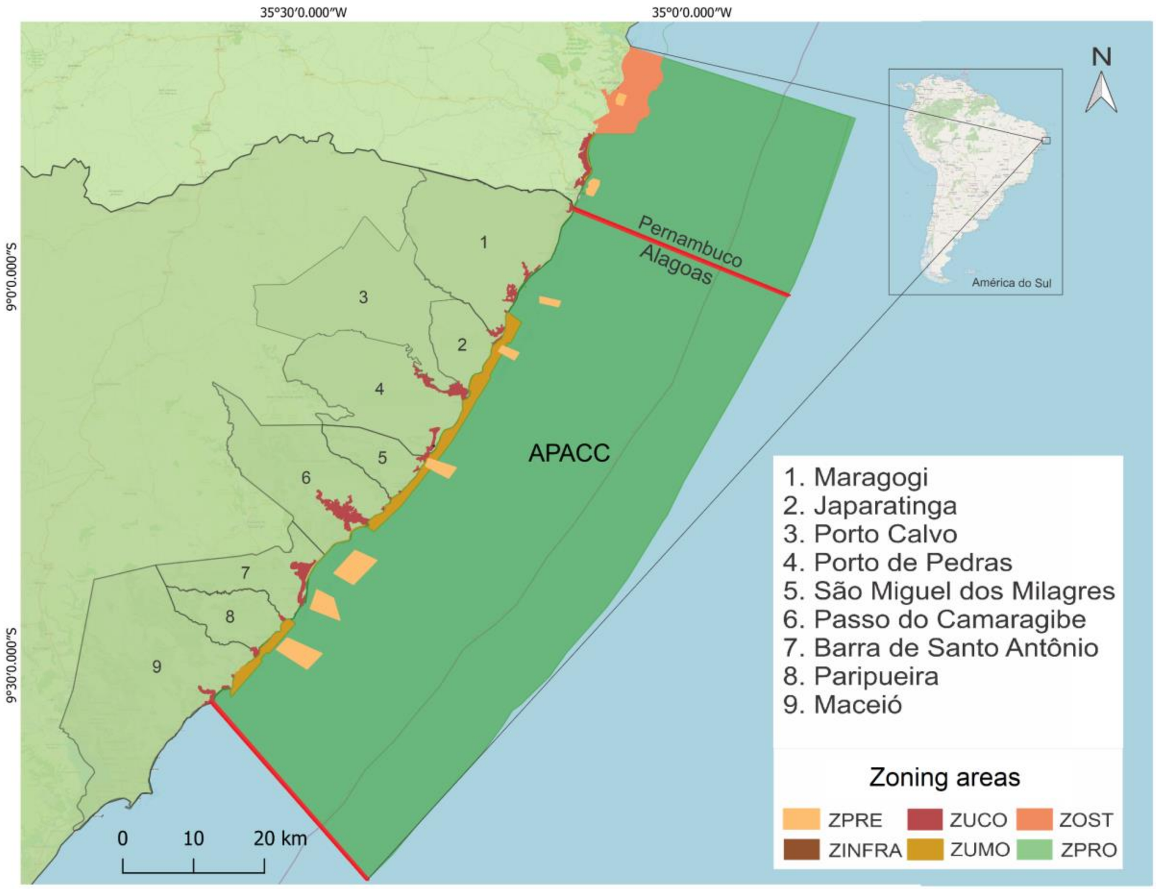

Figure 1. Costa dos Corais Environmental Protected Area. The study area corresponds to the segment of the state of Alagoas of the protected area, including nine cities along 95 km of coastline. Management zones: ZPRE – Preservation Zone; ZUCO – Community Use Zone; ZOST – Territorial Overlap Zone; ZINFRA – Infrastructure Zone; ZUMO – Moderate Use Zone; ZPRO – Production Zone.

3. 2. 2 Sea turtles in the foraging areas

To estimate the distribution and quantity of sea turtles that inhabit the APACC reef area, used for this study, photos were taken between November 2019 and February 2020 using the DJI Mavic 2 Zoom drone and Drone Deploy software. Overflights were previously planned in QGIS and Google Earth software and the entire coast was divided in transects of 120m wide. Of those, 136 transects (corresponding to 20% of the area) were randomly selected. The polygons were of variable length, between 745 – 1500 m, covering the area from the coastline to the coral reefs and 60m high (with variations from

1 to 5 meters – Figure 2). The camera was used at 90° between 2 pm and 5 pm and the photos were taken with 30% front and side overlap. The flights lasted between 3 and 15 minutes, with a maximum speed of 8m/s, covering the entire polygon. The flyovers were made in blocks, seeking to contemplate the maximum number of transects in a single day, also only one flight per transect was performed to avoid recounting turtles migrating between feeding areas. In addition, for standardization purposes, the flights were carried out during high tide, a factor that could enhances the sighting of sea turtles (Santos *et al,* 2015).

Figure 2. Detailed visualization of the transects randomly disperse and with variable length to cover the reef area (in green). The area corresponds to the city of Passo de Camaragibe (-9.2419, -35.4890), state of Alagoas.

To determine the number of turtles in each photograph, manual counts were carried out independently by two people. To avoid the turbidity of the water in different locations, only animals seen on the surface, above the waterline, with visible appendages or size, shape, and color similar to sea turtles were counted. Furthermore, we assume that all individuals sighted are *Chelonia mydas*, for being a specie with coastal habits, high fidelity to feeding areas (Hirth, 1997), and with many individuals that use the Alagoas coast as a feeding area, when compared to another turtle species (BIOTA Institute Personal Communication).

3. 2. 3 Dead stranded sea turtles

Data on sea turtles' interactions with potential local threats were based on the BIOTA Conservation Institute database. It gathers sea turtle stranding rates and necropsies information collected daily, through the beach monitoring plan (PMP) between May 2018 and April 2019. The database contains data of curved carapace length, identification, determination, and categorization of external tumors (details in section 3.2.4.4), and specific location of each dead stranded individual collected. The Gastrointestinal Tract (GT) contents of the stranded individuals were investigated to achieve plastic ingestion and diet data (details in sections 3.2.4.2 and 3.2.4.5).

3. 2. 4 Threats

Seeking to obtain the appropriate sample design, we used two methods to analyze the hypotheses. In the first, stranded turtles were used to create a 10 km diameter buffer departing from the point where the stranding was recorded, and the variables within each buffer were compiled. In the second, the study area was separated into sectors of 10 km parallel to the coastline (sectors A to I – Figure 3), and the variables in each sector were compiled.

Figure 3. Division points delimiting the nine 10 km sectors used in this study as sampling units.

3. 2. 4. 1 Fishing impacts

To determine the influence of fishing activity on turtles, the number of fishing huts along the coast was counted. Fishing huts are fixed places on the sand strip, used by fishermen as points of support, rest and maintenance of fishing equipment. Most of the artisanal fishing activity carried out involves gillnets and trawls (61%), where fishermen use rafts and small boats, close to the huts (ICMBio, 2019). This variable was considered as a proxy for fishing intensity, calculated using the number of fishing huts within the sampling units.

3. 2. 4. 2 Plastic ingestion

To assess the influence of plastic ingestion, this variable was analyzed by counting and identifying (size, use, possible origin, and type of material) items of anthropic origin found in the gastrointestinal tract of dead turtles by collaborators of the Marine Biology Laboratory and Conservation (LAMARC - UFAL), provided by the BIOTA Conservation Institute during the years 2018 and 2019. The percentage of turtles who ingested plastic items was calculated by considering the number of turtles with plastic in their GT content divided by the total number of turtles analyzed within the 10 km area.

During February and March of 2020, the LAMARC/UFAL laboratory collaborated with evaluators to determine the waste composition of beaches where dead sea turtles were found stranded. Through these assessments, researchers were able to gain valuable insights into the types of waste present on the beaches and how they may be impacting local wildlife populations. Three points were randomly chosen on each beach with an average distance of 200 meters between them. The transects were standardized with a fixed width of 2 meters and variable length, comprising the distance between the high tide line and the end of the sand strip. The materials found in situ were collected and taken to the laboratory where they were cleaned and cataloged, according to the size, use, possible origin, and type of material (plastic - rigid or flexible, styrofoam, glass, rubber, rope, and others).

3. 2. 4. 3 Urbanization

Considering that urbanized areas with different levels of human occupation use night light, we chose to use the data on night-light as a proxy (Shi et al., 2014). The index of light emitted during the night in the coastal area is known to be related to the urban infrastructure, exploitation of marine resources, pollution, and drainage (Todd et al., 2019). Night-light data were extracted from raster images from the Operational Linescan System (OLS) and Visible Infrared Imaging Radiometer Suite (VIIRS) sensors provided by Li and collaborators (2020) for the years 2010 to 2016. Image resolution is 30 arcseconds (about 1km) associated with digital numbers (DN) ranging from 0 to 63. For the 10 km buffer and 10 km coastline sectors, we calculated the mean number of night-lights within the area.

3. 2. 4. 4 Fibropapillomatosis (FP)

Considering that fibropapillomatosis is associated with environmental degradation and pollution (Santos et al, 2010), we investigated how the incidence of FP tumors on dead turtles correlates with its density in the units of 10 km of coastline. We also investigate the correlation between the severity of FP and the night-light in the units of 10 km buffer. Fibropapillomatosis data were obtained during daily monitoring activities (PMP) by the BIOTA Institute. The stranded turtles were collected for the BIOTA laboratory and the presence or absence of fibropapillomas (physical manifestation of fibropapillomatosis), as well as their severity, was determined by visual analysis during necropsy. Severity was calculated according to the formula presented by Rossi et al. (2016). The percentage of turtles with fibropapillomatosis was calculated by considering the number of turtles with fibropapillomas divided by the total number of turtles analyzed on each 10 km buffer.

3. 2. 4. 5 Diet impoverishment

Coastal degradation is known to alter the composition, diversity, and nutritional variety of benthic communities (Bastos et al., 2022), influencing turtles’ diet. Thus, we estimated the impoverishment of diet using the number of different genera ingested as proxy, through the analysis of GT contents made by collaborators of LAMARC/UFAL laboratory, of the stranded dead turtles. Stomach contents were collected, weighed, and preserved in 10% formalin solution. For each individual, 50g of GT content was removed, in cases where the total weight of the content was less than 50g, the entire stomach content was used. In this process, items were identified to the lowest possible taxonomic level, and the number of genera ingested algae genus was counted.

To compare food intake with availability in the environment, data collected from previous work carried out by the LAMARC/UFAL laboratory were used. The availability of food was collected by evaluating the benthic cover in three distinct areas of the APACC's central portion (Maragogi, Japaratinga and São Miguel dos Milagres cities). The data was collected during January and February 2020, through snorkeling surveys in 100 squares (25 x 25 cm) photographed along 10 transects randomly distributed and with a length of 10m in each area. The images were transferred to the CPCe program (Coral Point Count with Excel extensions, Kohler & Gill, 2006), where 20 randomly distributed points were analyzed to estimate the relative coverage of biotic and abiotic features.

3. 2. 5 Statistical analyses

3. 2. 5. 1 Sea Turtle density

Considering that assessments of the population using drones require incorporation of availability and perception biases as some turtles may be eventually missing in the count, we adapted the equation presented by Sykora-Bodie et al. (2017) to estimate turtle density. Therefore, density estimation calculations were obtained considering mean surface time (Ts), mean dive time (Tm) and the observation window (J(x) – which is the average time between shots that the drone takes to photograph) to calculate an availability bias (Vd) (equation 1).

$$Vd = \frac{Ts}{Ts + Tm} + \frac{J(x)}{Ts + Tm}$$

A literature review for *Chelonia mydas* (Ballorain et al., 2013; Blanco et al., 2013; Enstipp et al., 2016; Hazel, 2009; Southwood, 2003) showed that the mean surface time varies between 25 seconds and 7 minutes, as well as the mean dive time, which ranges from 6 to 35 minutes. Thus, we chose to use the average, aiming to standardize the equation for all transects. With the availability bias (Vd) calculated, the result was inserted into equation 2, where n is the number of turtles sighted in a 10 km diameter coastline area (A).

$$D = \left(\frac{1}{Vd}\right) \times \left(\frac{n}{A}\right)$$

3. 2. 5. 2 Stranded turtles

The number of stranded turtles of *Chelonia mydas* specie also were calculated through the sum of strandings within the 10 km sector of the coastline representing the average home range of a turtle (Seminoff, Resendiz, Nichols, 2002; Makowski, Seminoff, Salmon, 2006; MacDonald et al, 2012).

3. 2. 5. 3 Threats

Initially, to identify which statistical test should be applied, the Shapiro-Wilk normality test was performed. Data related to the 10 km diameter buffer did not present normal distribution ($p<0.1$). On the other hand, data separated by sectors of 10 km has a normal distribution ($p>0.1$). Then, we used Spearman's Correlation (cor() function in R software; R Core Team, 2022) for the 10 km diameter buffer to determine (1) the relationship between the percentage of ingested plastic and the density of plastic availability on the beaches within the 10 km buffers; (2) the relationship between the percentage of plastic ingestion and night-light index within the 10 km buffer areas; (3) the correlation between the night-light average and the incidence of fibropapillomatosis, as well as its severity; and (4) the correlation between Impoverishment of diet data and mean night-light (Table 1).

We used regression analysis (glm() function in R software; R Core Team, 2022) - with the data that we previously normalized using (log10(x)), for the 10 km coastline area - to (1) estimate the relation between the percentage of turtles with fibropapillomas and density of turtles related with the night-light index within the 10 km coastline sectors; as well as (2) the relation between the percentage of plastic ingestion by turtles and density of plastic deposited on the beaches associated with the night-light index within the 10 km coastline sectors (Table 1). Used as a proxy to quantify the mortality within each sector, the estimated population density divided by the number of strandings was correlated with fishing and urbanization (night-light) through the GLM function in table 1.

Table 1. Statistical analysis and their respective comparisons used for this work.

Spearman's Correlation - 10 km buffer		
% Of Plastic Ingestion	X	Density of plastic deposited on the beaches
% Of Plastic Ingestion	X	Night-light
% Incidence of FP	X	Night-light
Severity of FP	X	Night-light
Impoverishment of diet	X	Night-light
GLM regression analysis – 10 km sectors		
% Of Plastic Ingestion ~ Night-light + Density of plastic deposited on the beaches		

% Incidence of FP ~ Night-light + Density of turtles
$\frac{\text{Density of turtles}}{\text{N° of stranded turtles}} \sim$ Night-light + Fishing Huts

After obtaining all the data, Kernel density maps (heat maps) were produced using QGis software (version 2.18.4 Las Palmas). For this, we created raster images of 2.5 km radius for each individual sampled, with separation of data collected on land (stranded turtles) and at sea (drone observed turtles), in order to improve the visualization of the dataset.

3. 3 RESULTS

3. 3. 1 Observed and stranded turtles

A total of 13.538 images were obtained during the overflights. We were able to visually identify 182 turtle individuals in 162 images. An average density of 13.1 individuals/km² (SD ± 9.17) was observed in the 10 km sectors. The highest estimated population density was observed in sector I, in the city of Maceió (25.3 individuals/km²), followed by sector C in the city of Japaratinga (24.8 individuals/km²) (Figure 4). The spatial distribution of the observed individuals was not homogeneous, and several individuals were aggregated in specific sites, specially at coral reefs.

684 individuals found dead within the APACC and collected by the Beach Monitoring Plan (PMP) were used in this study. The highest number of stranded individuals was found in the city of Maceió (sector I - 154 individuals) which corresponds to the most urbanized area in our study. The city of Paripueira (sector H), located next to Maceió, had the second largest number of strandings (97 individuals), followed by the city of Porto de Pedras (sector D - 91 individuals).

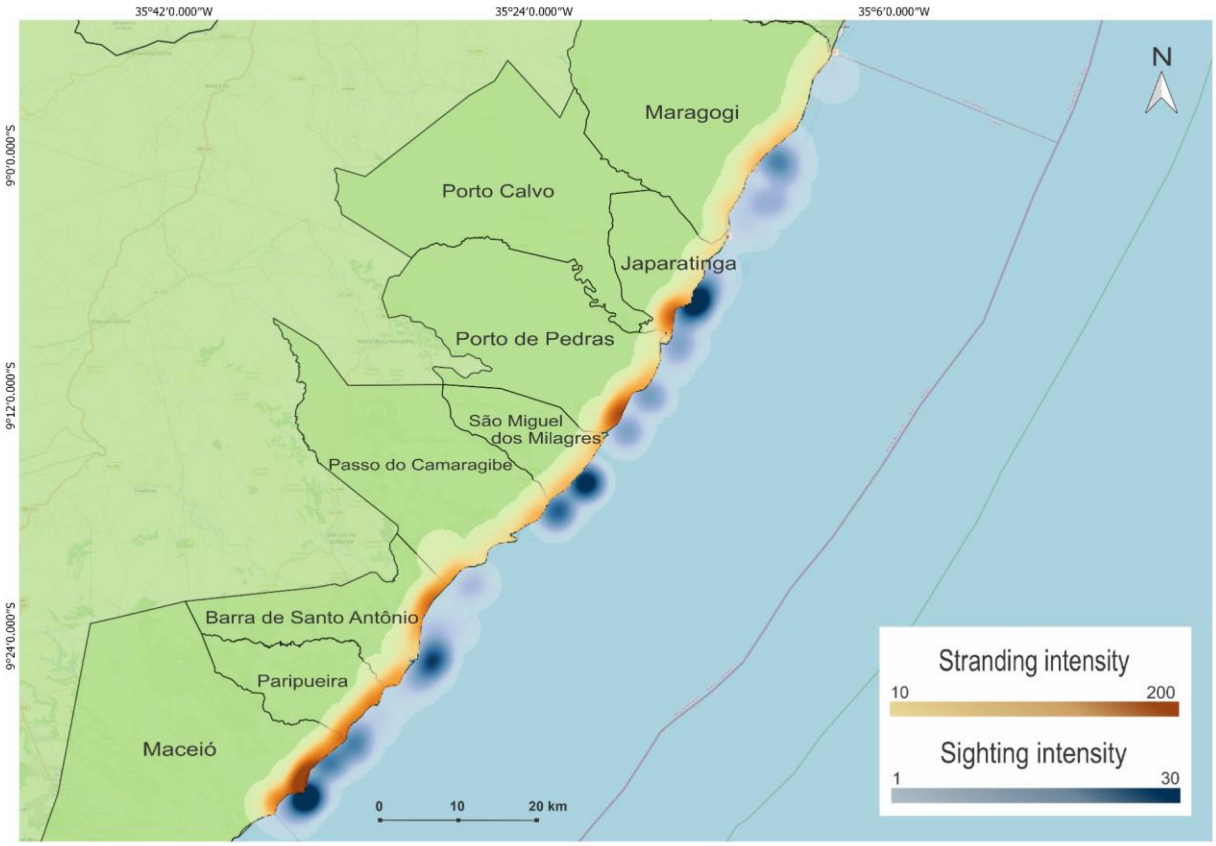

Figure 4. Distribution of turtles observed during drone flights (blue), and stranded turtles collected by the beach monitoring program (red), showing the intensity of data collected along the APACC coast of Alagoas.

3. 3. 2. Threats

3. 3. 2. 1. Fishing impacts

106 fishing huts were identified in the study area. The greater intensity was in the cities of Japaratinga (sector C - 28 huts), Maragogi (sector B - 14 huts) and São Miguel dos Milagres (sector E - 14 huts; Figure 5). Our results showed that our proxy for mortality (density of turtles divided by the number of strandings) is not related to fishing ($p = 0.15$) (Figure 11).

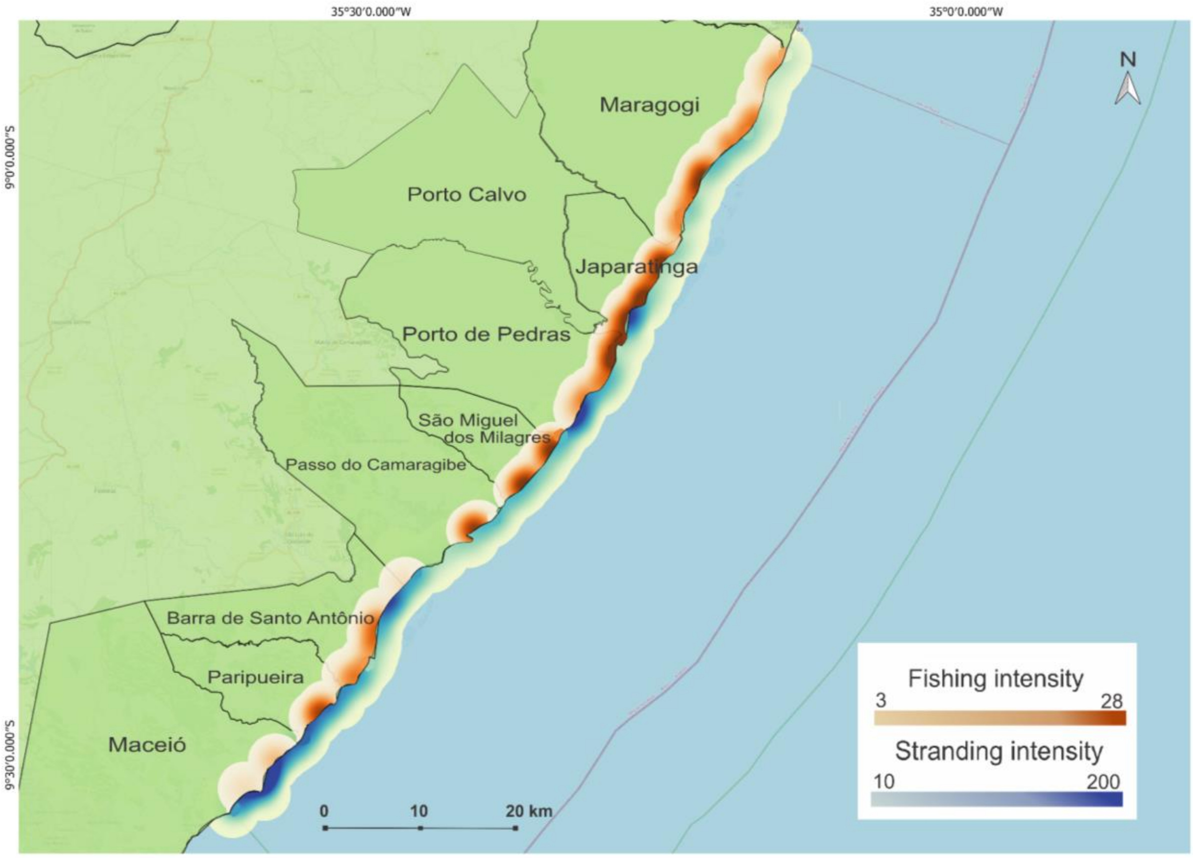

Figure 5. Kernel Density Map (heat map) representing the amount and aggregation of strandings and fishing huts as a proxy for fishing intensity within the APACC.

3. 3. 2. 2 Plastic ingestion

A total of 95 individuals (stranded turtles) had their GT analyzed and anthropogenic residues were found in 22 of these (23.15%; mean ± SD = 0.78 ± 3.72). The ingested plastic residues were analyzed and classified by type of material. The majority was flexible plastic (64.5%), and nylon (26.3%) (Figure 6 a).-

832 items were collected along 60 transects during the survey for beach litter. Plastic was the most abundant item (flexible plastic with 24.7% and rigid plastic with 16.3%;

Figure 6 b). The sector with the highest occurrence of plastic ingestion by turtles was in the city of Japaratinga (sector C - 33.3%; mean ± SD = 0.33 ± 0.5), followed by Barra de Santo Antônio (sector G - 30%; mean ± SD = 0.3 ± 0.48) (Figure 7).

The Spearman's Correlation indicates that there is a positive relation between plastic ingestion and density of litter on the beach ($p < 0.001$, $R = 0.37$; Figure 9 a). However, plastic ingestion is inversely correlated with night-light ($R = -0.5$; Figure 9 b). Generalized Linear Models indicated no significant association between the amount of beach litter and percentage of plastic ingested ($p = 0.41$). The models also suggest that night-light is not related with plastic ingestion ($p = 0.16$) (Figura 10).

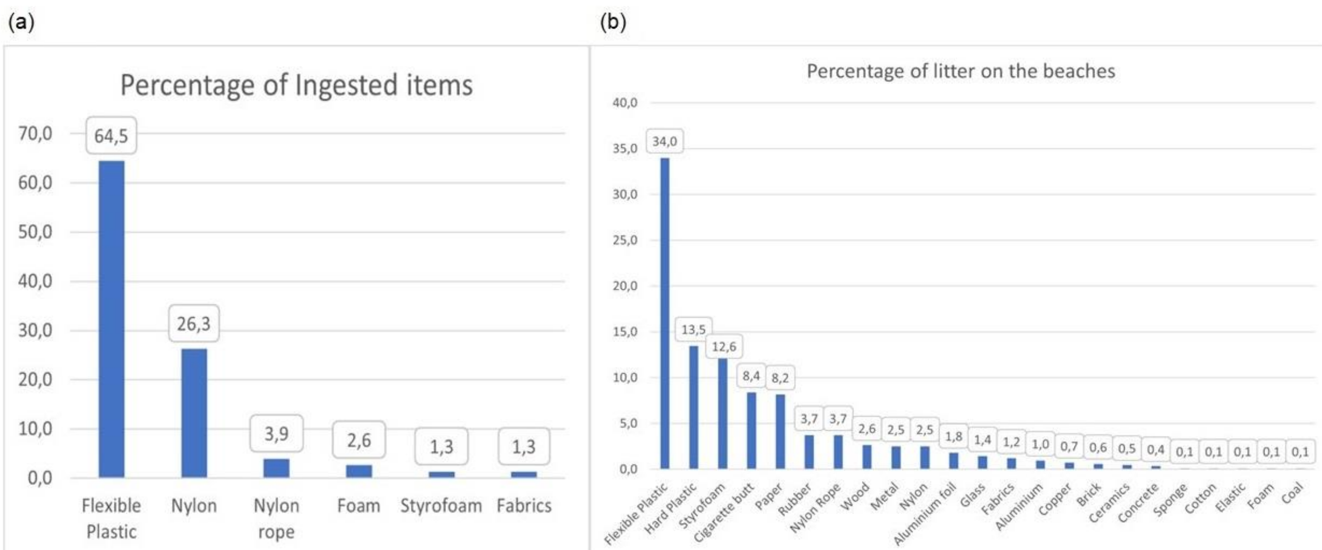

Figure 6. (a) Composition of beach litter found in the GT of stranded turtles; (b) Composition of the beach litter collected along 60 transects of the APACC.

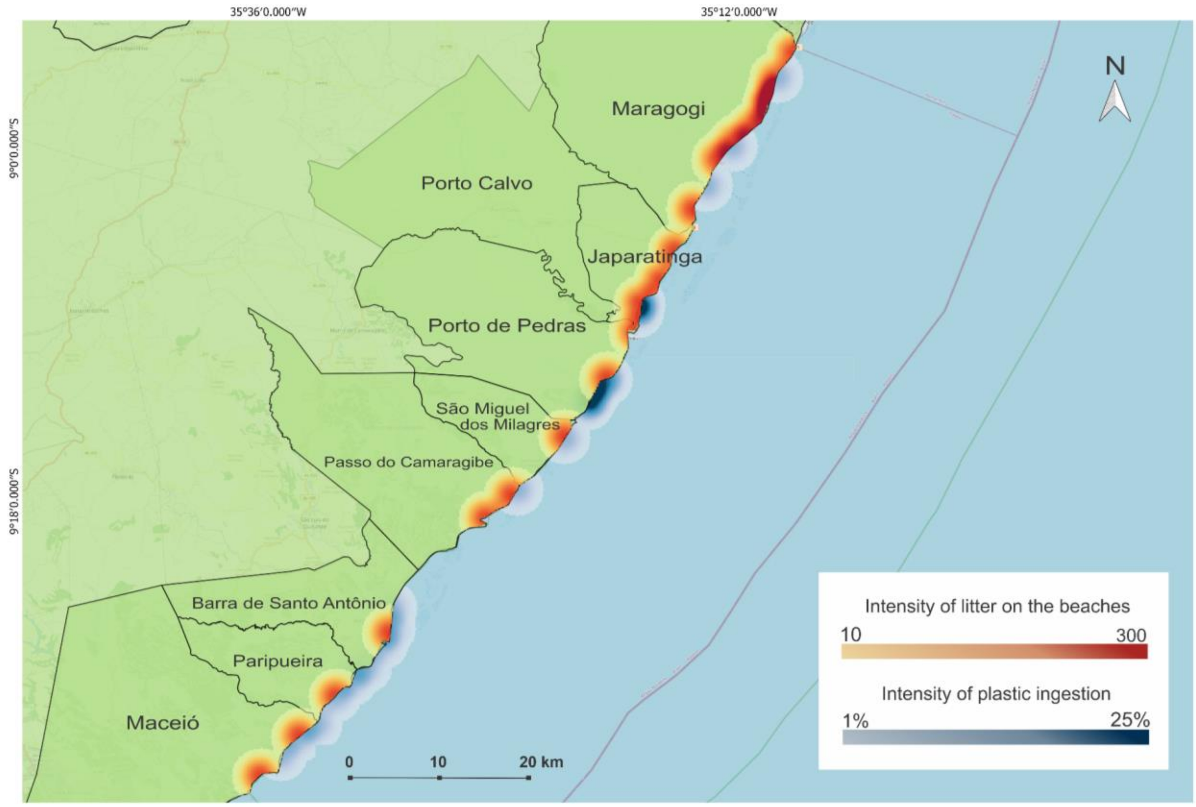

Figure 7. Kernel density map of the abundance of plastics found on beaches and the prevalence of plastic ingestion by green turtles.

3. 3. 2. 3 Urbanization (*night-light index*)

The study area has an average night-light of 16.94 DN (SD ± 7,38). The higher incidence of light is in the cities of Paripueira (sector H, mean ± SD = 29.20 ± 0.79), Maceió (sector I, mean ± SD = 24 ± 3.32), and north of Maragogi (sector A, mean ± SD = 23.94 ± 4.07).

3. 3. 2. 4 Fibropapillomatosis (FP)

A total of 293 individuals were visually analyzed and classified for FP presence and severity. While 87.8% of the individuals did not have any signs of fibropapillomatosis, 38 individuals (12.9%) had the disease. From these, 23.6% had a high degree of severity (FPI ≥120), 26.3% had a medium degree (40 ≤ FPI < 120) and 50% had a low degree of severity (FPI < 40). The highest rate of individuals presenting FP was found in the city of Japaratinga (sector C - 22.5%).

The percentage of individuals with fibropapillomatosis has a strong negative correlation with night-light (Spearman test, R = -0.73; Figure 9 c), generalized Linear Models corroborate with this result (p = 0.04). However, in the GLM results the percentage of fibropapillomatosis incidence was not related to turtle density (p = 0.06 - Figure 10). We found that severity of FP has a positive correlation with night-light (Spearman test, R = 0.4; Figure 9 d).

3. 3. 2. 5 Diet impoverishment

To assess the composition of food ingested by stranded turtles, 32 individuals had their GT contents analyzed. The APACC sectors with the greatest richness of ingested genera were the cities of São Miguel dos Milagres (sector E; mean ± SD = 9.3 ± 0.7) and Porto de Pedras (sector D; mean ± SD = 6.75 ± 2.12). Both sectors have a predominance of red algae, followed by green algae and marine angiosperms (Figure 8 a). The benthic cover has a predominance of algae (47%) and, from these, nearly half (20.9%) corresponds to the genera identified in the GT of the turtles (Figure 8 b). Although species of the order Gelidiales were the most consumed in the individuals analyzed, they represent only a small percentage of the benthic coverage of the APACC (0,4%; Figure 8 b). Spearman's correlation test showed that the number of genera ingested by turtles and the night-light index is very weakly associated (R = -0.17; Figure 9 e).

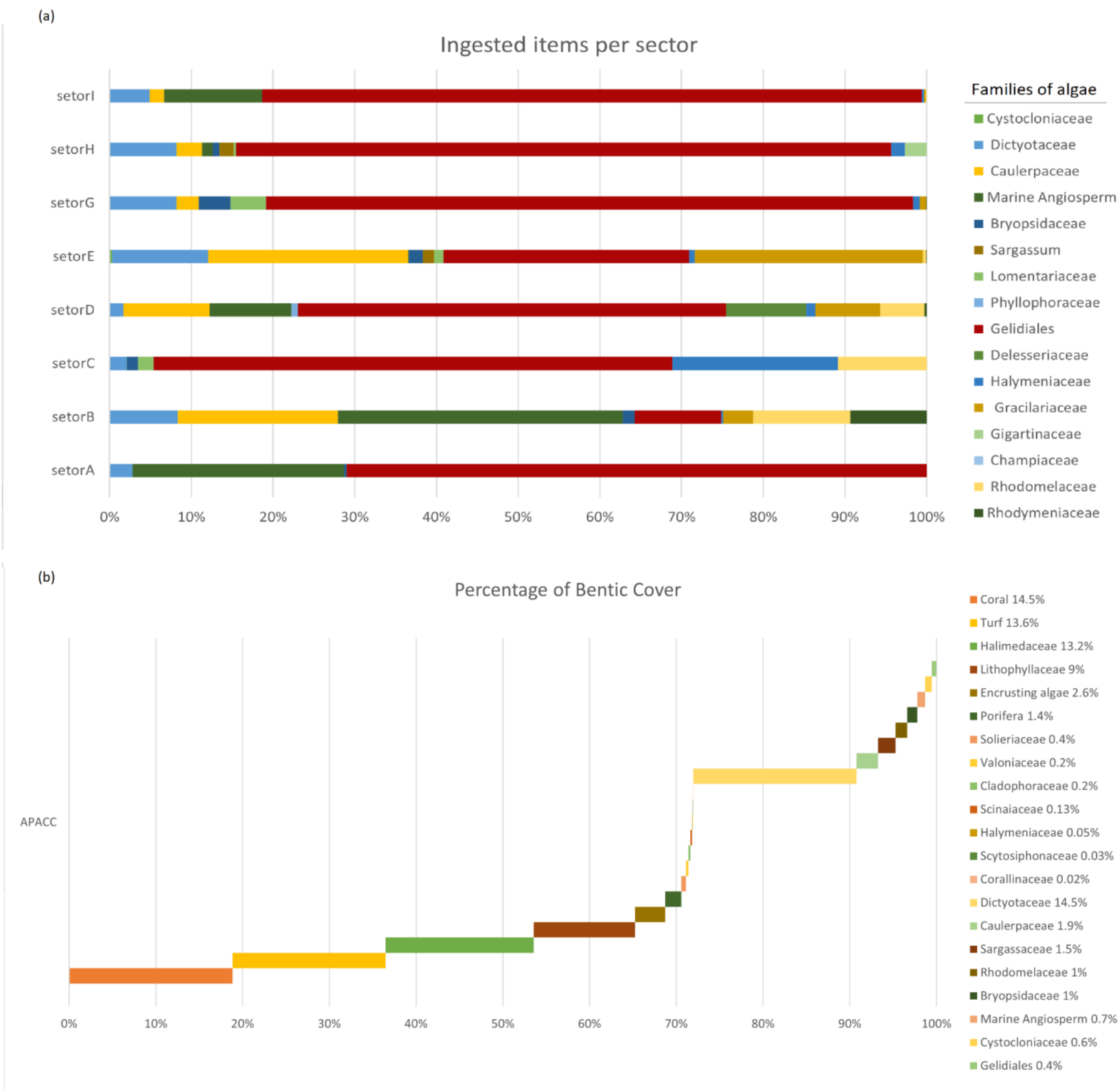

Figure 8. a) proportion of items ingested by stranded turtles by family per APACC sector and b) percentage of benthic cover in the study area.

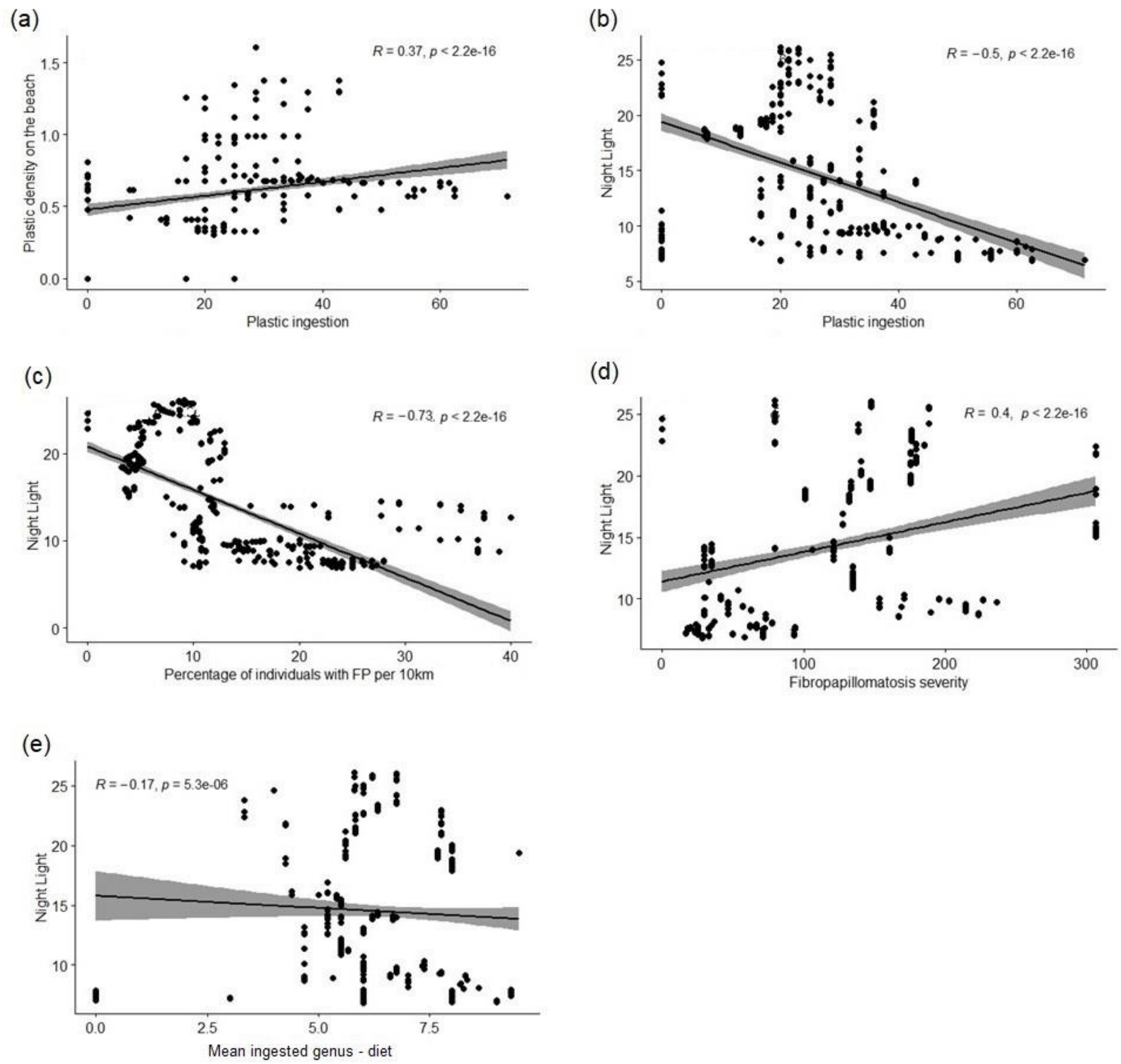

Figure 9. Spearman’s Correlation analysis. a) Correlation between plastic density (beach litter) and plastic ingestion (GT), b) amount of night-light and plastic ingestion, c) amount of night-light and proportion of individuals with FP in the 10km buffers, d) amount of night-light and FP severity and e) amount of night-light and number ingested genera. Dots correspond to the 10 km buffer of stranded individuals. Gray shades indicate confidence intervals.

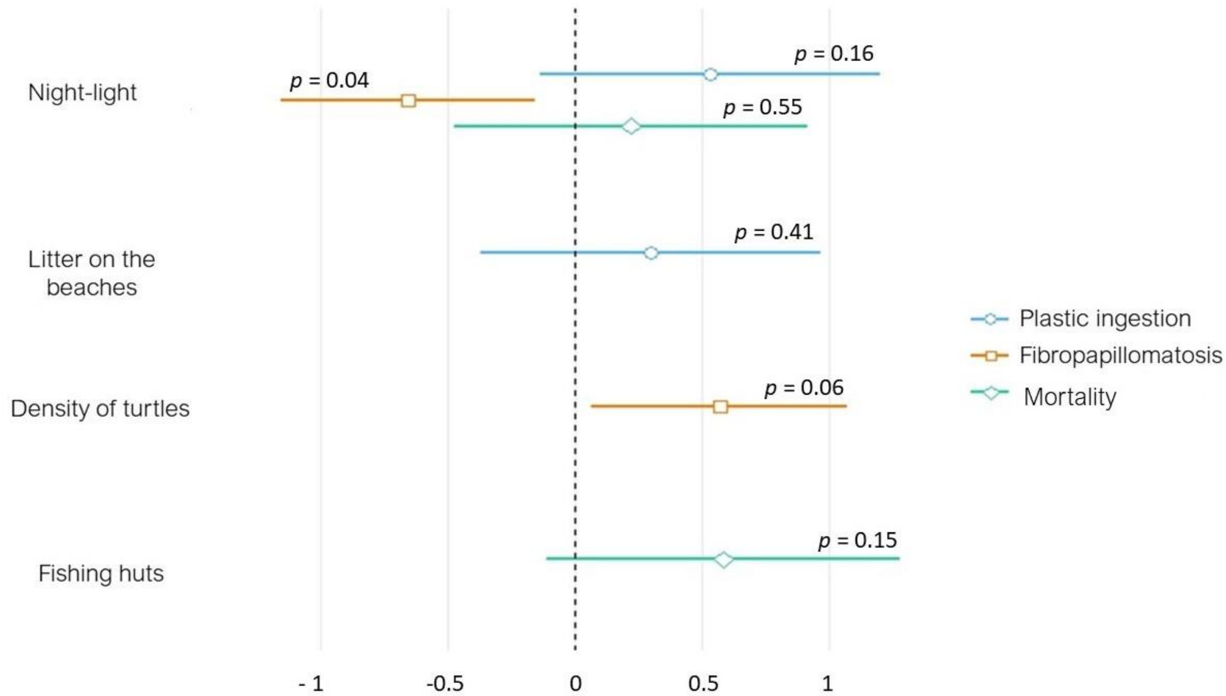

Figure 10. Coefficient estimates (±95% confidence intervals) of Generalized Linear Models indicating the direction and magnitude of the effect of different explanatory variables on plastic, mortality, percentage of fibropapillomatosis occurrence and turtle mortality in the sectors.

Our results revealed that the higher combination of threats occur in Porto de Pedras (sector D), followed by Barra de Santo Antônio and Maceió (sectors G and I). We also found that the cities of Maceió and Japaratinga are critical areas for *C. mydas* conservation since they have both high levels of threats and high density of turtles (Figure 11).

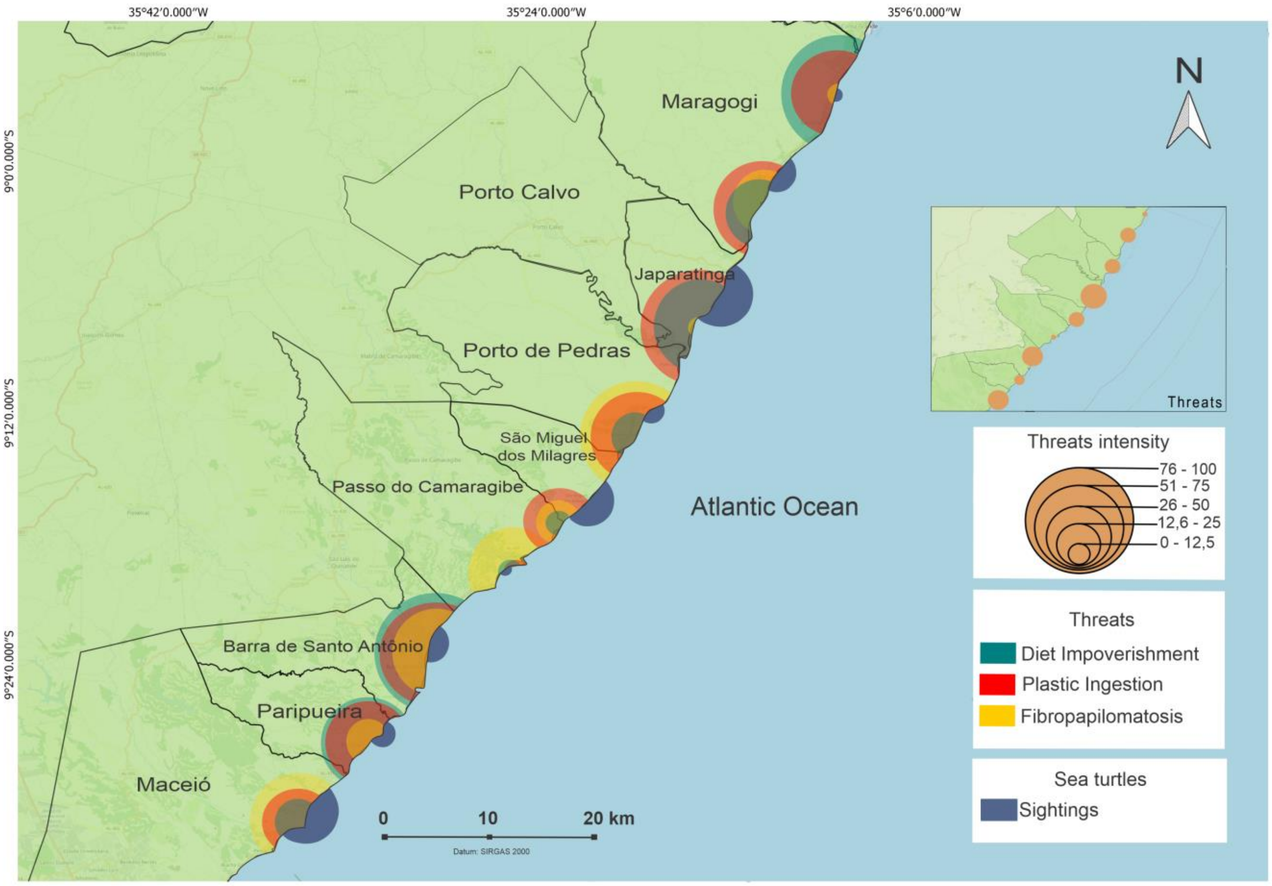

Figure 11. Spatial distribution of threats to sea turtles and sightings. Circle sizes are proportional to threat intensity.

3. 4 DISCUSSION

The utilization of drones to analyze the distribution pattern of *C. mydas* in the protected area revealed that the highest densities of the species were in two highly urbanized sectors (Maceió - sector I - 1.854,10 hab/km², and Japaratinga - sector C - 90,22 hab/km²). Also, the drone survey data indicates that their distribution is not random and that individuals tend to aggregate in reefs to form foraging and feeding groups, as previously suggested by Bresette et al. (2010). The evaluation of stranded turtle distributions revealed that areas with the highest number of strandings also had the highest densities of turtles, particularly in the city of Maceió, which had the highest density and stranding indices. This supports the idea that the number of strandings reflects the relative abundance of the species (Chaloupka et al. 2008). However, density alone does not fully explain stranding patterns. Several studies have suggested that the number of stranded individuals is associated with cumulative threats (Chaloupka et al. 2008; Monteiro et al., 2016; Tagliolatto et al., 2019; Cantor et al., 2020).

Artisanal fishing has been identified as a potential source of mortality for turtles worldwide (Alverson et al., 1994; Farias et al., 2019); however, our statistical analysis did not identify a correlation between mortality and the intensity of fishing pressure (here measured by the number of fishing huts). This lack of association can be clearly observed in the city of Japaratinga (sector C) which has many fishing huts and has the second highest density of individuals.

There are many ways to collect data related to fishing. Mancini et al. (2011) collected fishing data by daily monitoring fishermen to identify their type of net, the location and the number of turtles entangled in their nets. Monteiro et al. (2016) used logbooks of captains of vessels with gillnets and trawls. Other papers use data from animal carcasses with marks of direct interaction with fishing materials or collisions caused by engine propellers (Bugoni; Krause; Petry, 2001; Tagliolatto et al., 2019; Cantor et al., 2020). This serves to highlight that there is not a single approach to evaluate the impacts of fishing and it is likely that more accurate assessments can be achieved through the combination of various data related to the fishing activity in a given area.

Another major threat to green turtles is the ingestion of residues of anthropic origin. Corroborating with previous works, our results showed that the main component present in turtles' GT is flexible plastic (Bugoni; Krause; Petry, 2001; Carman et al., 2014; Farias et al., 2019). Despite expectations that plastic ingestion rates would be higher in urbanized areas, this study found that the highest rate of plastic ingestion occurred in Japaratinga, an area characterized by a low incidence of night-light (used here as a proxy for urbanization) and a high number of fishing huts. It is plausible that the high plastic ingestion rate is linked to fishing activity, as flexible plastic, nylon, and nylon rope (both fishing gear) were the three most ingested materials.

When analyzing the correlation between the percentage of ingested items and the distribution of litter on the beaches, it was found that, although a correlation existed, it was too weak to conclude that the availability of litter on beaches led to ingestion; this finding was reported in Schuyler et al. (2013). It is possible that, if the temporal and spatial scales are increased, this correlation can be accentuated (Schuyler et al., 2013). An initially controversial result of this research is the negative relationship between plastic intake and night-light indices. Although the data demonstrate that places with a higher incidence of night-light are the places with the lowest plastic intake, this relationship may be influenced by external factors, such as the low diversity of available food items in more urbanized areas (Santos et al., 2011; Bastos et al., 2022) and an attempt to avoid areas with a higher incidence of artificial light (Longcore & Rich, 2004).

Despite the increase in turtles with FP, the percentage of prevalence of fibropapillomatosis presented in this research is below the average found in several studies on the subject (Aguirre & Lutz, 2004; Foley et al., 2005; Jones et al., 2016; Shaver et al., 2019). Also, half of the individuals with FP had low severity of the disease, which is hardly a limiting factor for the animal (Chaloupka & Balazs, 2005). The relationship between the night-light index and the presence of FP indicates that the disease is strongly linked to urbanization. However, this correlation proved to be negative, indicating at first that the occurrence of the disease in turtles increases as the night-light rates decrease. This result differs from many studies that show a direct relationship between the two variables (Borysenko & Lewis, 1979; Santos et al., 2010; Todd et al., 2019; Bastos et al., 2022). One possible reason for this is that the occurrence of FP is associated with factors that were not accounted for in this study (i.e. concentration of pollutants in different regions of the APACC, genetic variations in different *C. mydas* populations).

We also observed that areas with little luminosity are areas with a greater amount of litter deposited on the beaches, indicating that night-light is a suitable index for urbanization. Also, very urbanized places (i.e., Maceió, Paripueira and Maragogi) have a higher urban sanitation index (ANA, 2013). This may explain the negative relationship between FP and night-light. It is also possible that horizontal transmission of FP may occur when infected turtles migrate between feeding sites and interact with recently recruited juveniles that have experienced immunosuppressive stressors consequent to pelagic excursion, alteration of diet, and acclimatization (Jones et al., 2016). Our results also showed that areas with a higher night-light index are related to greater severity. An association between FP severity and night-light was also found by several authors (Aguirre & Lutz, 2004; Foley et al., 2005; Jones et al., 2016; Shaver et al., 2019).

The dietary habits of the green sea turtle (*C. mydas*) characterized by herbivory and its strong preference for macroalgae have been extensively documented (Forbes, 1996; Fuentes, Lawler & Gyuris, 2005; Santos et al., 2015). When comparing the presence of algae in the benthic environment to the items found within the digestive tracts of local species, a clear pattern of food selectivity can be observed (Forbes, 1996; Fuentes, Lawler & Gyuris, 2005; Santos et al., 2015), with a particular preference for red algae. The preference for this group in turtles' diet was also observed in degraded environments (Santos et al., 2011) and rocky reefs (Reisser et al., 2012). Studies suggest that this is due to the high levels of nitrogen and low levels of fiber (Brand-Gardner, Lanyon & Limpus, 1999), which may favor digestibility (Campos & Cardona, 2020). The impoverishment of diet, also pointed out in degraded areas, can lead turtles to a lower intake of nutrients, causing immunosuppression and increasing their susceptibility to diseases. The sectors with the highest average of ingested food have a low night-light index. The statistical analysis showed that these variables are correlated, even if weakly. Although the studies show a high variation in the number of individuals analyzed - presenting results with 15 (Santos et al., 2011), 47 (Bastos et al., 2022) and up to 137 individuals (Santos et al., 2015) - it is likely that to accentuate the correlation with night-light data, it may be preferable to use a more robust N sample.

Even within a marine protected area, *C. mydas* is susceptible to several threats. Each of these threats interact with the species differently (Wallace et al., 2010). A spatial analysis of concurrent threats can be used to prioritize areas for increased conservation and management planning (Wallace et al., 2010; Fuentes et al., 2020; Dimitriadis et al., 2022).

3. 5 CONCLUSION

In conclusion, based on this research, it is possible to identify two areas to consider an approach more focused and intensified monitoring. The cities of Maceió and Japaratinga, both with high intensity of threats and high population density. Using as base the spatial distribution of the turtles and the threats to them, affecting the health of the turtles in a chronic way, by reducing the food variability, garbage ingestion and debilitation by fibropapillomatosis.

Finally, our findings provide crucial information that may be used to support decision making in an important protected area of the Brazilian coast. Our map of threats combining different datasets may be useful to optimize turtles' monitoring activities in the APACC. Therefore, this work suggests a revision in the APACC Management Plan to include these areas as priorities in the conservation of green turtles. We also recommend that the different institutions collecting data about green turtles and threats to biodiversity in the APACC should adopt integrative approaches to rapidly inform where green turtles and biodiversity in general can be especially vulnerable inside the protected area.

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Supplementary material

Table S1. Location and identification of each turtle observed by drone surveys.

10KM_SECTORS	CATEGORY	ID	LATITUDE	LONGITUDE	CITY
sectorA	Observed	OT182	-8,934338	-35,151337	Maragogi
sectorB	Observed	OT161	-9,047396	-35,22044	Maragogi
sectorB	Observed	OT162	-9,037909	-35,221718	Maragogi
sectorB	Observed	OT163	-9,026808	-35,219841	Maragogi
sectorB	Observed	OT164	-9,037109	-35,205379	Maragogi
sectorB	Observed	OT165	-9,04026	-35,200962	Maragogi
sectorB	Observed	OT166	-9,04026	-35,200962	Maragogi
sectorB	Observed	OT167	-9,039239	-35,201439	Maragogi
sectorB	Observed	OT168	-9,028708	-35,190414	Maragogi
sectorB	Observed	OT169	-9,00629	-35,202572	Maragogi
sectorB	Observed	OT170	-9,013721	-35,191181	Maragogi
sectorB	Observed	OT171	-9,011829	-35,193836	Maragogi
sectorB	Observed	OT172	-9,011829	-35,193836	Maragogi
sectorB	Observed	OT173	-9,009717	-35,194958	Maragogi
sectorB	Observed	OT174	-9,00067	-35,207642	Maragogi
sectorB	Observed	OT175	-9,009095	-35,193108	Maragogi
sectorB	Observed	OT176	-9,00256	-35,201309	Maragogi
sectorB	Observed	OT177	-8,999616	-35,205437	Maragogi
sectorB	Observed	OT178	-8,999189	-35,206036	Maragogi
sectorB	Observed	OT179	-9,007423	-35,185284	Maragogi
sectorB	Observed	OT180	-8,995485	-35,188278	Maragogi
sectorB	Observed	OT181	-8,993238	-35,190441	Maragogi
sectorC	Observed	OT159	-9,059788	-35,234325	Maragogi
sectorC	Observed	OT160	-9,059234	-35,216747	Maragogi
sectorC	Observed	OT123	-9,161766	-35,28104	Japaratinga
sectorC	Observed	OT124	-9,161123	-35,280891	Japaratinga
sectorC	Observed	OT125	-9,15874	-35,277939	Japaratinga
sectorC	Observed	OT126	-9,155198	-35,275539	Japaratinga
sectorC	Observed	OT127	-9,154931	-35,274864	Japaratinga
sectorC	Observed	OT128	-9,147556	-35,2789	Japaratinga
sectorC	Observed	OT129	-9,141519	-35,284409	Japaratinga
sectorC	Observed	OT130	-9,130693	-35,283031	Japaratinga
sectorC	Observed	OT131	-9,13019	-35,281078	Japaratinga
sectorC	Observed	OT132	-9,128531	-35,270542	Japaratinga
sectorC	Observed	OT133	-9,129999	-35,268494	Japaratinga
sectorC	Observed	OT134	-9,130592	-35,267666	Japaratinga
sectorC	Observed	OT135	-9,130201	-35,267197	Japaratinga

sectorC	Observed	OT136	-9,130135	-35,267292	Japaratinga
sectorC	Observed	OT137	-9,128956	-35,268932	Japaratinga
sectorC	Observed	OT138	-9,127613	-35,264431	Japaratinga
sectorC	Observed	OT139	-9,126287	-35,265347	Japaratinga
sectorC	Observed	OT140	-9,122598	-35,267765	Japaratinga
sectorC	Observed	OT141	-9,124225	-35,264557	Japaratinga
sectorC	Observed	OT142	-9,124134	-35,264683	Japaratinga
sectorC	Observed	OT143	-9,123684	-35,265312	Japaratinga
sectorC	Observed	OT144	-9,12278	-35,266571	Japaratinga
sectorC	Observed	OT145	-9,119466	-35,261173	Japaratinga
sectorC	Observed	OT146	-9,118638	-35,261311	Japaratinga
sectorC	Observed	OT147	-9,118541	-35,261448	Japaratinga
sectorC	Observed	OT148	-9,118443	-35,261585	Japaratinga
sectorC	Observed	OT149	-9,114904	-35,266514	Japaratinga
sectorC	Observed	OT150	-9,116173	-35,262096	Japaratinga
sectorC	Observed	OT151	-9,117547	-35,260178	Japaratinga
sectorC	Observed	OT152	-9,109618	-35,258392	Japaratinga
sectorC	Observed	OT153	-9,112075	-35,254967	Japaratinga
sectorC	Observed	OT154	-9,111627	-35,254574	Japaratinga
sectorC	Observed	OT155	-9,111529	-35,254711	Japaratinga
sectorC	Observed	OT156	-9,109075	-35,258133	Japaratinga
sectorC	Observed	OT157	-9,100211	-35,248528	Japaratinga
sectorC	Observed	OT158	-9,089726	-35,252106	Japaratinga
sectorD	Observed	OT109	-9,231464	-35,323193	Porto de Pedras
sectorD	Observed	OT110	-9,231464	-35,323193	Porto de Pedras
sectorD	Observed	OT111	-9,229578	-35,322151	Porto de Pedras
sectorD	Observed	OT112	-9,22965	-35,321949	Porto de Pedras
sectorD	Observed	OT113	-9,22965	-35,321949	Porto de Pedras
sectorD	Observed	OT114	-9,224144	-35,31955	Porto de Pedras
sectorD	Observed	OT115	-9,199198	-35,317688	Porto de Pedras
sectorD	Observed	OT116	-9,203542	-35,303337	Porto de Pedras
sectorD	Observed	OT117	-9,200414	-35,302315	Porto de Pedras
sectorD	Observed	OT118	-9,200915	-35,30151	Porto de Pedras
sectorD	Observed	OT119	-9,200414	-35,301289	Porto de Pedras
sectorD	Observed	OT120	-9,199762	-35,302193	Porto de Pedras
sectorD	Observed	OT121	-9,199429	-35,302658	Porto de Pedras
sectorD	Observed	OT122	-9,173102	-35,28619	Porto de Pedras
sectorE	Observed	OT079	-9,300733	-35,381496	Passo de Camaragibe
sectorE	Observed	OT080	-9,300733	-35,381496	Passo de Camaragibe
sectorE	Observed	OT081	-9,300733	-35,381496	Passo de Camaragibe
sectorE	Observed	OT082	-9,299357	-35,383411	Passo de Camaragibe
sectorE	Observed	OT083	-9,299163	-35,382835	Passo de Camaragibe
sectorE	Observed	OT084	-9,299647	-35,381207	Passo de Camaragibe
sectorE	Observed	OT085	-9,291623	-35,386009	Passo de Camaragibe

sectorE	Observed	OT086	-9,295921	-35,379059	Passo de Camaragibe
sectorE	Observed	OT087	-9,294914	-35,378635	Passo de Camaragibe
sectorE	Observed	OT088	-9,291833	-35,378391	São Miguel dos Milagres
sectorE	Observed	OT089	-9,291986	-35,378178	São Miguel dos Milagres
sectorE	Observed	OT090	-9,293673	-35,37582	São Miguel dos Milagres
sectorE	Observed	OT091	-9,287299	-35,370113	São Miguel dos Milagres
sectorE	Observed	OT092	-9,280541	-35,367493	São Miguel dos Milagres
sectorE	Observed	OT093	-9,2727	-35,361073	São Miguel dos Milagres
sectorE	Observed	OT094	-9,275493	-35,357079	São Miguel dos Milagres
sectorE	Observed	OT095	-9,275493	-35,357079	São Miguel dos Milagres
sectorE	Observed	OT096	-9,275493	-35,357079	São Miguel dos Milagres
sectorE	Observed	OT097	-9,274928	-35,356934	São Miguel dos Milagres
sectorE	Observed	OT098	-9,271421	-35,355522	São Miguel dos Milagres
sectorE	Observed	OT099	-9,27175	-35,355064	São Miguel dos Milagres
sectorE	Observed	OT100	-9,27175	-35,355064	São Miguel dos Milagres
sectorE	Observed	OT101	-9,27175	-35,355064	São Miguel dos Milagres
sectorE	Observed	OT102	-9,271913	-35,354836	São Miguel dos Milagres
sectorE	Observed	OT103	-9,271913	-35,354836	São Miguel dos Milagres
sectorE	Observed	OT104	-9,271216	-35,354778	São Miguel dos Milagres
sectorE	Observed	OT105	-9,271049	-35,355011	São Miguel dos Milagres
sectorE	Observed	OT106	-9,271049	-35,355011	São Miguel dos Milagres
sectorE	Observed	OT107	-9,270891	-35,355232	São Miguel dos Milagres
sectorE	Observed	OT108	-9,270728	-35,355457	São Miguel dos Milagres
sectorG	Observed	OT057	-9,426257	-35,485264	Barra de Santo Antônio
sectorG	Observed	OT058	-9,427	-35,485104	Barra de Santo Antônio
sectorG	Observed	OT059	-9,426575	-35,485703	Barra de Santo Antônio
sectorG	Observed	OT060	-9,419624	-35,483471	Barra de Santo Antônio
sectorG	Observed	OT061	-9,419624	-35,483471	Barra de Santo Antônio
sectorG	Observed	OT062	-9,41709	-35,481544	Barra de Santo Antônio
sectorG	Observed	OT063	-9,416723	-35,482174	Barra de Santo Antônio
sectorG	Observed	OT064	-9,417635	-35,481678	Barra de Santo Antônio
sectorG	Observed	OT065	-9,417432	-35,481964	Barra de Santo Antônio
sectorG	Observed	OT066	-9,417432	-35,481964	Barra de Santo Antônio
sectorG	Observed	OT067	-9,417432	-35,481964	Barra de Santo Antônio
sectorG	Observed	OT068	-9,417227	-35,482254	Barra de Santo Antônio
sectorG	Observed	OT069	-9,406683	-35,48056	Barra de Santo Antônio
sectorG	Observed	OT070	-9,407143	-35,479919	Barra de Santo Antônio
sectorG	Observed	OT071	-9,395621	-35,492329	Barra de Santo Antônio
sectorG	Observed	OT072	-9,39026	-35,488808	Barra de Santo Antônio
sectorG	Observed	OT073	-9,392449	-35,47374	Barra de Santo Antônio
sectorG	Observed	OT074	-9,394207	-35,466793	Barra de Santo Antônio
sectorG	Observed	OT075	-9,365779	-35,464268	Barra de Santo Antônio
sectorG	Observed	OT076	-9,358023	-35,452103	Passo de Camaragibe
sectorG	Observed	OT077	-9,356765	-35,449329	Passo de Camaragibe

sectorG	Observed	OT078	-9,356196	-35,44915	Passo de Camaragibe
sectorH	Observed	OT040	-9,489462	-35,546593	Paripueira
sectorH	Observed	OT041	-9,489618	-35,546379	Paripueira
sectorH	Observed	OT042	-9,489618	-35,546379	Paripueira
sectorH	Observed	OT043	-9,489618	-35,546379	Paripueira
sectorH	Observed	OT044	-9,489773	-35,546162	Paripueira
sectorH	Observed	OT045	-9,485102	-35,551727	Paripueira
sectorH	Observed	OT046	-9,485102	-35,551727	Paripueira
sectorH	Observed	OT047	-9,475404	-35,549721	Paripueira
sectorH	Observed	OT048	-9,473034	-35,531849	Paripueira
sectorH	Observed	OT049	-9,472214	-35,532997	Paripueira
sectorH	Observed	OT050	-9,453424	-35,518894	Paripueira
sectorH	Observed	OT051	-9,442093	-35,504467	Barra de Santo Antônio
sectorH	Observed	OT052	-9,436343	-35,495945	Barra de Santo Antônio
sectorH	Observed	OT053	-9,435927	-35,495571	Barra de Santo Antônio
sectorH	Observed	OT054	-9,431273	-35,492901	Barra de Santo Antônio
sectorH	Observed	OT055	-9,430303	-35,493359	Barra de Santo Antônio
sectorH	Observed	OT056	-9,427461	-35,492725	Barra de Santo Antônio
sectorI	Observed	OT001	-9,543385	-35,613544	Maceió
sectorI	Observed	OT002	-9,548239	-35,606762	Maceió
sectorI	Observed	OT003	-9,547269	-35,598026	Maceió
sectorI	Observed	OT004	-9,546705	-35,597843	Maceió
sectorI	Observed	OT005	-9,540448	-35,593731	Maceió
sectorI	Observed	OT006	-9,537093	-35,595722	Maceió
sectorI	Observed	OT007	-9,537409	-35,595282	Maceió
sectorI	Observed	OT008	-9,539432	-35,592457	Maceió
sectorI	Observed	OT009	-9,539744	-35,592022	Maceió
sectorI	Observed	OT010	-9,539373	-35,591564	Maceió
sectorI	Observed	OT011	-9,539067	-35,591991	Maceió
sectorI	Observed	OT012	-9,537037	-35,594826	Maceió
sectorI	Observed	OT013	-9,533458	-35,587967	Maceió
sectorI	Observed	OT014	-9,533627	-35,58773	Maceió
sectorI	Observed	OT015	-9,533431	-35,586971	Maceió
sectorI	Observed	OT016	-9,533431	-35,586971	Maceió
sectorI	Observed	OT017	-9,533274	-35,587189	Maceió
sectorI	Observed	OT018	-9,533111	-35,587418	Maceió
sectorI	Observed	OT019	-9,530818	-35,590618	Maceió
sectorI	Observed	OT020	-9,529907	-35,589237	Maceió
sectorI	Observed	OT021	-9,532079	-35,586182	Maceió
sectorI	Observed	OT022	-9,531333	-35,586246	Maceió
sectorI	Observed	OT023	-9,530561	-35,58733	Maceió
sectorI	Observed	OT024	-9,529616	-35,584156	Maceió
sectorI	Observed	OT025	-9,530279	-35,583241	Maceió
sectorI	Observed	OT026	-9,529692	-35,583023	Maceió

sectorI	Observed	OT027	-9,507988	-35,578514	Maceió
sectorI	Observed	OT028	-9,507522	-35,579166	Maceió
sectorI	Observed	OT029	-9,507667	-35,570744	Maceió
sectorI	Observed	OT030	-9,508591	-35,569454	Maceió
sectorI	Observed	OT031	-9,50795	-35,569393	Maceió
sectorI	Observed	OT032	-9,505306	-35,572273	Maceió
sectorI	Observed	OT033	-9,505952	-35,571354	Maceió
sectorI	Observed	OT034	-9,506111	-35,571114	Maceió
sectorI	Observed	OT035	-9,502709	-35,568546	Maceió
sectorI	Observed	OT036	-9,503553	-35,567379	Maceió
sectorI	Observed	OT037	-9,498477	-35,554707	Maceió
sectorI	Observed	OT038	-9,498477	-35,554707	Maceió
sectorI	Observed	OT039	-9,494555	-35,550495	Maceió

Table S2. Coordinates of Fishing Huts used in this work.

FISHING HUTS	**LATITUDE**	**LONGITUDE**	**10km_SECTORS**
1	-8,914431	-35,1524	sectorA
2	-8,921482	-35,1562	sectorA
3	-8,930334	-35,1643	sectorA
4	-8,930334	-35,1643	sectorA
5	-8,950997	-35,1708	sectorA
6	-8,987439	-35,1936	sectorB
7	-8,971585	-35,1786	sectorA
8	-8,971653	-35,1787	sectorA
9	-8,971653	-35,1787	sectorA
10	-8,971653	-35,1787	sectorA
11	-8,988675	-35,1954	sectorB
12	-8,988675	-35,1954	sectorB
13	-8,994162	-35,2031	sectorB
14	-9,008902	-35,2173	sectorB
15	-9,01137	-35,2191	sectorB
16	-9,01239	-35,2204	sectorB
17	-9,014886	-35,2216	sectorB
18	-9,018053	-35,2231	sectorB
19	-9,021522	-35,2244	sectorB
20	-9,023088	-35,2247	sectorB
21	-9,034799	-35,23	sectorB
22	-9,034799	-35,23	sectorB

23	-9,035613	-35,2302	sectorB
24	-9,050127	-35,2392	sectorC
25	-9,050649	-35,2393	sectorC
26	-9,059292	-35,2395	sectorC
27	-9,093996	-35,2586	sectorC
28	-9,06094	-35,2393	sectorC
29	-9,085614	-35,2529	sectorC
30	-9,086346	-35,2538	sectorC
31	-9,086673	-35,2542	sectorC
32	-9,087293	-35,2552	sectorC
33	-9,091134	-35,2577	sectorC
34	-9,093435	-35,2586	sectorC
35	-9,111521	-35,2668	sectorC
36	-9,111517	-35,2669	sectorC
37	-9,111517	-35,2669	sectorC
38	-9,113687	-35,2682	sectorC
39	-9,116147	-35,2691	sectorC
40	-9,124263	-35,2734	sectorC
41	-9,124521	-35,2743	sectorC
42	-9,134812	-35,2854	sectorC
43	-9,142028	-35,2874	sectorC
44	-9,125	-35,2775	sectorC
45	-9,12883	-35,2829	sectorC
46	-9,137918	-35,2864	sectorC
47	-9,139628	-35,2869	sectorC
48	-9,141224	-35,2873	sectorC
49	-9,151495	-35,2857	sectorC
50	-9,159102	-35,2952	sectorC
51	-9,158879	-35,2952	sectorC
52	-9,163374	-35,2956	sectorD
53	-9,163908	-35,2956	sectorD
54	-9,164389	-35,2956	sectorD
55	-9,164966	-35,2955	sectorD
56	-9,178538	-35,2986	sectorD
57	-9,181262	-35,2996	sectorD
58	-9,181839	-35,2998	sectorD
59	-9,182425	-35,3	sectorD
60	-9,195987	-35,3134	sectorD
61	-9,195987	-35,3134	sectorD
62	-9,201671	-35,3215	sectorD
63	-9,210376	-35,3245	sectorD
64	-9,21069	-35,3246	sectorD
65	-9,243503	-35,3471	sectorE
66	-9,243503	-35,3471	sectorE

67	-9,24355	-35,3471	sectorE
68	-9,243633	-35,3472	sectorE
69	-9,244295	-35,3477	sectorE
70	-9,244873	-35,3481	sectorE
71	-9,256792	-35,3555	sectorE
72	-9,268382	-35,3661	sectorE
73	-9,269075	-35,3667	sectorE
74	-9,27494	-35,3726	sectorE
75	-9,275119	-35,3727	sectorE
76	-9,310685	-35,4124	sectorF
77	-9,273182	-35,371	sectorE
78	-9,277849	-35,3747	sectorE
79	-9,277861	-35,3748	sectorE
80	-9,308684	-35,4099	sectorF
81	-9,311804	-35,4136	sectorF
82	-9,311747	-35,4144	sectorF
83	-9,311747	-35,4144	sectorF
84	-9,311747	-35,4144	sectorF
85	-9,413586	-35,4981	sectorG
86	-9,412651	-35,4978	sectorG
87	-9,396037	-35,4965	sectorG
88	-9,393911	-35,4961	sectorG
89	-9,390797	-35,4952	sectorG
90	-9,381779	-35,4913	sectorG
91	-9,356421	-35,4711	sectorG
92	-9,398332	-35,4979	sectorG
93	-9,43252	-35,5191	sectorH
94	-9,420129	-35,5036	sectorG
95	-9,435895	-35,5112	sectorH
96	-9,434875	-35,5116	sectorH
97	-9,440578	-35,5163	sectorH
98	-9,459979	-35,5386	sectorH
99	-9,461718	-35,5402	sectorH
100	-9,464159	-35,5419	sectorH
101	-9,465508	-35,5428	sectorH
102	-9,467329	-35,5442	sectorH
103	-9,468216	-35,5467	sectorH
104	-9,527932	-35,6063	sectorI
105	-9,504605	-35,5808	sectorI
106	-9,504385	-35,5803	sectorI