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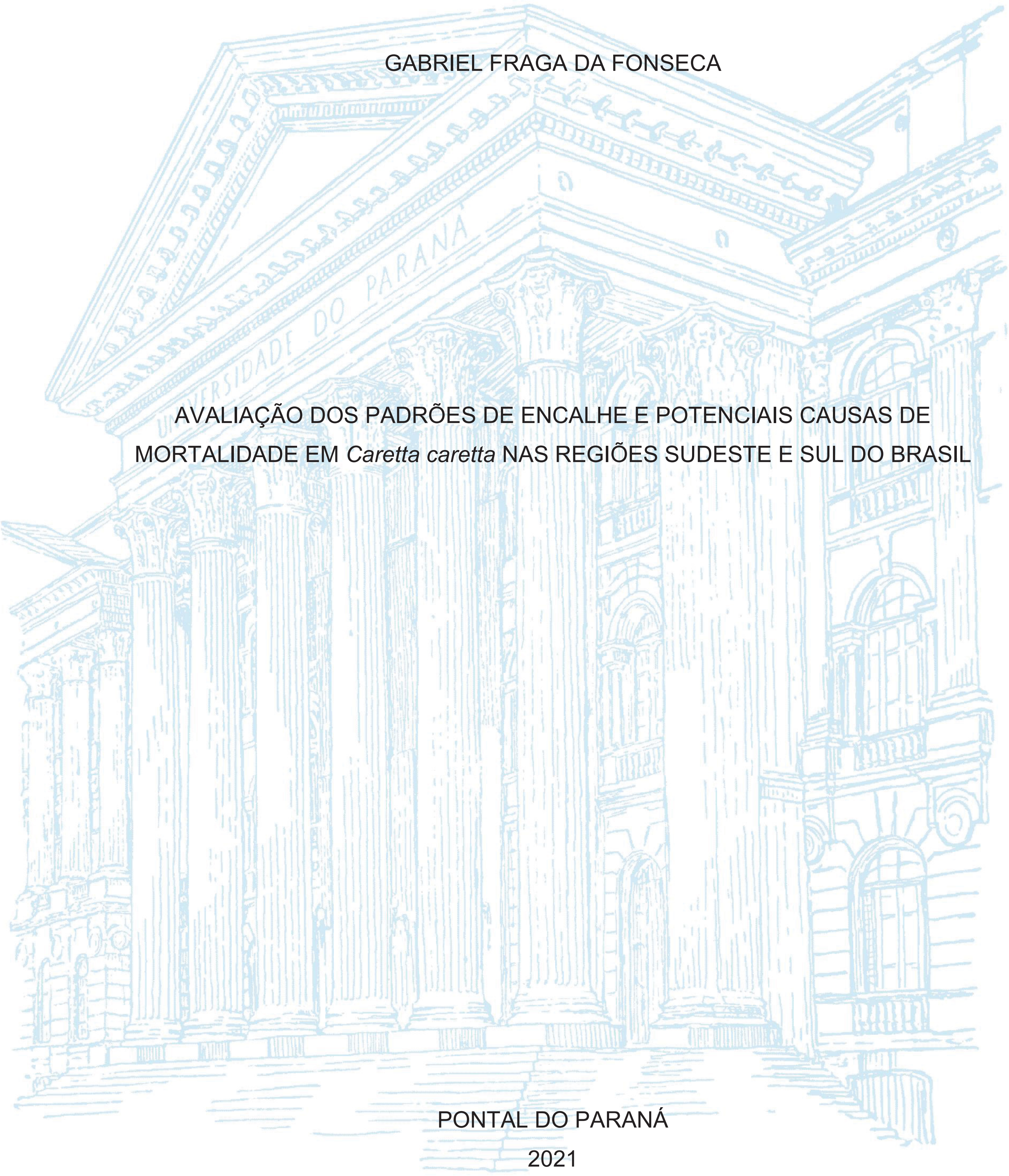

GABRIEL FRAGA DA FONSECA

AVALIAÇÃO DOS PADRÕES DE ENCALHE E POTENCIAIS CAUSAS DE MORTALIDADE EM *Caretta caretta* NAS REGIÕES SUDESTE E SUL DO BRASIL

PONTAL DO PARANÁ
2021

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Dissertação apresentada ao curso de Pós-Graduação em Sistemas Costeiros e Oceânicos, Setor de Ciências da Terra, Universidade Federal do Paraná, como requisito parcial à obtenção do título de Mestre em Biologia e Ecologia de Sistemas Costeiros e Oceânicos.

Orientadora: Profa. Dra. Camila Domit

Coorientador: Prof. Dr. Maikon Di Domenico

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Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação SISTEMAS COSTEIROS E OCEÂNICOS da Universidade Federal do Paraná foram convocados para realizar a arguição da Dissertação de Mestrado de GABRIEL FRAGA DA FONSECA intitulada: Avaliação dos padrões de encalhe e potenciais causas de mortalidade em Caretta caretta nas regiões sudeste e sul do Brasil sob orientação da Profa. Dra. CAMILA DOMIT, que após terem inquirido o aluno e realizada a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

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Às tartarugas marinhas;

A aqueles que sempre me deram suporte,

em especial a vó Darling e vô Âlvaro, tia Silésia e tio Carlinhos.

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“Quando as pessoas protegem algo verdadeiramente especial a elas, podem atingir o seu verdadeiro potencial” – Naruto Uzumaki

RESUMO

Neste trabalho, exploramos os dados de encalhe da espécie *Caretta caretta* obtidos pelo Projeto de Monitoramento de Praias da Bacia de Santos, uma condicionante do IBAMA para a exploração de petróleo e gás natural por parte da PETROBRAS na costa brasileira, para contribuir na elucidação de lacunas de conhecimento e efetividade de ações de conservação da espécie. Em um primeiro capítulo, analisamos encalhes obtidos pelo PMP-BS no período de 2015 a 2020, entre os estados do Rio de Janeiro e Santa Catarina, buscando determinar características populacionais das tartarugas-cabeçuda encalhadas, os principais fatores de mortalidade que influenciam os encalhes, e seus padrões espaço-temporais de distribuição. Em um segundo capítulo, considerando a aplicação de metodologias de modelagem relacionadas à natureza *only-presence* de pontos espaciais que constituem bancos de dados como os do PMP-BS, apresentamos a primeira aplicação de “Point Process Models” para dados de encalhe para explorar sua viabilidade e estabelecer a resolução espacial adequada para a sua aplicação. No primeiro capítulo, detectamos um alto índice de mortalidade de *C. caretta*. Os 2795 encalhes são em sua maioria de juvenis e adultos, com comprimento curvilíneo de carapaça médio de 77,75 cm ± SD 10,82. Além disso, apresentam proporção sexual de 2:1 de fêmeas para machos e idade média de 15,3 anos. Interações antropogênicas relacionadas a múltiplas fontes foram registradas, sendo a interação com a pesca a mais evidente (n = 266 indivíduos). Os *hotspots* de encalhes foram identificados no litoral sul de São Paulo, Paraná e norte de Santa Catarina, e uma variação sazonal com menores índices nos meses de fim de outono e começo de inverno (época de defeso da pesca de camarão sete-barbas por arrasto) e com maiores valores entre o fim do inverno e primavera. No segundo capítulo, utilizando uma arquitetura Bayesiana, comparamos 20 diferentes modelos log-Gaussian Cox PPMs a partir de seus índices DIC e relevância ecológica e conservacional, identificando como modelos mais relevantes aqueles com células de 40 km². Além disso, estabelecemos índices de diferentes intensidades de encalhes em múltiplos cenários de distribuição espacial. De maneira geral, nossos resultados sugerem uma alta mortalidade, possivelmente não sustentável, para a população pertencente a unidade de manejo regional do Atlântico Sudoeste (SWA-RMU); ainda indicam a importância de uma nova análise da classificação da espécie perante as categorias de risco de extinção. Apresentamos também a bem-sucedida aplicação de PPMs para encalhes de *C. caretta,* um robusto embasamento para futuras e mais aprofundadas modelagens, e recomendamos o uso da metodologia para próximas análises de encalhes de outras espécies marinhas e de uso de múltiplos critérios envolvendo a avaliação de ocorrência, mortalidade e encalhe de animais marinhos. Os resultados aqui apresentados poderão contribuir para a para a conservação de *C. caretta* ao gerar conhecimento científico inédito e com potencial de embasar gestores, atores governamentais e sociais, tomadores de decisão e outros cientistas em ações de conservação, especialmente em um cenário de amplo esforço para o manejo costeiro que se apresenta frente ao início da Década do Oceano - ONU.

Palavras-chave

Tartaruga-cabeçuda; Ecologia populacional; Captura incidental; Ecologia da conservação; Point Process Model; Manejo costeiro;

ABSTRACT

This study evaluated *Caretta caretta* stranding data obtained by the Santos Basin Beach Monitoring Project (PMP-BS), an IBAMA constraint related to oil and natural gas exploration in the Brazilian coast by PETROBRAS, to help elucidate knowledge gaps and improve impact mitigation actions for the species conservation. In the first chapter, we analyzed the strandings obtained by PMP-BS from 2015 to 2020, in between Rio de Janeiro and Santa Catarina Brazilian states, aiming to identify populational data regarding the stranded loggerheads, the most impacting mortality factors in strandings' incidence, and the spatiotemporal patterns of strandings. In the second chapter, we considered stranding datas' characteristics as only-presence information on spatial point locations to perform the first application of "Point Process Models" on strandings, as we aimed to explore the method viability and determine the adequate spatial resolution to model design. In the first chapter, the 2795 obtained individuals revealed high *C. caretta* mortality indices for the region and a populational structure of late juveniles and adults with a mean curved carapace length of 77.75 cm ± SD 10.82. We also identified a sexual proportion of 2 females to one male and a mean age of 15.3 years. Anthropogenic interactions related to bycatch and plastic ingestion directly affected 266 and 116 loggerheads. We detected stranding hotspots in SCSP, PC, and SCSC mesoregions, with seasonal incidence increasing from winter to spring and decreasing from October to May (shrimp trawling suspension period). In the second chapter, through a Bayesian framework, we compared 20 log-Gaussian Cox PPMs by their DIC indexes and ecological and conservational relevance. We identified models with approximately 40 km^2 as cell spatial resolution to be the most appropriate for this loggerhead stranding dataset. We also determined minimum, mean and maximum stranding intensity values for models cells. Overall, our results suggest non-sustainable mortality rates for loggerheads and indicate the need to reevaluate the species' "Least Concerned" conservation status in the SWA-RMU. Furthermore, we present the successful application of PPMs for loggerhead strandings, provide robust background for more complex stranding modeling, and encourage the use of PPMs for the stranding modeling of additional marine species. Therefore, we believe this study can benefit decision-makers, cientists, the government and social actors involved in *C. caretta* conservation by providing important information for coastal management, especially in a positive scenario for conservation efforts presented by the upcoming Ocean Decade – ONU.

Keywords

Loggerhead; Population ecology; Bycatch; Conservation ecology; Point Process Model; Coastal management.

RESUMO EM LINGUAGEM ACESSÍVEL

Neste trabalho, fizemos uma análise dos dados de encalhe e mortalidade de tartarugas-cabeçuda, uma das cinco espécies de tartaruga marinha que utilizam a costa brasileira. Os animais encalhados, mortos ou debilitados, foram encontrados por integrantes de diferentes laboratórios que participam de um esforço padronizado de monitoramento de encalhe no Projeto de Monitoramento de Praias da Bacia de Santos, uma condicionante do IBAMA para a exploração de petróleo e gás natural por parte da PETROBRAS na costa brasileira, entre 2015 e 2020, na área entre os estados do Rio de Janeiro e Santa Catarina. Com os dados de encalhe, em um primeiro capítulo, detectamos uma alta mortalidade de tartarugas-cabeçuda na região, afetadas por diversos impactos múltiplos e cumulativos, como pela interação com a pesca, com poluentes e lixos, por acidentes com embarcações e por agressões. A grande maioria dos 2795 animais encontrados são juvenis e adultos, com tamanho médio de quase 80 centímetros de carapaça. Ainda, determinamos também a presença de uma maioria de tartarugas fêmeas nos animais encalhados, com uma proporção sexual de 2:1, e uma concentração desses encalhes em pontos dos litorais catarinense, paranaense e paulista. Em um segundo capítulo, realizamos um bem sucedido teste da aplicação de uma metodologia de análise inovadora para trabalhos com animais encalhados, com potencial de nos fornecer respostas quanto à influência de fatores biológicos, de mortalidade e ambientais na ocorrência de encalhes com menos vieses que os intrínsecos a metodologias utilizadas anteriormente. De maneira geral, os resultados obtidos indicam uma alta mortalidade de tartarugas pertencentes a uma espécie, *Caretta caretta*, já ameaçada de extinção, que deveria possuir uma alta taxa de sobrevivência nas fases de vida em que as encontramos no litoral brasileiro, reforçando a necessidade das ações voltadas à conservação da espécie expostas em diversos documentos nacionais e internacionais. Os resultados desse trabalho poderão contribuir para o cumprimento dessas ações, além de fornecer uma nova ferramenta para a ciência de encalhes, com potencial de gerar conhecimento que auxilie gestores, tomadores de decisão e a sociedade em um cenário de esforço coletivo para o manejo costeiro que se apresenta no início da Década da Ciência Oceânica – ONU.

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LISTA DE ABREVIATURAS OU SIGLAS

CCC	- Comprimento curvilíneo de carapaça
CCL	- Curved carapace length
IUCN	- União Internacional para a Conservação da Natureza
PMP-BS	- Projeto de Monitoramento de Praias da Bacia de Santos
PPM	- Point Process Model
SD	- Standard deviation
SDM	- Species Distribution Models
SIMBA	- Sistema de Informação de Monitoramento da Biota Aquática
SWA-RMU	- Southwest Atlantic Regional Management Unit

MESOREGIONS

ECRJ	- Eastern Coast of Rio de Janeiro
CCRJ	- Central Coast of Rio de Janeiro
WCRJ	- Western Coast of Rio de Janeiro
NCSP	- North Coast of São Paulo
CCSP	- Central Coast of São Paulo
PC	- Paraná Coast
NCSC	- North Coast of Santa Catarina
NCCSC	- North Central Coast of Santa Catarina
CCSC	- Central Coast of Santa Catarina
SCSC	- South Coast of Santa Catarina

SUMÁRIO

1. INTRODUÇÃO

A tartaruga marinha *Caretta caretta* Linnaeus, 1758 (Cheloniidae) é uma das cinco espécies de tartarugas marinhas que habitam o território brasileiro. Assim como as quatro demais espécies com ocorrência nacional, *C. caretta* está incluída na lista vermelha de espécies ameaçadas de extinção da IUCN (União Internacional para Conservação da Natureza), considerada "Vulnerável", principalmente devido a sua exposição a múltiplos e cumulativos impactos (CASALE; TUCKER, 2017; FLINT et al., 2015; LÓPEZ-MENDILAHARSU et al., 2020a; MARCOVALDI; CHALOUPKA, 2007; SANTANA et al., 2011). Algumas das atividades antropogênicas que conhecidamente provocam a mortalidade de tartarugas-cabeçuda são as interações com a pesca, colisão com embarcações, caça e variadas fontes de poluição e degradação ambiental (BRAGA; SCHIAVETTI, 2013; CANTOR et al., 2020a; FARIAS et al., 2019; FLINT et al., 2015, 2017a; KOTAS et al., 2004; NOGUEIRA; ALVES, 2016; SALES; GIFFONI; BARATA, 2008a; SANTANA et al., 2011; TAGLIOLATTO et al., 2020a).

No sudoeste Atlântico, a captura incidental (*bycatch*) é a atividade antrópica mais impactante à sobrevivência de indivíduos de *C. caretta,* principalmente pelas modalidades de pesca de arrasto de fundo e espinhel pelágico (KOTAS et al., 2004; LÓPEZ-MENDILAHARSU et al., 2020a; PINEDO; POLACHECK, 2004; TAGLIOLATTO et al., 2020a). A pesca de arrasto de fundo, que opera mais próxima a costa brasileira, têm como principal alvo o camarão sete-barbas (*Xiphopenaeus kroyeri*), mas interage e induz a mortalidade indivíduos neríticos adultos e juvenis de tartaruga-cabeçuda (LÓPEZ-MENDILAHARSU et al., 2020b; TAGLIOLATTO et al., 2020a). Por outro lado, a pesca de espinhel pelágico, é conhecida por impactar indivíduos juvenis que habitam zonas mais oceânicas, na região de águas internacionais em que o esforço pesqueiro se concentra (LÓPEZ-MENDILAHARSU et al., 2020a; MARCOVALDI et al., 2006; MONTEIRO et al., 2016a; SALES; GIFFONI; BARATA, 2008b). Mesmo com o entendimento de que ambas as modalidades de pesca sejam as que mais afetam a espécie na costa brasileira, as taxas de mortalidade provocadas por essa interação são provavelmente subestimadas (FLINT et al., 2015; HART; MOORESIDE; CROWDER, 2005; KOTAS et al., 2004; LÓPEZ-MENDILAHARSU et al., 2020b). Fatores como a dificuldade em estabelecer taxas de morte de indivíduos soltos após captura, em determinar os efeitos crônicos de poluentes, doenças emergentes e mudanças climáticas na sobrevivência das tartarugas, e em obter dados estatísticos sobre as atividades impactantes, como os esforços pesqueiros, prejudicam o conhecimento sobre os efeitos antropogênicos sobre a espécie e a elaboração de medidas efetivas de conservação (FLINT et al., 2015; HART; MOORESIDE; CROWDER, 2005; KOTAS et al., 2004). Esse quadro é ainda mais grave devido às lacunas de conhecimento acerca da ecologia populacional, uso de hábitat e áreas de conectividade das tartarugas-cabeçuda na região (HAYS, 2008; WILDERMANN et al., 2018).

Buscando reduzir as lacunas de conhecimento da espécie e o desenvolvimento de medidas efetivas de mitigação de impactos, uma abordagem localizada foi desenvolvida a partir da caracterização de Unidades de Manejo Regional (RMU) para a espécie (WALLACE et al., 2010). Sob esse foco, pesquisadores compilaram, por exemplo, informações essenciais à conservação da espécie obtidas a partir de constantes estudos realizados em áreas de desova nos estados da Bahia, Espírito Santo, Rio de Janeiro e Sergipe (C. Baptistotte et al., 2003; Marcovaldi et al., 2010a; Marcovaldi and Chaloupka, 2007; Santana et al., 2011; Tagliolatto et al., 2020; Tiwari and Bjorndal, 2015). Os períodos em terra de fêmeas adultas, provocados pela atividade da desova, promoveram a construção de um conhecimento científico que ainda é escasso para indivíduos neríticos em áreas de forrageio ou migração, justamente pela dificuldade de acesso à esses animais (HAYS, 2008; MARCOVALDI et al., 2010; REES et al., 2016; WILDERMANN et al., 2018).

Buscando contornar os empecilhos logísticos intrínsecos aos estudos de animais migratórios em ambientes marinhos, e fornecer essas informações essenciais, são implementadas diversas tecnologias e metodologias analíticas como as análises de isótopos estáveis, rastreamento/marcação por satélite e monitoramentos embarcados (CASALE et al., 2012; FUENTES et al., 2020; MARCOVALDI et al., 2010; PAJUELO et al., 2012; PECKHAM et al., 2011; THUMS et al., 2013). Entretanto, o alto custo e dificuldades logísticas normalmente impedem a aplicação dessas metodologias em áreas extensas ou em longos períodos de tempo (CANTOR et al., 2020a; CASALE et al., 2012; FUENTES et al., 2020; MARCOVALDI et al., 2010; PAJUELO et al., 2012).

Como uma alternativa de relativo custo-benefício, os encalhes se tornam uma ótima oportunidade de produzir conhecimento científico de qualidade sobre espécies marinhas, como a *C. caretta* (CANTOR et al., 2020a; MONTEIRO et al., 2016a; PELTIER et al., 2014; PELTIER; RIDOUX, 2015; TAGLIOLATTO et al., 2020a). Quando obtidos de maneira sistemática e padronizada, encalhes nos permitem inferir sobre padrões de uso de área, ecologia, causas de mortalidade, diversidade α, dinâmica populacional e principais ameaças antropogênicas atuando sobre as espécies (CANTOR et al., 2020a; MEAGER; SUMPTON, 2016; MONTEIRO et al., 2016a; PELTIER et al., 2012, 2014, 2016; PELTIER; RIDOUX, 2015; SANTOS et al., 2018; TAGLIOLATTO et al., 2020a). Ainda, dados de encalhes podem prover informações sobre qualidade ambiental e saúde populacional, sendo considerados como dados prioritários para medidas locais de mitigação de impactos e desenvolvimento de modelos estatísticos (CANTOR et al., 2020a; MONTEIRO et al., 2016a; PELTIER et al., 2016; TAGLIOLATTO et al., 2020a).

No Brasil, segundo o Plano de Ação Nacional para a Conservação de Tartarugas Marinhas, o Ministério do Meio Ambiente considera o monitoramento dos encalhes de tartarugas marinhas, assim como a investigação de suas causas, ação prioritária para sua conservação (MARCOVALDI; SANTOS; SALES, 2011). O mesmo contexto de prioridade é apresentado a trabalhos que visem uma avaliação de interações antrópicas sobre esses animais (MARCOVALDI; SANTOS; SALES, 2011). Um intenso e amplo esforço de monitoramento de encalhes é realizada em praias situadas ao longo do litoral dos estados do Rio de Janeiro, São Paulo, Paraná e Santa Catarina, desde 2015, por meio de uma condicionante ambiental conduzida pelo Ibama. Esta condicionante está relacionada a avaliação de potenciais impactos da produção e escoamento de petróleo e gás natural da PETROBRAS na Bacia de Santos sobre a fauna de tetrápodes e é denominada de Projeto de Monitoramento de Praias da Bacia de Santos (PMP-BS).

O PMP-BS tem como responsabilidades o registro de ocorrências dos encalhes e o atendimento veterinário para reabilitação, ou necropsia, das tartarugas marinhas encontradas no trecho costeiro entre o centro-sul do Rio de Janeiro e o sul de Santa Catarina (PETROBRAS, 2017). O esforço diário de monitoramento de cerca de 1700km de praia produziu, até o momento, uma base de dados de cinco anos com mais de 2700 encalhes registrados de *C. caretta*, disponibilizada publicamente no Sistema de Informação de Monitoramento da Biota Aquática (PETROBRAS, 2017). As informações contidas no sistema, acerca de cada encalhe, são de caráter biológico (como dados biométricos, de idade, maturidade e sexo dos animais), ambiental (local e data da ocorrência), e quanto às interações antrópicas que podem ter afetado a condição física dos animais, a mortalidade e mesmo a condição de saúde dos organismos (PETROBRAS, 2017).

Estudos utilizando bases de dados como o SIMBA têm sido recentemente utilizados para, com sucesso, auxiliar na melhoria de políticas públicas voltadas à conservação de espécies marinhas ameaçadas (Hart et al. 2006, Tomás et al. 2008, Wang et al. 2015, Moura et al. 2016, Meynecke and Meager 2016, Monteiro et al. 2016, Flint et al. 2017, Tagliolatto et al. 2020, Cantor et al. 2020, Dudhat et al. 2021). Entretanto, a ausência de modelagens de distribuição espacial que considerem a natureza desses dados, constituídos de pontos espaciais de encalhes em uma matriz com apenas observações de presença, pode indicar um caminho de aprimoramento acerca dessas análises.

A aplicação dos dados de encalhes de *C. caretta* obtidos pelo PMP-BS em modelos "Point Process" (PPMs) pode, diferentemente de Modelos Lineares Generalizados (GLMs), MAXENTs e RSFs, fornecer resultados com menos vieses, mais próximos da realidade espacial de ocorrência das carcaças, e em níveis ecológicos de menor resolução e relevantes, como o de indivíduo (Aarts et al. 2012, Pearce and Boyce 2006a, Warton and Shepherd 2010a, Renner et al. 2015a, Velázquez et al. 2016).

Portanto, nesse trabalho, analisamos os dados de encalhes de 2795 tartarugas-cabeçuda obtidas pelo PMP-BS entre 2015 e 2020, na área entre os estados do Rio de Janeiro e Santa Catarina, para, em um primeiro capítulo, contribuir na elucidação de lacunas de conhecimento bioecológicas de *C. caretta*, promover a melhoria de políticas públicas e ações voltadas à redução e mitigação de impactos; e, em um segundo capítulo, estabelecer nova e robusta metodologia de análise para a melhor utilização de dados de encalhe como ferramenta de conservação.

1.1 OBJETIVOS

1.1.1 Objetivo geral

Capítulo 1: Análise espaço-temporal dos padrões de mortalidade e encalhes de tartarugas-cabeçuda na região monitorada pelo PMP-BS.

Capítulo 2: Avaliar a aplicabilidade de "Point Process Models" e desenvolver modelos com base em datasets constituídos de dados *only-presence* referentes a encalhes de *C. caretta*.

1.1.2 Objetivos específicos

Capítulo 1:

- Inferir sobre a estrutura populacional de *C. caretta* que ocorrem e encalham na costa sudeste-sul do Brasil.
- Avaliar os padrões espaço-temporais de mortalidade e distribuição de encalhes de *C. caretta.*
- Determinar atividades antropogênicas com potencial impacto à sobreviência de *C. caretta* na região.

- Elucidar lacunas de conhecimento sobre a espécie para a região sudeste-sul do Brasil, fornecendo dados essenciais para o delineamento de medidas de conservação e mitigação de impactos.
- Determinar áreas de concentração de encalhes e prioritárias para a conservação de *C. caretta* na região sudeste e sul do Brasil.

Capítulo 2:

- Explorar a aplicabilidade de “Point Process Models” em dados referentes a encalhes de megafauna marinha, utilizando *C. caretta* encalhadas como dado experimental.
- Determinar o melhor modelo, acerca da sua resolução especial em grids, utilizando PPMs.
- Testar a viabilidade de ferramenta estatística inédita para tratamento de dados de encalhes
- Contribuir com melhor resilucao espacial para uso dos encalhe e como ferramenta para o manejo coesteiro e ações voltadas à conservação de espécies marinhas, como a *C. caretta.*

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CAPÍTULO 1

Padrões de encalhe de *Caretta caretta* no sudeste e sul do Brasil: altas (e em crescimento) taxas de mortalidade

Stranding patterns of *Caretta caretta* in southeastern and southern Brazil: high (and increasing) mortality rates

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Stranding patterns of *Caretta caretta* in southeastern and southern Brazil: high (and increasing) mortality rates

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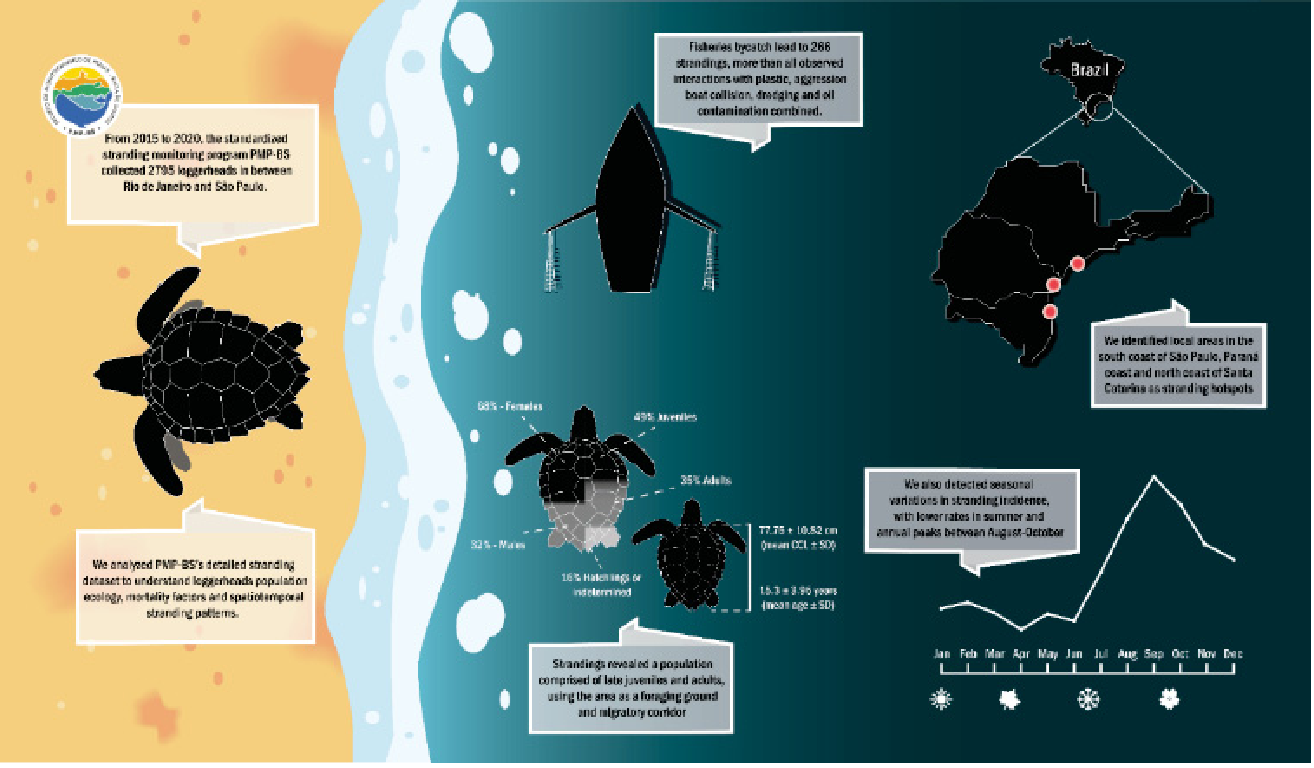
Graphical abstract



From 2015 to 2020, the standardized stranding monitoring program PMP-BS collected 2795 loggerheads in between Rio de Janeiro and São Paulo.

We analyzed PMP-BS's detailed stranding dataset to understand loggerheads population ecology, mortality factors and spatiotemporal stranding patterns.

Fisheries bycatch lead to 266 strandings, more than all observed interactions with plastic, aggression boat collision, dredging and oil contamination combined.

Strandings revealed a population comprised of late juveniles and adults, using the area as a foraging ground and migratory corridor

We identified local areas in the south coast of São Paulo, Paraná coast and north coast of Santa Catarina as stranding hotspots

We also detected seasonal variations in stranding incidence, with lower rates in summer and annual peaks between August-October

Highlights

- **1 –** Encalhes revelam mortalidade de juvenis tardios e, em maioria, fêmeas na região.
- **2 –** Interações com pesca têm maior contribuição nas taxas de mortalidade.
- **3 –** Encalhes se concentram entre inverno e primavera, em áreas de SP, PR e SC.
- **4 –** Alta mortalidade sugere reavaliação do status de conservação da espécie na SWA-RMU.

Resumo

Neste trabalho, exploramos os dados de encalhe de *Caretta caretta* obtidos pelo Projeto de Monitoramento de Praias da Bacia de Santos (PMP-BS), uma condicionante do IBAMA para a exploração de petróleo e gás natural por parte da

PETROBRAS na bacia de Santos, para contribuir na elucidação de lacunas de conhecimento e orientar ações de conservação da espécie. Os encalhes obtidos pelo PMP-BS no período de 2015 a 2020, entre os estados do Rio de Janeiro e Santa Catarina, evidenciam alta mortalidade de *C. caretta* na região. Os 2795 encalhes se deram majoritariamente como de juvenis e adultos, com um comprimento curvilíneo de carapaça médio de 77,75 cm ± SD 10,82. Além disso, observamos uma proporção sexual de 2:1 de fêmeas para machos e uma idade média de 15,3 anos (± 3,95). Interações antropogênicas relacionadas à pesca e ingestão de plástico afetaram 266 e 116 indivíduos, respectivamente. Observamos hotspots de encalhes no litoral sul de São Paulo, Paraná e norte de Santa Catarina, e uma variação sazonal com menores valores nos meses de fim de outono e começo de inverno (época de defeso para a pesca de camarão sete-barbas por arrasto) e com maiores valores no fim do inverno e primavera (temporada intensa de pesca de arrasto na região). De maneira geral, nossos resultados sugerem uma mortalidade não sustentável para a população de juvenis pertencente a unidade de manejo regional do Atlântico sudoeste (SWA-RMU), e indicam a necessidade de novas análises acerca da categorização de risco de extinção da espécie na região, considerando os impactos sob esta fase de vida da espécie.

Palavras-chave

Tartaruga-cabeçuda; Taxas de encalhe; Ecologia populacional; Captura incidental; Impactos à conservação.

Highlights

- **1 –** Loggerhead strandings reveal mortality rates of primarily females and late juveniles.

- **2 –** Mortality rates are mainly affected by fisheries interactions.
- **3 –** Higher stranding incidence from winter to spring, with hotspots in SCSP, PC and SCSC.
- **4 –** Mortality rates suggest a species' conservation status reevaluation in the SWA-RMU.

Abstract

This study evaluated *Caretta caretta* stranding data obtained by the Santos Basin Beach Monitoring Project (PMP-BS), an IBAMA constraint related to oil and natural gas exploration in the Brazilian coast by PETROBRAS, to contribute in elucidating knowledge gaps and improving impact mitigation actions for the species conservation. The strandings were obtained by PMP-BS from 2015 to 2020, in between Rio de Janeiro and Santa Catarina Brazilian states. The total of 2795 stranded individuals revealed high *C. caretta* mortality indices for the region, composed mainly by late juveniles and adults with a mean curved carapace length of 77.75 cm (± SD 10.82). We also identified a sexual proportion of 2 females to one male and a mean age of 15.3 years (± 3.95 SD). Anthropogenic interactions related to bycatch and plastic ingestion directly affected 266 and 116 loggerheads. We detected stranding hotspots in SCSP, PC, and SCSC mesoregions, with seasonal incidence increasing from winter to spring and decreasing from October to May (shrimp trawling suspension period). Overall, our results suggest non-sustainable mortality rates for juvenile loggerheads and indicate the need to reevaluate the species' "Least Concerned" conservation status in the SWA-RMU.

Keywords

Loggerhead; Stranding rates; Population ecology; Bycatch; Conservation impacts.

1. INTRODUCTION

The loggerhead sea turtle *Caretta caretta* Linnaeus, 1758 (Cheloniidae), is one of five sea turtle species in Brazilian territory. This species is globally classified as "Vulnerable" by IUCN (International Union for Conservation of Nature), particularly due to the exposition to an array of multiple and cumulative impacts (Casale and Tucker, 2017; Flint et al., 2015; López-Mendilaharsu et al., 2020a; Marcovaldi and Chaloupka, 2007; Santana et al., 2011). Some of the known threats that can directly lead to death and stranding of *C. caretta* are fisheries interactions, vessel collisions, hunting, and other multiple sources of pollution and habitat degradation (Braga and Schiavetti, 2013; Cantor et al., 2020a; Farias et al., 2019; Flint et al., 2017, 2015; Kotas et al., 2004; Nogueira and Alves, 2016; Sales et al., 2008a; Santana et al., 2011; Tagliolatto et al., 2020).

In the southwest Atlantic Ocean, the leading mortality cause of *C. caretta* is fisheries bycatch by trawling and surface pelagic longlines (Kotas et al., 2004; López-Mendilaharsu et al., 2020a; Pinedo and Polacheck, 2004; Tagliolatto et al., 2020). Bottom trawling is known to induce mortality of bycaught neritic adult and juvenile loggerheads, operating alongside the Brazilian coast, within the Exclusive Economic Zone (López-Mendilaharsu et al., 2020b; Tagliolatto et al., 2020). Nevertheless, pelagic surface longlines are threats mainly to oceanic loggerhead juveniles as the fleets are actively fishing in international waters in the southwest Atlantic Ocean (López-Mendilaharsu et al., 2020a; Marcovaldi et al., 2006; Monteiro et al., 2016a; Sales et al., 2008b). Notwithstanding, the mortality rates caused by anthropogenic interactions are still likely underestimated (Flint et al., 2015; Hart et al., 2005; Kotas et al., 2004; López-Mendilaharsu et al., 2020b). In addition, unobserved deaths of individuals released after capture, difficulties in assessing chronic effects of pollutants and health issues, and unknown fishing data are factors that hinder the knowledge on the impacts that multiple human activities cause and how to mitigate them (Flint et al., 2015; Hart et al., 2005; Kotas et al., 2004). Furthermore, knowledge gaps regarding populational ecology, habitat use, and connectivity can also restrain mitigation actions and the effectiveness of the species' conservation (Hays, 2008; Wildermann et al., 2018).

The characterization of Regional Management Units (RMU) proposed to assess sea turtle populations' statuses provided a framework for identifying available information and knowledge gaps concerning regional populations or subpopulations (Wallace et al., 2010). Along the Brazilian coast, the behavior of nesting *C. caretta* females has been intensively studied on rookery areas in Bahia, Espírito Santo, Rio de Janeiro, and Sergipe states (C. Baptistotte et al., 2003; Marcovaldi et al., 2010a; Marcovaldi and Chaloupka, 2007; Santana et al., 2011; Tagliolatto et al., 2020; Tiwari and Bjorndal, 2015). However, there are many knowledge gaps concerning, in particular, the neritic individuals aggregated on foraging areas and migration routes, as they are further less accessible than in-land nesting turtles (Hays, 2008; Marcovaldi et al., 2010a; Rees et al., 2016; Wildermann et al., 2018).

Implementing different technologies and analytical approaches has been the key to increasing data regarding foraging grounds and migratory routes, as recent studies using stable isotopes, satellite tags, and in-water surveys demonstrate (Casale et al., 2012a; Fuentes et al., 2020; Marcovaldi et al., 2010a; Pajuelo et al., 2012; Peckham et al., 2011; Thums et al., 2013). Unfortunately, most applied methodologies are still expensive and logistically challenging to maintain for extended periods or to cover large areas (Cantor et al., 2020a; Casale et al., 2012a; Fuentes et al., 2020; Marcovaldi et al., 2010a; Pajuelo et al., 2012). Nonetheless, strandings are relatively common events and can provide important information at a high cost-benefit (Cantor et al., 2020a; Monteiro et al., 2016a; Peltier et al., 2014; Peltier and Ridoux, 2015; Tagliolatto et al., 2020).

Stranding data obtained in a systematic and standardized way allows inferences on habitat use patterns, ecology, mortality causes, species diversity, population dynamics, and main threats affecting those species (Cantor et al., 2020a; Meager and Sumpton, 2016; Monteiro et al., 2016a; Peltier et al., 2016, 2014, 2012; Peltier and Ridoux, 2015; Santos et al., 2018a; Tagliolatto et al., 2020). Additionally, standardized stranding data can be considered a reliable indicator of environmental quality and populational health, thus being considered priority data for local management and predictive models (Cantor et al., 2020a; Monteiro et al., 2016a; Peltier et al., 2016; Tagliolatto et al., 2020).

Also, pairing stranding data with oceanic and atmospheric information can allow inferences on which environmental and anthropogenic factors influence the most on mortality and drift of *C. caretta*, as well as the likely location of mortality while highlighting stranding hotspots (Cantor et al., 2020a; Flint et al., 2015; Meager and Sumpton, 2016; Monteiro et al., 2016a; Peltier et al., 2016, 2014, 2012; Peltier and Ridoux, 2015; Tagliolatto et al., 2020). The potential use of stranding data makes stranding monitoring associated with mortality analysis assessment crucial to identify the most significant threats affecting the species conservation, therefore assuring that the methodology is globally recognized as a priority action for sea turtles' conservation (IUCN - MTSG).

In Brazil, the Environment Ministry highlights stranding monitoring actions as a priority activity in the National Action Plan for the Conservation of Sea Turtles (Marcovaldi et al., 2011). Therefore, systematic monitoring has been carried out on beaches located in the states of Rio de Janeiro, São Paulo, Paraná, and Santa Catarina, comprising southeast and southern Brazil, since 2015/2016. The Santos Basin Beach Monitoring Project (*Projeto de Monitoramento de Praias da Bacia de Santos* - PMP-BS) is one of the monitoring programs required by Brazil’s federal environmental agency, IBAMA, for the environmental licensing process of oil production and transport by Petrobras at the pre-salt province (25º05’S 42º35’W a 25º55’S 43º34’W). To evaluate the possible impacts of these activities on sea turtles, marine mammals, and seabirds, the main activity of the PMP-BS is to monitor approximately 1700km of coastline, recording any stranding occurrences and providing veterinary care for rehabilitation or necropsy of individuals found stranded (Petrobras, 2017). The daily monitoring effort has produced, so far, a five-year database with more than 2700 strandings of *C. caretta*, available at the Monitoring Information System of Aquatic Biota (Petrobras, 2017). Each stranding is characterized by information on biological (such as biometric data, age, development stage, and sex of the animals) and environmental parameters (location and date of occurrence); regarding the carcass decomposition state and the anthropogenic interactions that may have affected the physical or health condition of the animals (IBAMA, 2018).

Notwithstanding the above, this detailed stranding dataset was analyzed to i) inferring on the populational structure of loggerheads; ii) evaluate the space-temporal distribution and mortality patterns of stranded loggerheads; iii) determine main anthropogenic threats affecting *C. caretta*. Therefore, we aim to access and solve gaps essential to establishing priority areas for the conservation of loggerheads in the Southwest Atlantic RMU (Rees et al., 2016; Wallace et al., 2010; Wildermann et al., 2018).

2. METHODS

2.1. Data sampling

The standardized monitoring program executed by the PMP-BS covered a coastal area comprising more than 1000km of coastline, between Saquarema (22° 93’ S, 42° 36' W) and Laguna (28° 29' S, 48° 45' W), within the states of Rio de Janeiro, São Paulo, Paraná, and Santa Catarina. Most of the area is covered daily by foot or vehicles (mainly by cars, boats, and bicycles) during low tides; however, a few sectors are monitored weekly.

A network of 13 institutions perform the monitoring, all trained to apply a single methodological protocol (e.g. species identification, biometric measures, and other actions). Stranded animals, dead or alive, were collected and transported by the field teams to their respective laboratories for rehabilitation or necropsy. Standardized data from the stranding site and procedures executed posteriorly for each occurrence are added to a unified online database (SIMBA), available at https://simba.petrobras.com.br. Technical teams confirmed the individual species through morphological and biometric assessment. Biological samples are collected following standardized protocols, with specific guidelines for different taxa and carcass decomposition codes. Necropsy teams determined loggerheads' sex and development stage based on macro and micro histological characterization of gonadal development whenever possible. For individuals in which it was not viable to perform histologic determination of development stage, animals were classified as adults when curved carapace length were larger than 83 cm, which is the minimum value observed at the nearest nesting site (Baptistotte et al., 2003). When feasible, skeletochronology is applied to estimate age, analyzing histologically annual growth marks on humerus bone sections (Zug et al., 1986).

2.2. Data analysis

The stranding dataset was downloaded from SIMBA, and we checked the obtained information to remove and correct potential errors made during data collection or upload. Then, we proceeded to the unification of the different data frames downloaded and exploratory analysis in the R environment, version 4.0.3 (R Core Team, 2020), Microsoft Excel (2011), and QGIS, version 3.10.10 (2020). For exploratory analysis, stranding location (latitude and longitude), date and condition of the carcass (decomposition code state: from 2 to 5), were considered as stranding variables; body size (curved carapace length - CCL), sex (female and male), and development stage (hatchling, juvenile, and adult classes) were considered as individual variables. Furthermore, the causes of death (Factor responsible for primary lesion), health index evaluation (organs afflicted by diseases or external agents), and body condition (great, good, bad, or terrible) of each animal, in addition to the indicative indexes of anthropogenic interaction, were considered health/impact variables. Aware of decomposition's effect on information obtainability, we decided to keep COD 5 (mummified individuals) carcasses from specific analysis. Using a Kernel Density Estimation, we plotted exploratory analysis in various stranding density maps in QGIS through the Heatmap plugin. We used a 2.4 mm influence radius as a standard.

The study area was split into 11 mesoregions characterized by geopolitical and physiographic attributes (ex. geomorphology) to evaluate stranding spatiotemporal distribution patterns (Cantor et al., 2020b; MMA, 2007). We analyzed the variation in stranding patterns regarding biological, mortality, and spatiotemporal factors by comparing mean, maximum, and minimum values, standard deviations, as well as observed frequencies and percentual. We applied Shapiro-Wilk tests to detect normality distribution within the dataset variables (Shapiro and Wilk, 1965). For non-parametrical data, we performed Kruskal-Wallis and Wilcoxon's rank tests to identify statistical differences between observed stranding factors (Kruskal and Wallis, 1952; Zar, n.d.).

3. RESULTS

3.1. Stranding patterns

Between September 3rd, 2015, and April 7th, 2020, the PMP-BS field team covered about 1.62 million kilometers along the Brazilian coast, recording 2795 *C. caretta* stranded along the coastline. Daily monitoring of 782.91 km occurred for the 1678 days in our dataset and is responsible for 81.19% of the total distance covered, while the remaining 18.81% were covered weekly.

Most of the individuals were recorded in advanced decomposition state (decomposition codes 4), corresponding to 88.05% (n = 2022) of the total sample: Code 1 (alive) n = 75; Code 2 (fresh carcasses) n = 37; Code 3 (decomposed carcasses) n = 222; Code 5 (mummified) n = 439.

Concerning biological attributes, only 33.13% had sex determined, as the decomposition state hampered the detection; among those, 68% (n=634) were females and 32% (n=292) males. Juveniles (49%, n= 807) were the most frequent individuals, however adults (35%; n= 585) and a few hatchlings (n= 04) were also recorded. Age was estimated for 392 individuals, ranging from 6 to 29 years old (15.3 years ± 3.95; mean±*SD)*. The average curved carapace length (CCL) was 77.75 cm ± 10.82 (mean±SD), with a median of 77.20 cm, reinforcing the majority of juveniles (Figure 1). A Shapiro test revealed a *p-value* < 0.05, indicating that *C. caretta* CCL does not follow a normal distribution in this dataset, and a Kruskal-Wallis test did not reveal a statistically significant difference between females and males CCL (*p-value* = 0.979). For *C. caretta* ages, we observed a non-normal distribution (Shapiro test *p-value* < 0.05) and a significant difference between ages of loggerheads with no determined sex in comparison to males and females (Kruskal-Wallis test *p-value* < 0.01). Further variations in age and CCL for varying sexes, development stages, and strandings' spatial and temporal distributions can also be visualized in Figure 1 and Figure 3.

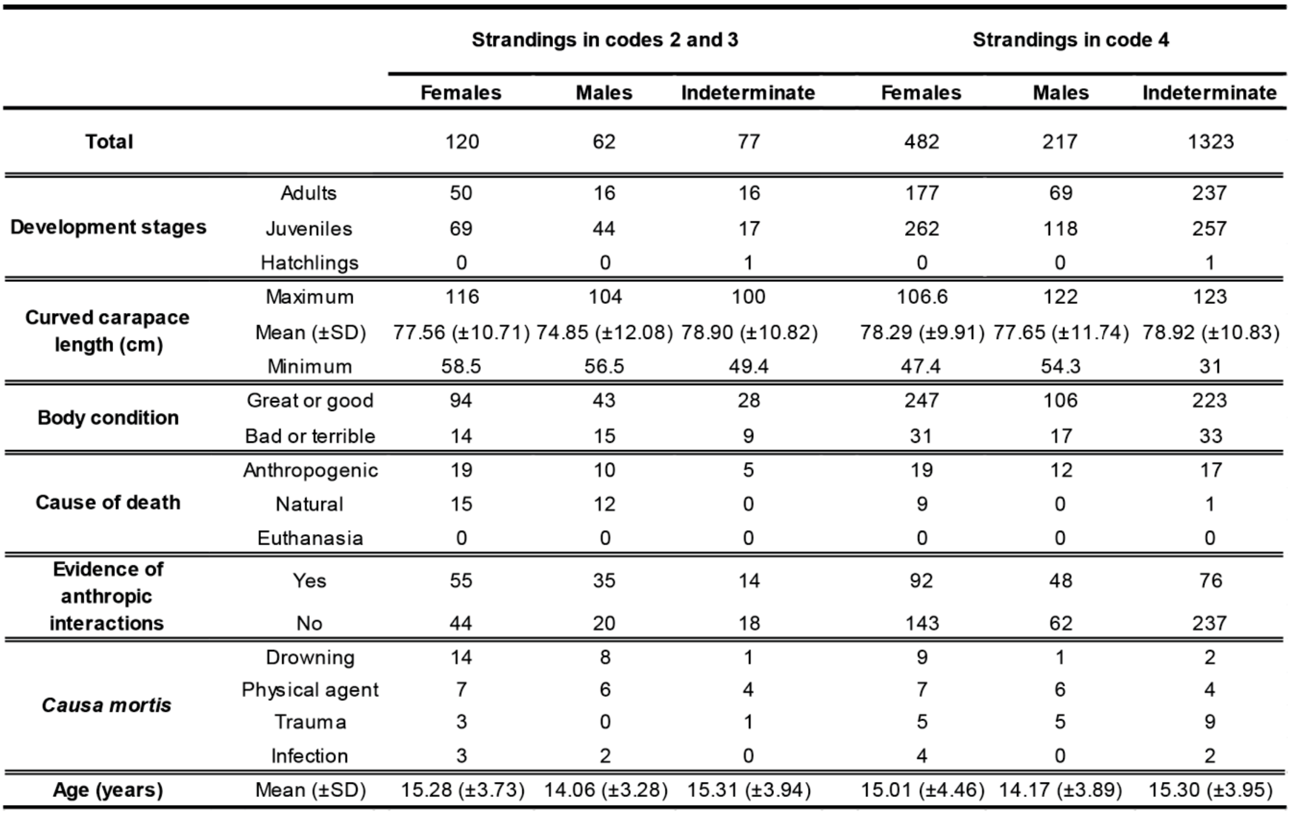
External evidence of anthropogenic interactions was investigated for 905 individuals and confirmed on 352, with interaction intensity being classified on three different levels. We observed fishing gear interactions for 63.35% of those individuals (mean CCL±SD; 78.00 ±10.49 cm - mean age±SD; 15.02±3.57 years). Debris ingestion was observed in 32.95% (mean CCL±SD; 70.50 ±15.94 cm - mean age±SD; 14.72±4.07 years); Boat collision or interaction with dredges was observed in 11.34% of individuals (mean CCL±SD; 81.32 ±12.21 cm - mean age±SD; 14.71±2.69 years); Vandalism and aggression evidence was accounted for 5.96% of individuals (mean CCL±SD; 79.37 ±10.27 cm - mean age±SD; 15.40±2.22 years). Regarding individual health attributes, 765 individuals were classified in great or good body condition instead of 151 in bad or terrible; however, body condition evaluation was not viable for 72.63% of the records due to their decomposition state. The primary cause of death was determined only for 61 *C. caretta* (code 2 and 3), and anthropogenic actions resulted directly in 55.73% of such strandings. Death by natural causes accounted for 44.26% of strandings, and euthanasia procedures were necessary for three *C. caretta*. Regarding pathologies identified during necropsies, a total of 57 loggerheads presented lesions on their digestive organs. In addition, lesions in respiratory systems were crucial factors influencing the death of other 49 individuals, circulatory systems for 24, and muscular systems for 16 loggerheads. Finally, we determined *causa mortis* as drowning for 41 individuals, physical agent interaction for 39, trauma for 20, and infection for 17 loggerheads. Variations in body size, age, spatiotemporal distribution and frequency of strandings affected by anthropogenic activities can be visualized in Figures 5, 6, 7, 8 and 9.

3.2. Spatiotemporal patterns of *C. caretta* strandings

Loggerhead turtle's strandings occurred along the entire monitored area; however, the stranding distribution is heterogeneous, with concentrations on the south coast of São Paulo, Paraná coast, and north coast of Santa Catarina Mesoregions (Figure 10). The stranding spatial patterns differed between fresh and decomposed to advanced decomposition states (Figure 4), with São Paulo being a stranding hotspot for both categories. Female and male loggerheads differed in the number and location of strandings across the study area. The core stranding areas for female individuals were in São Paulo, Paraná, and Santa Catarina. On the other hand, male loggerhead strandings spread out more and were only slightly concentrated in Paraná and São Paulo (Figure 2).

Loggerheads with evident signs of anthropogenic interactions were mainly found in southern São Paulo, followed by the Paraná coast. Conversely, strandings that did not present such evidence were recorded primarily on the north coast of São Paulo (Figure 5). A slight variation in average body size (CCL) was also observed for stranded *C. caretta* across mesoregions and austral seasons (Figure 1, Figure 10 and Figure 11), mainly as Paraná coast individuals were significantly smaller (Kruskal-Wallis test p-value < 0.05) than those in other areas, and individuals registered in summer were significantly larger for all areas (Kruskal-Wallis test p-value < 0.05). The incidence of loggerhead strandings also varied across time. There is a substantial increase in strandings between July and November, suggesting an influence of winter and spring in these events (Figure 11). Additionally, the winter of 2018 had an unusual peak of strandings that should be better explored (Figure 6).

Table 1: Biological data of loggerhead turtles stranded along the S-SE Brazilian coast, stratified by sex and decomposition codes.



		Strandings in codes 2 and 3			Strandings in code 4		
		Females	Males	Indeterminate	Females	Males	Indeterminate
Total		120	62	77	482	217	1323
Development stages	Adults	50	16	16	177	69	237
	Juveniles	69	44	17	262	118	257
	Hatchlings	0	0	1	0	0	1
Curved carapace length (cm)	Maximum	116	104	100	106.6	122	123
	Mean (±SD)	77.56 (±10.71)	74.85 (±12.08)	78.90 (±10.82)	78.29 (±9.91)	77.65 (±11.74)	78.92 (±10.83)
	Minimum	58.5	56.5	49.4	47.4	54.3	31
Body condition	Great or good	94	43	28	247	106	223
	Bad or terrible	14	15	9	31	17	33
Cause of death	Anthropogenic	19	10	5	19	12	17
	Natural	15	12	0	9	0	1
	Euthanasia	0	0	0	0	0	0
Evidence of anthropic interactions	Yes	55	35	14	92	48	76
	No	44	20	18	143	62	237
Causa mortis	Drowning	14	8	1	9	1	2
	Physical agent	7	6	4	7	6	4
	Trauma	3	0	1	5	5	9
	Infection	3	2	0	4	0	2
Age (years)	Mean (±SD)	15.28 (±3.73)	14.06 (±3.28)	15.31 (±3.94)	15.01 (±4.46)	14.17 (±3.89)	15.30 (±3.95)

Table 2: Size, age, and the number of strandings for female and male loggerheads through mesoregions and austral seasons.

			Mesoregions										
			ECRJ	CCRJ	WCRJ	NCSP	CCSP	SCSP	PC	NCSC	NCCSC	CCSC	SCSC
Curved carapace length (cm, mean +- SD)	**Females**	Summer	81	86.7 (±12.0)	-	94	79.1 (±10.7)	83.7 (±10.4)	71.4 (±7.55)	86.9 (±13.1)	82.8 (±11.9)	80.5	80.0 (±10.7)
		Autumn	-	75.9 (±9.11)	77	83.6 (±16.3)	77.9 (±6.70)	74.4 (±20.3)	68.8 (±1.13)	78.4 (±8.80)	80.4 (±14.5)	79.3 (±4.48)	78.2 (±17.4)
		Winter	88.4 (±15.5)	75.3 (±7.03)	67.7 (±4.82)	81.8 (±8.50)	80.4 (±9.79)	77.4 (±8.42)	76.4 (±10.1)	76.5 (±8.44)	78.3 (±10.8)	76.6 (±8.25)	79.1 (±9.46)
		Spring	81.6 (±0.354)	80.8 (±15.7)	73.5 (±9.90)	79.4 (±11.3)	74.7 (±7.65)	79.9 (±10.7)	72.9 (±10.9)	80 (±11.9)	76 (±16.5)	72 (±10)	78.2 (±10.6)
	Males	Summer	-	95.7	-	80.5 (±2.12)	90.6 (±14.0)	82.4 (±11.8)	82.2 (±2.55)	84.3	79 (±4.24)	71.2	88.2 (±18.0)
		Autumn	-	65.1	-	62	80.2 (±8.77)	72.4 (±6.47)	64.8 (±11.5)	79	76.4 (±7.50)	77.9 (±13.9)	99.6 (±27.4)
		Winter	-	72.2 (±3.15)	77.7 (±3.25)	86.3 (±15.3)	79.4 (±9.16)	76.0 (±10.7)	73.8 (±10.3)	73.9 (±11.5)	75.3 (±7.63)	71.3 (±6.76)	74.2 (±6.08)
		Spring	-	79.1 (±16.4)	75.7	94.2 (±0.495)	78.3 (±13.5)	76.9 (±11.5)	68.0 (±9.27)	79.6 (±8.00)	73.3 (±4.39)	86.0 (±22.9)	78.4 (±13.3)
Age (years, mean +- SD)	**Females**	Summer	-	-	-	15	14.6 (±2.19)	14.8 (±2.22)	17.3 (±3.79)	24	-	-	20 (±2.83)
		Autumn	-	6	-	13	19	12.9 (±1.73)	15	-	-	20.5 (±3.54)	-
		Winter	-	-	-	14.7 (±2.58)	12 (±1.56)	13.1 (±2.49)	19.1 (±4.95)	21	15	19.4 (±4.22)	18 (±0)
		Spring	-	20	-	10.8 (±1.71)	14 (±4)	12.4 (±1.91)	17.4 (±3.94)	18 (±4.24)	-	17.2 (±5.45)	21
	Males	Summer	-	-	-	16	11 (±0)	13 (±2.62)	-	19	-	-	-
		Autumn	-	-	-	-	12	11.5 (±3.54)	15 (±5.66)	17	-	13	-
		Winter	-	-	-	-	13 (±1.58)	13.8 (±2.23)	15.4 (±3.31)	-	-	17 (±2.45)	23
		Spring	-	8	-	-	10.8 (±0.5)	12.7 (±2.10)	17.7 (±5.48)	17.5 (±4.95)	-	17.5 (±0.71)	-
Number of strandings	**Females**	Summer	1	10	-	1	12	7	8	9	5	1	10
		Autumn	-	6	1	4	6	16	5	11	5	7	9
		Winter	3	10	5	22	61	61	58	42	13	9	9
		Spring	2	9	3	14	32	30	43	24	23	13	17
	Males	Summer	-	1	-	2	5	13	4	2	2	1	2
		Autumn	-	1	-	1	2	3	4	1	3	5	3
		Winter	-	3	2	7	21	29	31	17	11	8	3
		Spring	-	6	1	3	17	23	20	13	9	4	11

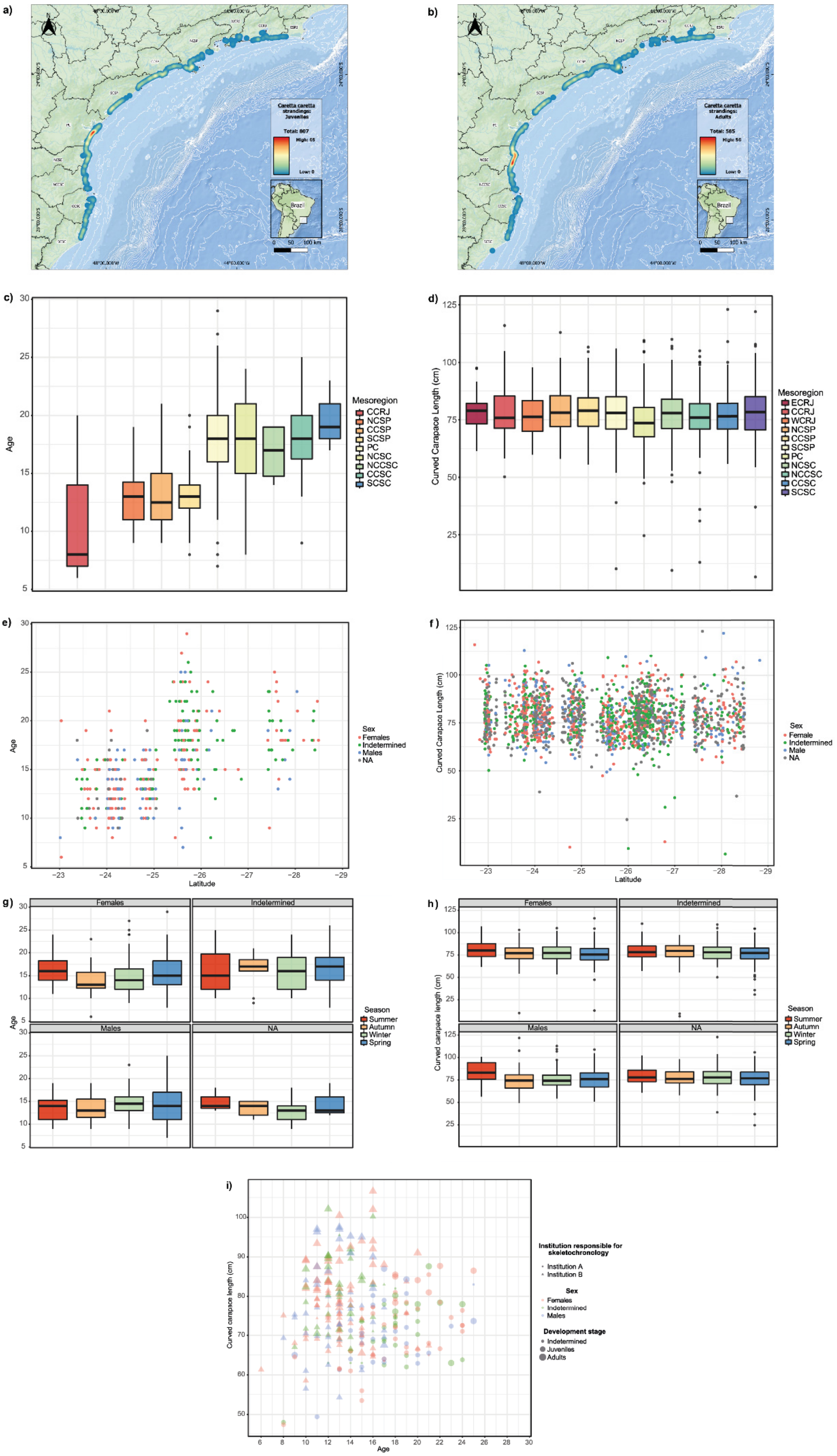

a)
Caretta caretta strandings: Juveniles
Total: 807
High: 65
Low: 0
Brazil
0 50 100 km
b)
Caretta caretta strandings: Adults
Total: 585
High: 56
Low: 0
Brazil
0 50 100 km
c)
Age
Mesoregion
CCRJ
NCSP
CCSP
SCSP
PC
NCSC
NCCSC
CCSC
SCSC
d)
Curved Carapace Length (cm)
Mesoregion
ECRJ
CCRJ
WCRJ
NCSP
CCSP
SCSP
PC
NCSC
NCCSC
CCSC
SCSC
e)
Age
Latitude
Sex
Females
Indetermined
Males
NA
f)
Curved Carapace Length (cm)
Latitude
Sex
Female
Indetermined
Male
NA
g)
Females
Indetermined
Males
NA
Age
Season
Summer
Autumn
Winter
Spring
h)
Females
Indetermined
Males
NA
Curved carapace length (cm)
Season
Summer
Autumn
Winter
Spring
i)
Curved carapace length (cm)
Age
Institution responsible for skeletochronology
Institution A
Institution B
Sex
Females
Indetermined
Males
Development stage
Indetermined
Juveniles
Adults

Figure 1 – Populational parameters of stranded C. caretta along the south and southeastern Brazil, between 2015-2020 (PMP-BS database; https://simba.petrobras.com.br). a) Spatial distribution of juvenile *C. caretta* strandings. **b)** Spatial distribution of adult *C. caretta* strandings. **c)** Variation of age, obtained by skeletochronology, through mesoregions. **d)** Variation of curved carapace length through mesoregions. **e)** Observed ages and their spatial distribution for each sex gender. **f)** Observed curved carapace lengths and their spatial distribution for each sex gender. **g)** Variation in age through austral seasons for each sex gender. **h)** Variation in curved carapace length through austral seasons for each sex gender. **i)** Relation between determined age, curved carapace length, and developmental stage for each sex-gender, accounting for variation in skeletochronology results obtained by both teams responsible for the analysis.

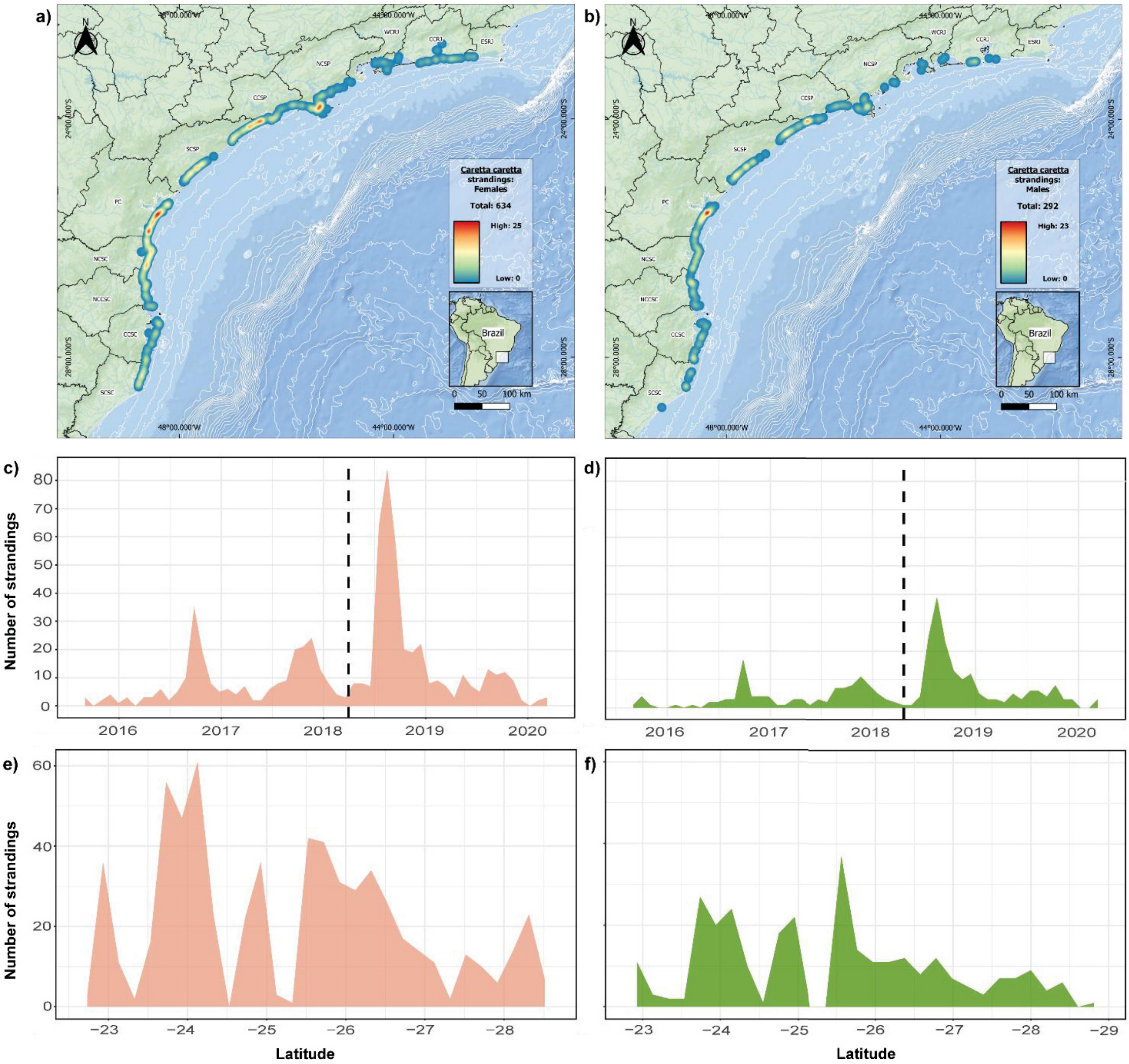


Figure 2 – Spatial and temporal distribution of strandings for female and male C. caretta along the south and southeastern Brazil, between 2015-2020 (PMP-BS database; https://simba.petrobras.com.br). **a)** Spatial distribution of female *C. caretta* strandings. **b)** Spatial distribution of male *C. caretta* strandings. **c)** Temporal distribution of female *C. caretta* strandings. **d)** Temporal distribution of male *C. caretta* strandings. **e)** Variation of the number of strandings through latitude for female loggerheads. **f)** Variation of the number of strandings through latitude for female loggerheads.

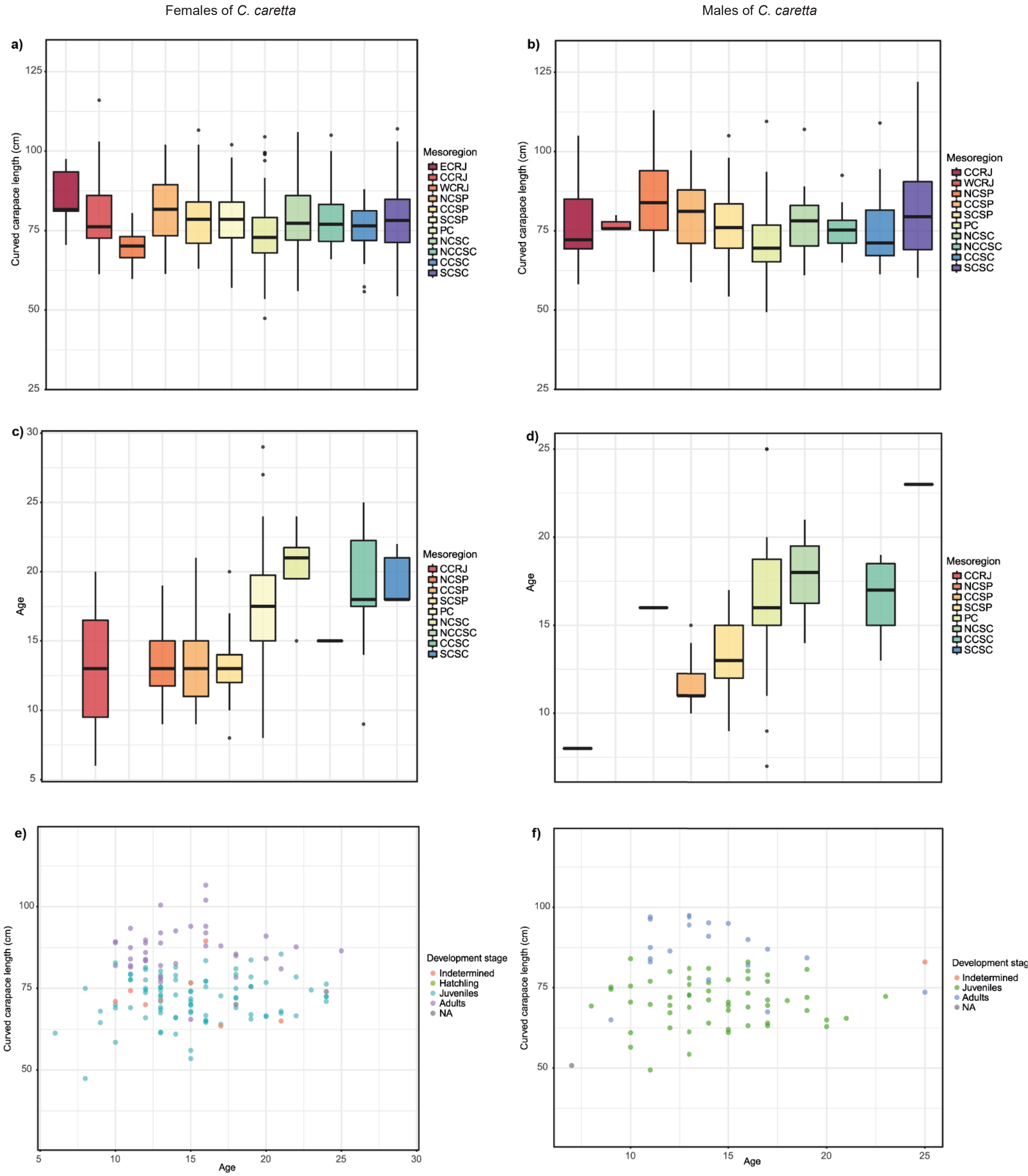


Figure 3 – Populational parameters for female and male stranded C. caretta along the south and southeastern Brazil, between 2015-2020 (PMP-BS database; https://simba.petrobras.com.br/simba/web/sistema/). a) Distribution of the curved

carapace length of female *C. caretta* through mesoregions. **b)** Distribution of the curved carapace length of male *C. caretta* through mesoregions. **c)** Distribution of the age of female *C. caretta* through mesoregions. **d)** Distribution of the age of male *C. caretta* through mesoregions. **e)** Relation between curved carapace length and age for female loggerheads in various developmental stages. **f)** Relation between curved carapace length and age for male loggerheads in various developmental stages.

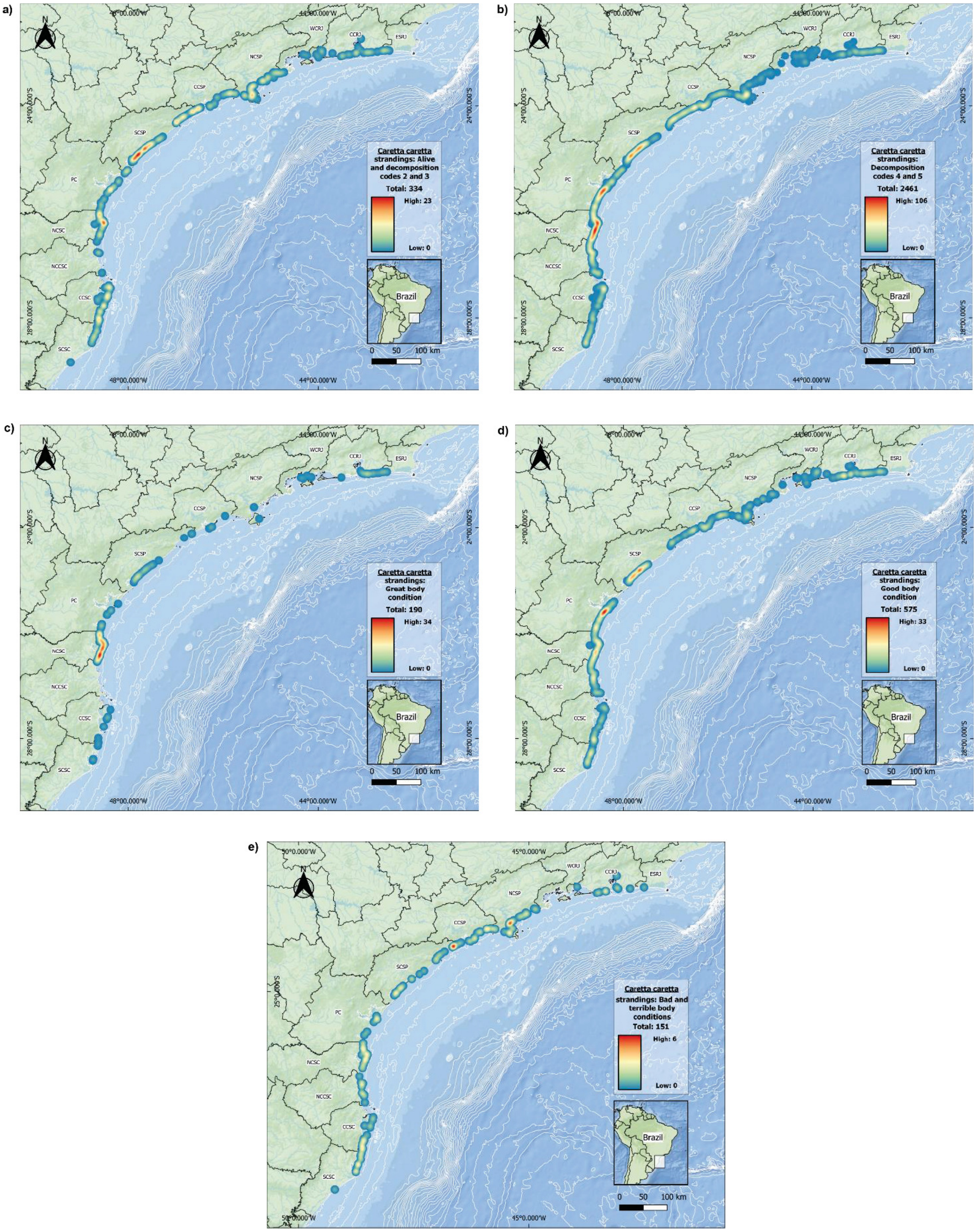


Figure 4 – Spatial distribution of C. caretta strandings in different decomposition and body condition levels along the south and southeastern Brazil, between 2015-2020 (PMP-BS database;

https://simba.petrobras.com.br/simba/web/sistema/). **a)** Spatial distribution of slightly decomposed *C. caretta* strandings. **b)** Spatial distribution of *C. caretta* strandings in advanced decomposition state. **c)** Spatial distribution of *C. caretta* strandings in great body condition. **d)** Spatial distribution of *C. caretta* strandings in good body condition. **e)** Spatial distribution of *C. caretta* strandings in bad and terrible body conditions.

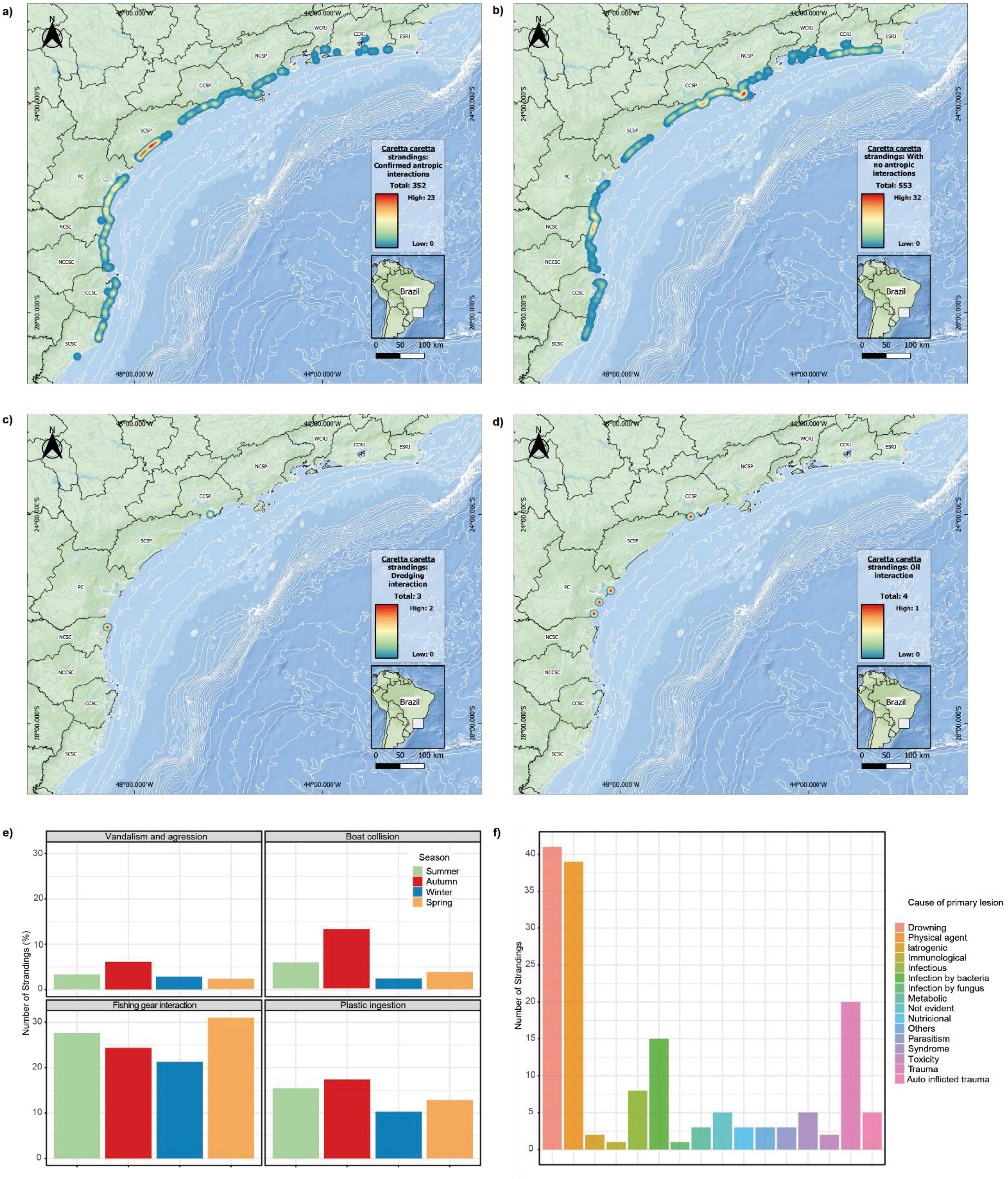


Figure 5 – Impact of anthropogenic activities on C. caretta strandings along the south and southeastern Brazil, between 2015-2020 (PMP-BS database; https://simba.petrobras.com.br/simba/web/sistema/). a) Spatial distribution of *C.*

caretta strandings with confirmed anthropogenic interactions. **b)** Spatial distribution of *C. caretta* strandings with no confirmed anthropogenic interactions. **c)** Spatial distribution of *C. caretta* strandings caused by interaction with dredging. **d)** Spatial distribution of *C. caretta* strandings caused by interaction with oil. **e)** Percentage of strandings with confirmed anthropogenic interaction caused by each activity through austral seasons. **f)** Number of strandings resulted from each identified cause of primary lesion.

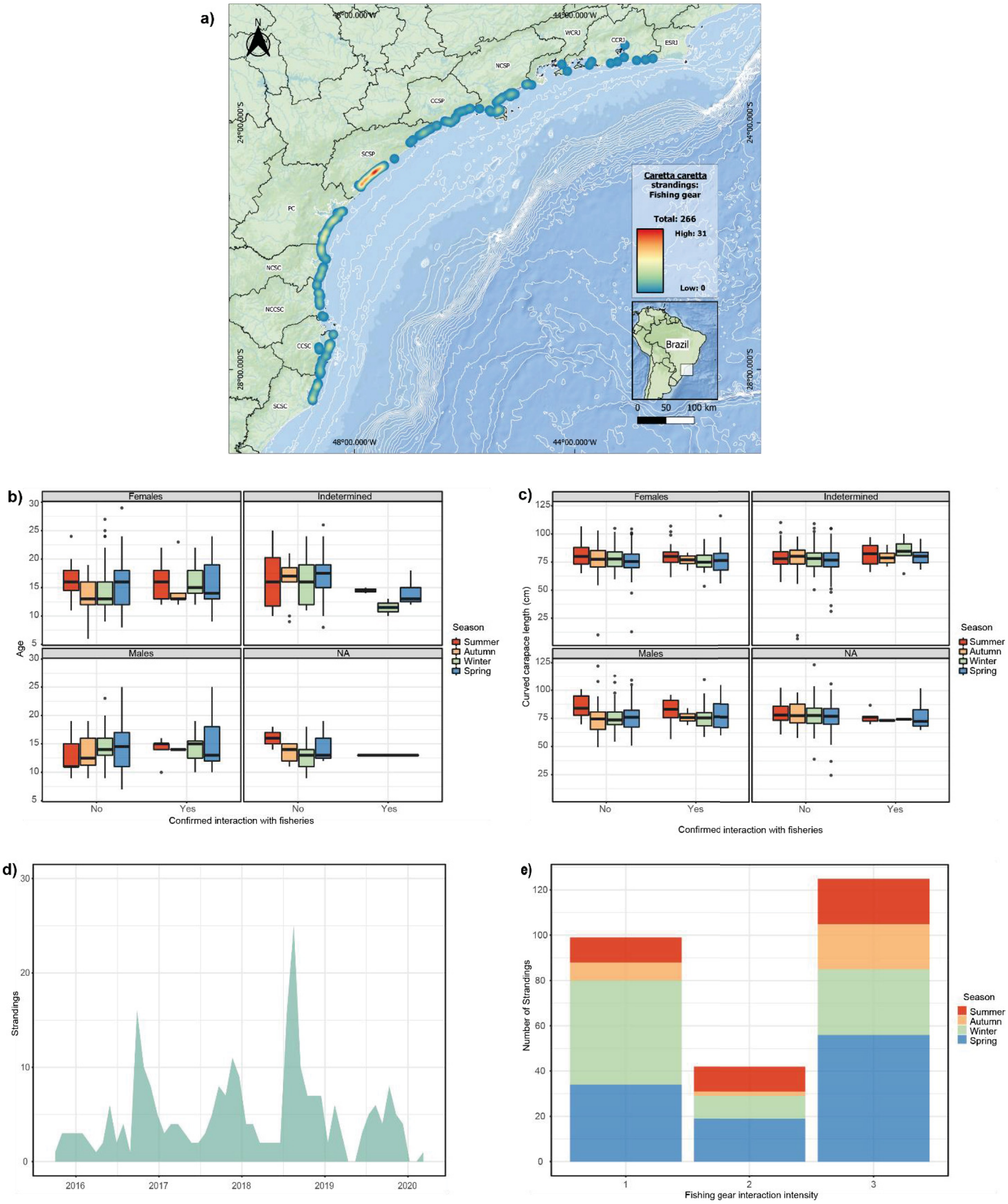


Figure 6 – Patterns of C. caretta strandings caused by fisheries interaction along the south and southeastern Brazil, between 2015-2020 (PMP-BS database; https://simba.petrobras.com.br/simba/web/sistema/). a) Spatial distribution of *C. caretta* strandings with confirmed interaction with fisheries. **b)** Age variation of

loggerheads regarding fisheries interaction, sex gender, and austral seasons. **c)** Curved carapace length variation of loggerheads regarding fisheries interaction, sex gender, and austral seasons. **d)** Number of strandings affected by fisheries through sampled years. **e)** Number of strandings for each intensity level of fisheries interaction by austral seasons.

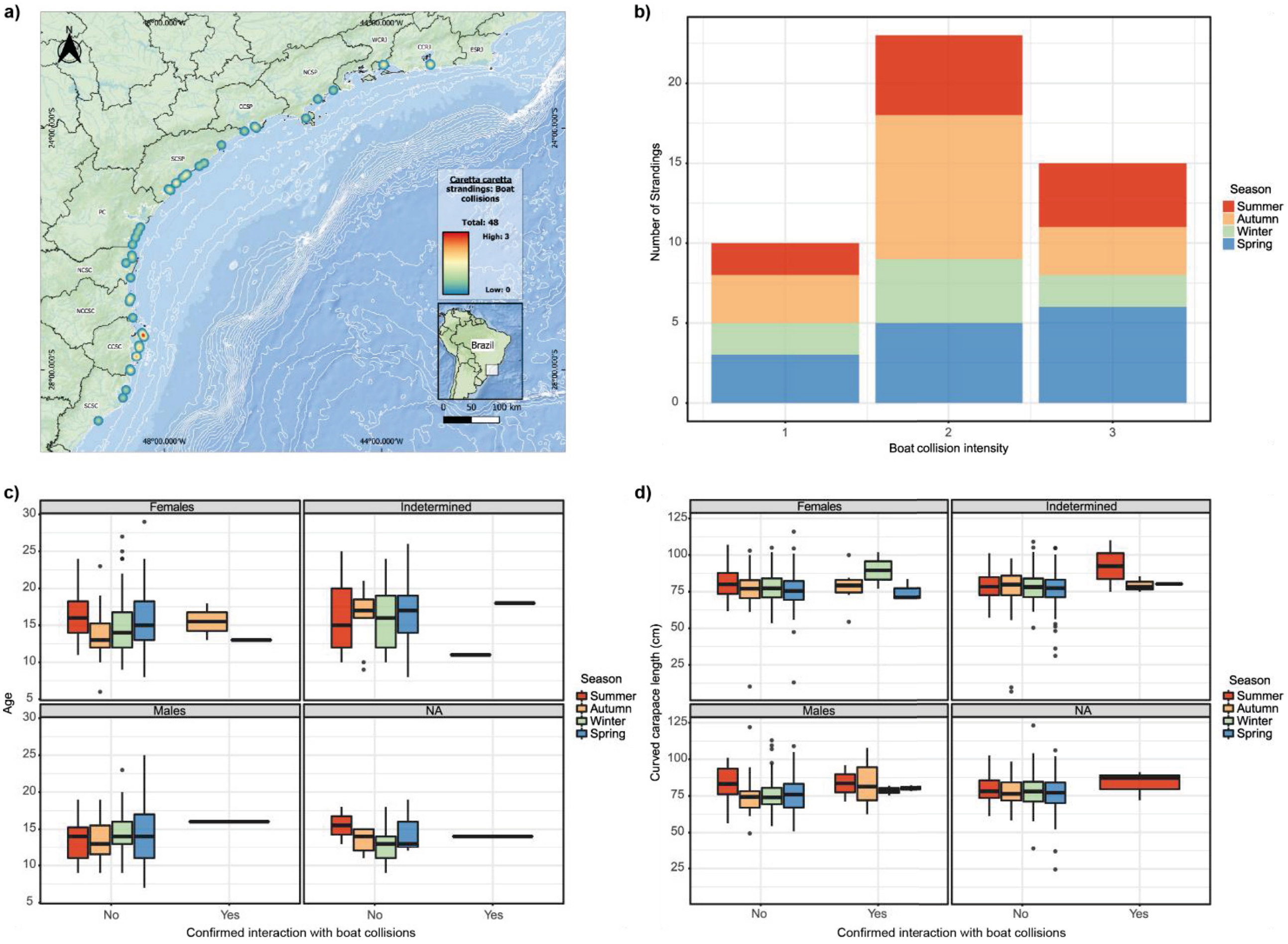


Figure 7 – Patterns of C. caretta strandings caused by boat collisions along the south and southeastern Brazil, between 2015-2020 (PMP-BS database; https://simba.petrobras.com.br/simba/web/sistema/). a) Spatial distribution of *C. caretta* strandings with confirmed impact by boat collisions. **b)** Number of strandings for each intensity level of interaction with boat collision by austral seasons. **c)** Age variation of loggerheads regarding interaction with boat collisions, sex-gender, and

austral seasons. **d)** Curved carapace length variation of loggerheads regarding interaction with boat collisions, sex-gender, and austral seasons.

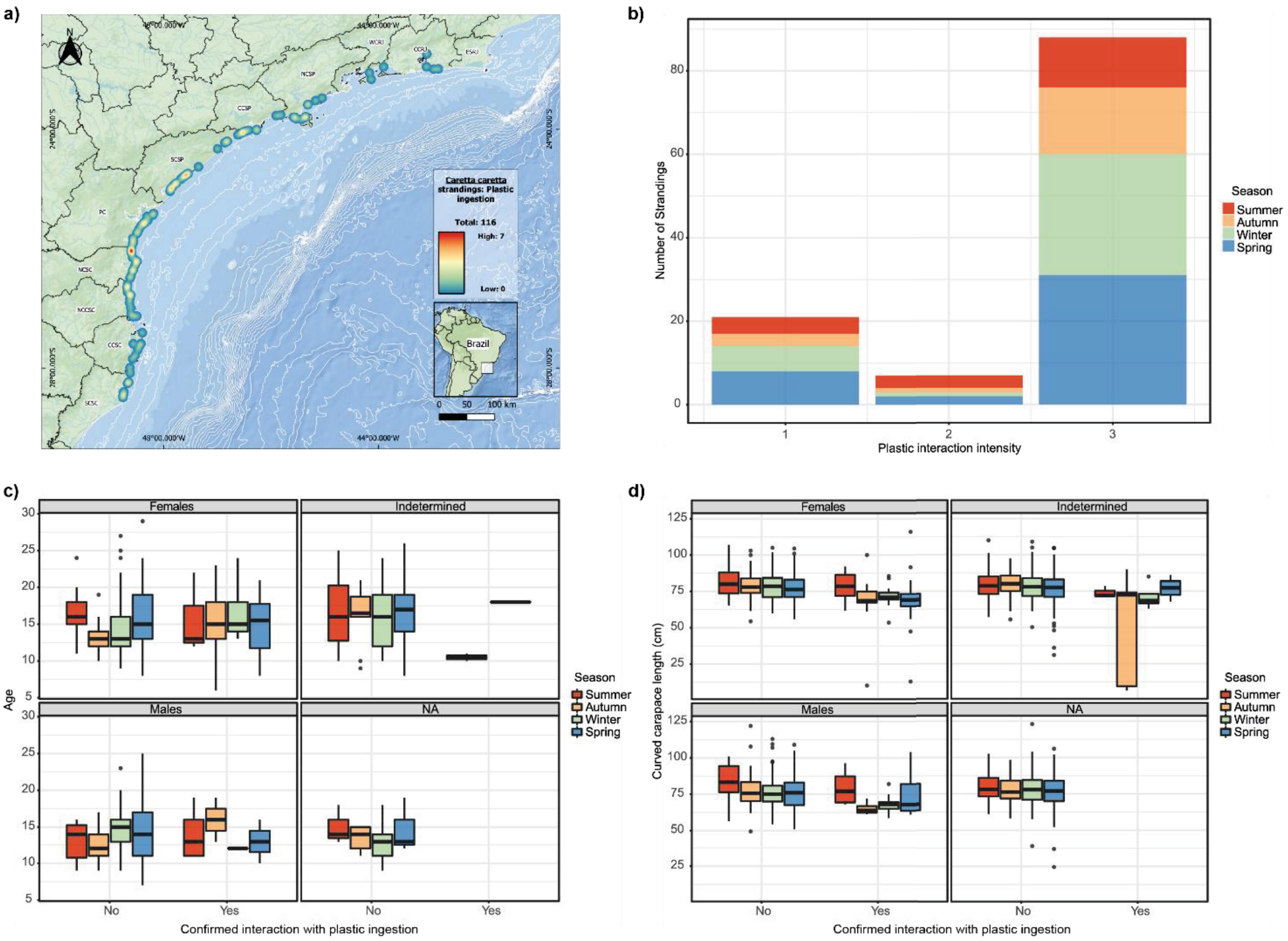


Figure 8 – Patterns of C. caretta strandings caused by interactions with plastic debris along the south, and southeastern Brazil, between 2015-2020 (PMP-BS database; https://simba.petrobras.com.br/simba/web/sistema/). a) Spatial distribution of *C. caretta* strandings with confirmed impact by interaction with plastic debris. **b)** Number of strandings for each intensity level of interaction with plastic debris by austral seasons. **c)** Age variation of loggerheads regarding interaction with plastic debris, sex-gender, and austral seasons. **d)** Curved carapace length variation of loggerheads regarding interaction with plastic debris, sex-gender, and austral seasons.

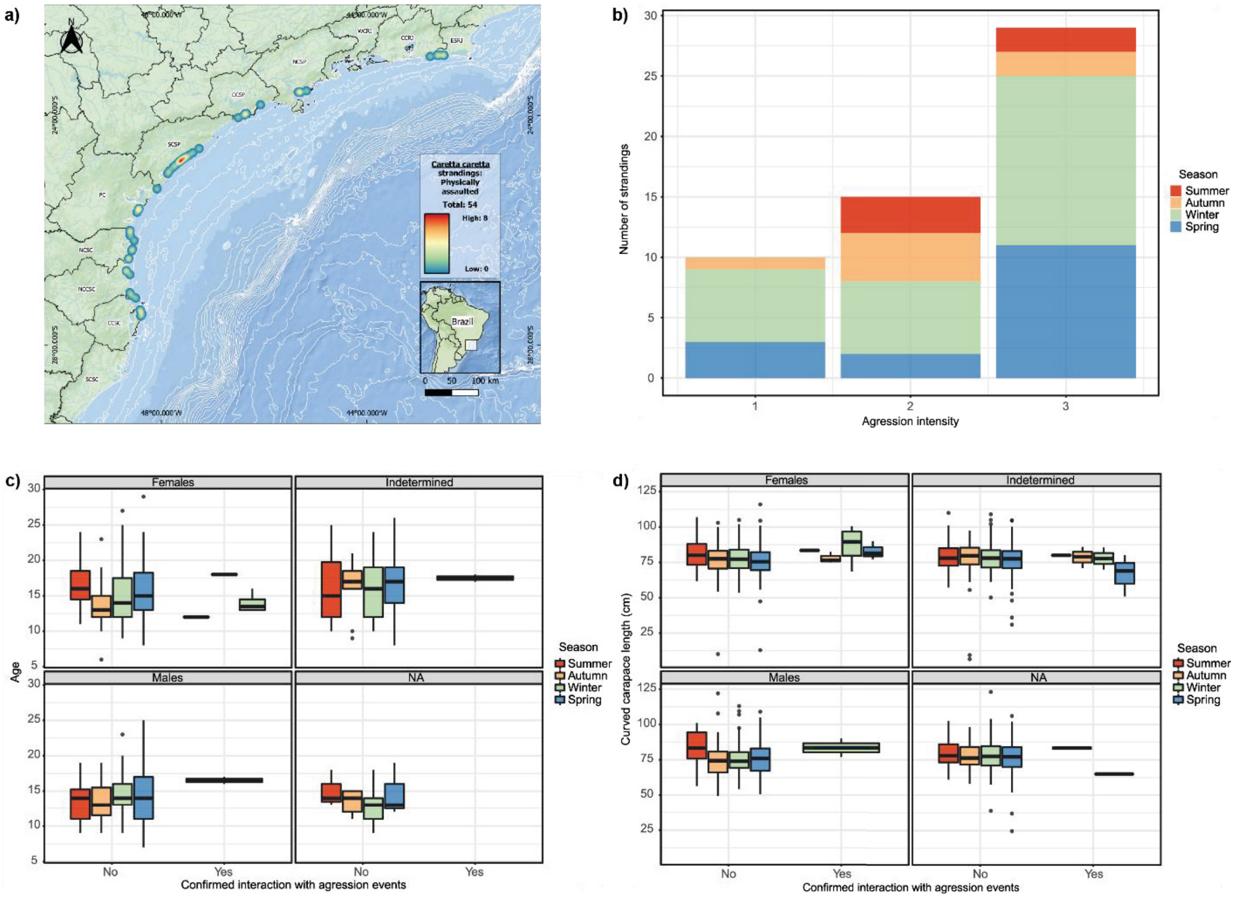


Figure 9 – Patterns of C. caretta strandings caused by interactions by aggression along the south and southeastern Brazil, between 2015-2020 (PMP-BS database; https://simba.petrobras.com.br/simba/web/sistema/). a) Spatial distribution of *C. caretta* strandings with confirmed impact by vandalism and aggression. **b)** Number of strandings for each intensity level of aggression by austral seasons. **c)** Age variation of loggerheads regarding interaction by aggression, sex-gender, and austral seasons. **d)** Curved carapace length variation of loggerheads regarding interaction by aggression, sex-gender, and austral seasons.

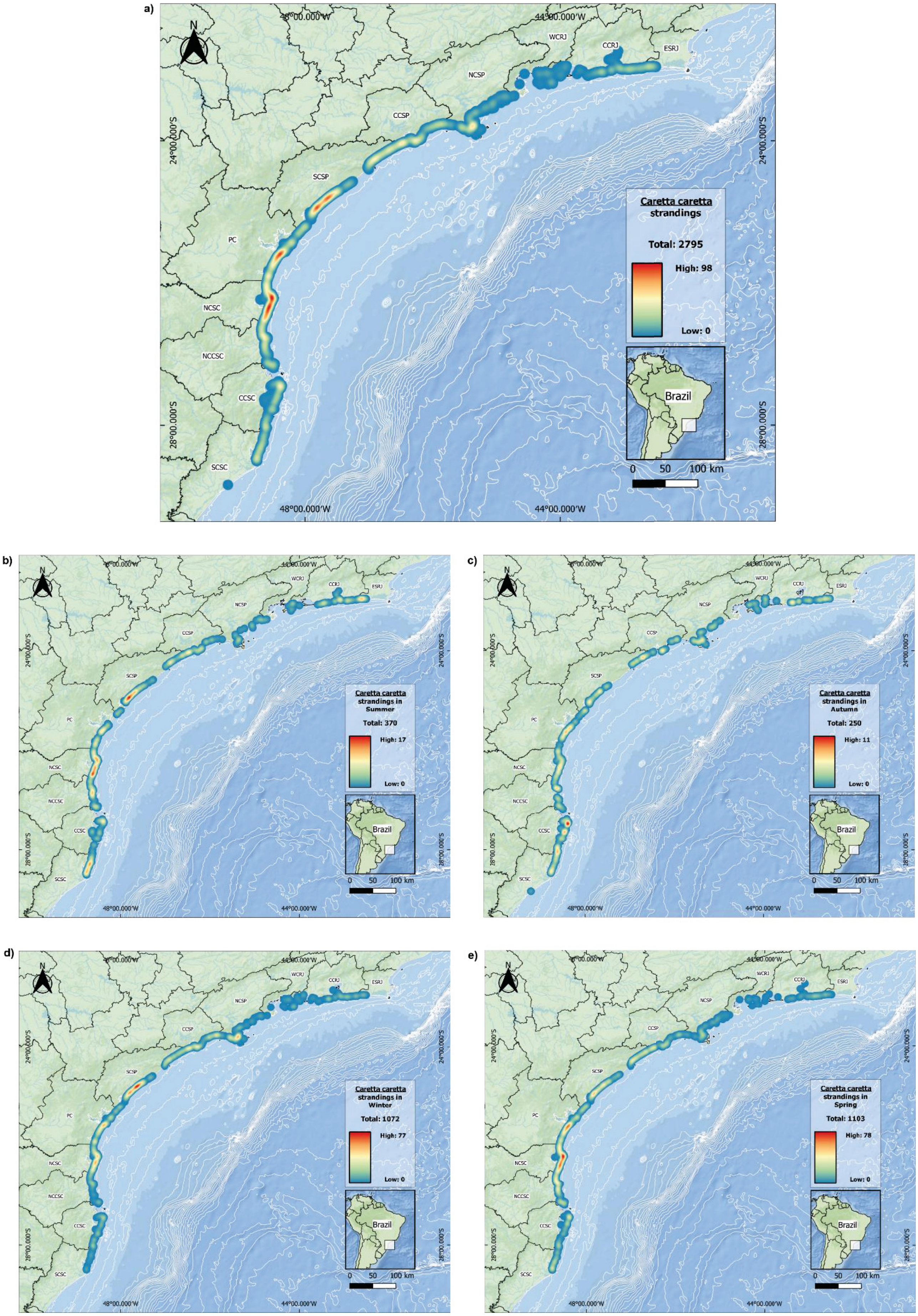

a)
48°00.000'W
44°00.000'W
24°00.000'S
28°00.000'S
WCRJ
CCRJ
ESRJ
NCSP
CCSP
SCSP
PC
NCSC
NCCSC
CCSC
SCSC
Caretta caretta strandings
Total: 2795
High: 98
Low: 0
Brazil
0 50 100 km
b)
Caretta caretta strandings in Summer
Total: 370
High: 17
Low: 0
c)
Caretta caretta strandings in Autumn
Total: 250
High: 11
Low: 0
d)
Caretta caretta strandings in Winter
Total: 1072
High: 77
Low: 0
e)
Caretta caretta strandings in Spring
Total: 1103
High: 78
Low: 0

Figure 10 – C. caretta strandings' distribution in the study area along the south and southeastern Brazil, between 2015-2020 (PMP-BS database; https://simba.petrobras.com.br/simba/web/sistema/). **a)** Spatial distribution of *C. caretta* strandings. **b)** Spatial distribution of *C. caretta* strandings in the summer. **c)** Spatial distribution of *C. caretta* strandings in autumn. **d)** Spatial distribution of *C. caretta* strandings in the winter. **e)** Spatial distribution of *C. caretta* strandings in spring.

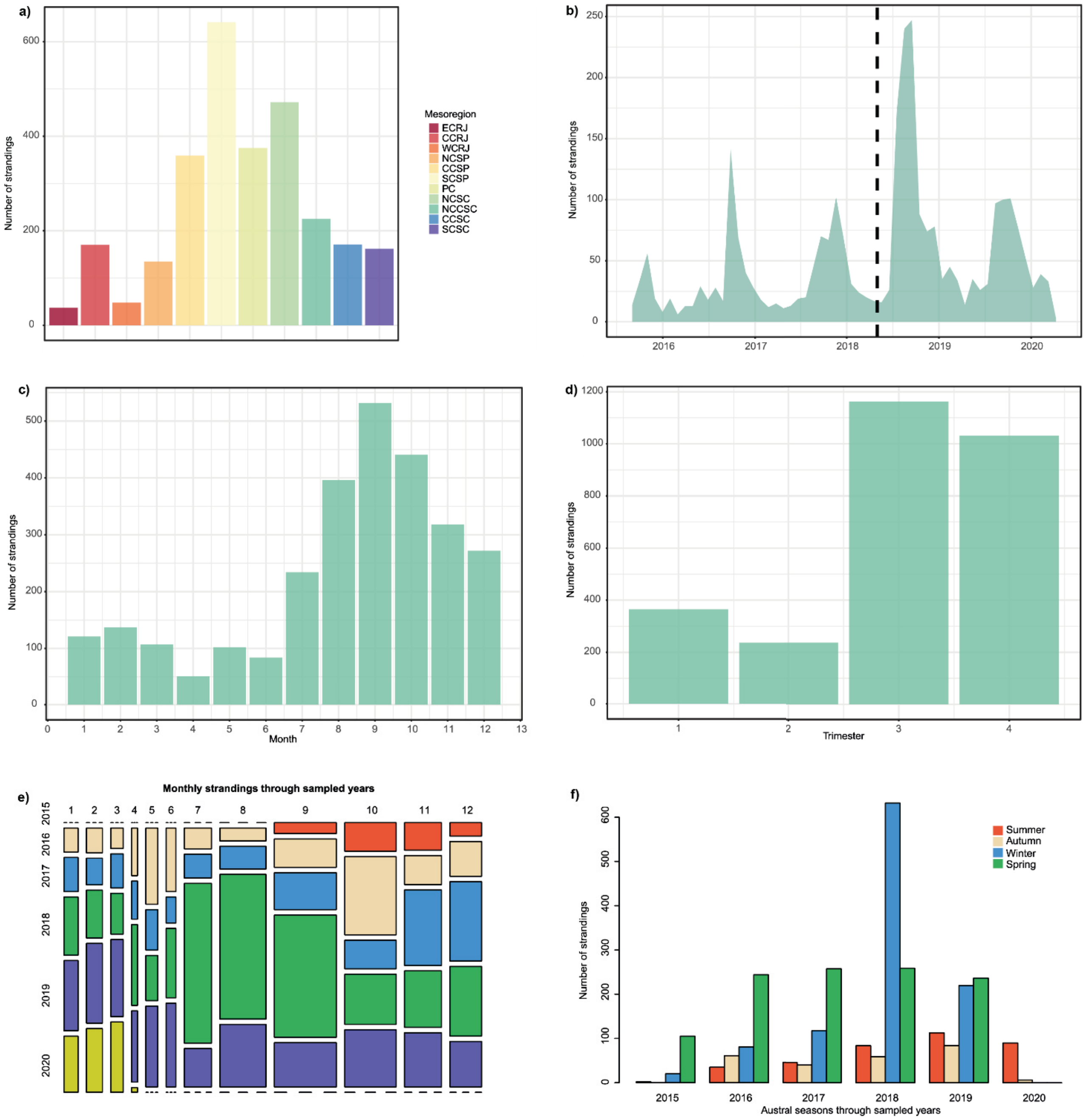


Figure 11 – Spatiotemporal patterns of C. caretta strandings along the south and southeastern Brazil, between 2015-2020 (PMP-BS database; https://simba.petrobras.com.br/simba/web/sistema/). **a)** Number of *C. caretta* strandings in each mesoregion. **b)** Number of *C. caretta* strandings through the sampled period. **c)** Number of *C. caretta* strandings in by month. **d)** Number of *C. caretta* strandings by trimester. **e)** Number of monthly *C. caretta* strandings through sampled years. **f)** Number of *C. caretta* strandings by austral season in each sampled year.

4. DISCUSSION

Our results revealed a high incidence of loggerhead strandings from a population structured as of late juveniles and adults, with overall body size and age values slightly lower than those of newly reproductive individuals in Brazilian nesting sites (Marcovaldi et al., 2010b). The population consisted mainly of females (2:1 sexual proportion). The strandings' spatiotemporal distribution indicates SCSP, PC, and NCSC as stranding hotspots, and the period comprising the end of winter and the start of the spring as with higher stranding rates. We also identified fisheries bycatch as the main anthropogenic threat affecting *C. caretta* mortality, followed by interaction with plastic debris. Although the external evidences of bycatch interactions was confirmed only in a few individuals (266), animals with good body condition and high CCL would be also assign as mortality by fishing interaction (Monteiro et al., 2016a). The observed high mortality and strandings' incidence of juvenile loggerheads in our dataset ultimately suggest the need for a re-evaluation on the "Least Concerned" classification proposed to the species in the SWA-RMU (Casale and Tucker, 2017; Wallace et al., 2010).

4.1. High loggerhead mortality incidences revealed by stranding data

Our study reveals stranding rates of more than 600 individuals annually and 3.5 per kilometer of the daily monitored area, indicating possible consequences of the species exposition to cumulative threats in the SWA-RMU (Cantor et al., 2020a; Monteiro et al., 2016a; Tagliolatto et al., 2020). This high mortality was observed mainly for females (2:1 sexual proportion) and for juveniles and adults of *C. caretta*, which comprised more than 80% of our data as determined by gonadal evaluation, average body size larger than 77 cm, and a mean age of 15.3 years. Although we identified stranded females as statistically larger and older than males, and a tendency of older and smaller loggerheads stranding from PC to SCSC, these slight variations remained within the life stages of late juveniles and adults. Therefore, our results indicate high mortality of loggerheads in development stages critical to populational maintenance, as they present significant relative reproductive value due to their possibility to generate offspring (Bolten et al., 2011).

The observed populational characteristics of stranded loggerheads corroborate with the understanding of the SWA-RMU as being both an essential feeding ground and a migratory corridor for females nesting in Brazilian rookeries in-between reproductive seasons (Casale et al., 2011; Prosdocimi et al., 2015; Reis et al., 2010; Santana et al., 2011). Since late juveniles (juveniles with size approximate to the minimum for reproductive individuals) and adults’ foraging behavior is aimed at benthic invertebrates in neritic and coastal areas, whereas small juveniles tend to prey on pelagic items in oceanic regions, there are increased chances of both interaction with anthropogenic activities and carcass drifting resulting in stranding (Hart et al., 2005;

Medeiros et al., 2019). Similarly, inter and post-nesting behavior of reproductive females in northeast Brazil, with migration to foraging grounds in coastal areas, may also account for the observed sexual proportions in strandings (Marcovaldi et al., 2010b).

Considering that the natural annual survival rate estimation of adult loggerheads in other RMUs could reach 97% and that areas highly impacted by anthropogenic activities could reach rates as low as 71%, we highlight not only a high number of strandings provoked by anthropogenic interactions but an array of human-induced *causa mortis* (Schroeder, 2017; Casale et al., 2015). Despite advanced decomposition states hindering identification of both anthropogenic interactions and *causa mortis* in more than 90% of the strandings, 352 loggerheads were identified as directly caused by anthropogenic interactions (Casale et al., 2012b). We report cases of aggression, boat collision, plastic ingestion, oil contamination, dredging, and fisheries bycatch. Unfortunately, we were unable to establish how different threats influence each other and their possible synergic effects, or even how they influence the loggerhead individuals' mortality.

Among those threats, we detected plastic ingestion as an impactful mortality factor. With a slightly even distribution in spatiotemporal frequency, the mean body size of 70.6 cm and age of 14.72 years reveals a trend between plastic ingestion and earlier mortality influenced by constant threat exposition. We suggest further studies to comprehend whether this correlation is a result of factors such as prey selection and lack of debris identification by younger animals, resulting in less ingested plastic for larger loggerheads; impaired development by debris ingestion affecting foraging and nutrient absorption; or lower survival rates and life expectancy of individuals with higher rates of debris ingestion in earlier development stages. However, as frequent as it is, plastic ingestion more commonly has sub-lethal effects that decrease individuals' fitness, leading to greater exposition to additional cumulative threats such as fisheries bycatch (Bjorndal et al., 1994).

Moreover, fisheries bycatch has already been indicated as the most impactful anthropogenic interaction for loggerhead mortality along the SWA-RMU, and was responsible for the major part of strandings with identified interactions (266 individuals) in our dataset (López-Mendilaharsu et al., 2020d; Monteiro et al., 2016b; Sales et al., 2008c). Even though we could not differentiate between fishery modalities on each stranding, they could be a result of the previously reported impacts of bottom trawling and surface longline in the study region on adults and juveniles of the species inhabiting oceanic and neritic zones (Berrêdo et al., n.d.; Kotas et al., 2004; López-Mendilaharsu et al., 2020b; Marcovaldi et al., 2006; Monteiro et al., 2016a; Sales et al., 2008b; Tagliolatto et al., 2020).

Additionally, even if fisheries bycatch was identified as the main threat in our dataset, our results highlight a certain sub-estimation of its impact. As external evidence of fisheries' interaction can be minimal or non-existent, it is usual for strandings of healthy loggerheads (indicated by their body conditions and *causa mortis*) to be considered as a non-evident bycatch result (Monteiro et al., 2016b). Then, the strandings' observed spatial and temporal patterns regarding fishing effort and health parameters reinforce concerning scenarios of anthropogenic driven mortality for the regional population (López-Mendilaharsu et al., 2020e; Monteiro et al., 2016b).

The identified stranding concentration areas, or stranding hotspots, in SCSP, PC, and NCSC (Figure 10) include large estuarine systems, comprising protected areas with unique geomorphological and physical oceanographic features, but are all highly impacted by human activities and support large active fleets of artisanal and industrial fisheries (de Castro et al., 2012; Mazzer and Gonçalves, 2012; Mendonça, 2015; Noernberg, 2002; Sales et al., 2008b; Seeliger and Kjerfve, 2001). The concentration of strandings with confirmed fisheries' interaction in SCSP (Figure 6) shows how this mortality factor may account for a stranding hotspot. Additionally, as we identified PC and SCSC as areas with strandings' concentration of individuals in good body conditions and advanced decomposition states, we assume that SCSP represents the stranding hotspot in which bycatch is most detected, rather than most frequent, reinforcing the influence of anthropogenic threats on the observed stranding patterns. Fresh carcasses allow for better *causa mortis* determination in necropsies, which could have influenced the number of detected bycaught loggerheads. We were unable to single out which factors caused the observed concentrations of fresh carcasses, but we reckon they could be associated with variation in turtles' behavior and fishing modality effort. Aside from environmental factors affecting drift, loggerheads inhabiting areas closer to the coast and with increased activity from trawling fisheries may result in higher mortality rates and carcasses with shorter drifting periods (Hart et al., 2005).

We further strengthen the relevance of bycatch in loggerheads mortality and stranding patterns by verifying the temporal variation in stranding rates concerning fisheries' effort. Stranding rates seem to decrease to a minimum from March to June, the period in which shrimp (e.g. *Xiphopenaeus kroyeri*) fishing, the main focus of artisanal and industrial bottom trawling in Brazilian coastal waters, is prohibited by IBAMA's 189 normative instruction (09/23/2008) (Berrêdo et al., n.d.; López-Mendilaharsu et al., 2020b; Marcovaldi et al., 2006; Monteiro et al., 2016a; Tagliolatto et al., 2020). During this period, with supposed decreased bycatch, strandings do not present concentration areas. When fishing effort increases in warmer months, stranding concentrations in SCSP, PC, and NCSC are observed.

We also highlight that although fishing effort increases in spring and summer, the stranding rates also seem to be influenced by migration patterns of loggerheads (Monteiro et al., 2016a). Thus, we identified higher stranding incidences when both fishing effort and migration patterns were increased in the region. In warmer months, even with higher fishing effort, reduced stranding rates could be due to the movement of individuals to reproductive areas in Rio de Janeiro and to feeding grounds in Rio Grande do Sul, resulting in less strandings. Then, from late winter to spring, loggerheads return to São Paulo, Paraná and Santa Catarina as a response to the end of reproductive season and to the intrusion of Malvinas and Falklands currents in Rio Grande do Sul and are threatened by the rise of fishing effort, culminating in the highest stranding incidences. (Monteiro et al., 2016a; Santana et al., 2011; Tagliolatto et al., 2020). Finally, from autumn to the beginning of winter, strandings decrease in a period of fishing prohibitions even with loggerheads presence in the area (Monteiro et al., 2016a; Tagliolatto et al., 2020). We also note that we did not identify significant body size variation between loggerheads with and without confirmed interactions with fisheries as in Rio Grande do Sul, but detected similar loggerhead CCL between our dataset and the bycaught individuals at that state (Monteiro et al., 2016a). Therefore, we believe it is essential to analyze the implementation of a loggerhead conservation corridor between these foraging and reproductive grounds in southern Brazil, sustaining the conservation success obtained for adult nesting females in breeding areas (López-Mendilaharsu et al., 2020e).

Further analyzing temporal stranding patterns, though we identified the seasonal increase from late winter to spring, there was an excessive rise in loggerhead mortality between July-October 2018. In September 2018, the Brazilian state of Rio Grande do Sul instituted the law 15.223/2018 prohibiting trawling fisheries from occurring within 12 miles of the state's coastal zone. Following the law implementation, the peak in strandings within our study area could suggest increased fishing effort in Santa Catarina, and Paraná due to a relocation of Rio Grande do Sul's trawling fleet. However, we recommend thoroughly investigating the available data regarding strandings, trawling activities, and environmental variables to produce more certain assumptions.

We have also identified an increase in strandings following La Niña periods (2017-2018) and lower stranding rates after El Niño activities (2015-2016). Therefore, it is possible that, similarly to what was observed in Rio Grande do Sul, the positive shift in jellyfish availability in coastal waters caused by La Niña induces loggerhead occurrence in our study area, being the animals more exposed to coastal anthropogenic threats (Monteiro et al., 2016a).

4.1. Conservation implications

Our study strengthens the advantageous use of systematic stranding data in generating inferences and basal knowledge on sea turtle's biology, ecology, and exposure to anthropogenic impacts in areas such as the SWA-RMU (Başkale et al., 2018; Cantor et al., 2020a; Casale et al., 2010; Hama et al., 2020; Hélène et al., 2020; Monteiro et al., 2016a; Peltier et al., 2016, 2014, 2012; Santos et al., 2018b; Tagliolatto et al., 2020). Furthermore, when designing our study, we especially considered how these pieces of information could be used to fill high-priority knowledge gaps for sea turtles conservation in Brazil. The National Action Plan for Sea Turtles Conservation is developed by ICMBio in partnership with several researchers and institutes and establishes 7 Specific Objectives (achieved through 56 actions) to improve conservation actions, research, and social engagement directed at the protection of marine turtle species in Brazil (https://www.icmbio.gov.br/portal/faunabrasileira/plano-de-acao-nacional-lista/841-plano-de-acao-nacional-para-a-conservacao-das-tartarugas-marinhas). We understand that the results presented here could complement other data to aid in achieving at least five Specific Objectives (1, 2, 5, 6 and 7) through 17 actions (1.1, 1.2, 1.4, 1.9, 2.1, 2.6, 5.1, 5.2, 5.3, 5.4, 5.5, 6.5, 7.2, 7.3, 7.5, 7.6, 7.10), therefore, providing information for improved decision-making and showcasing the necessity for adjustments in public policies for loggerhead conservation in Brazil. Moreover, we investigated how our study could also benefit international assessments of loggerhead conservation, mainly for the SWA-RMU. Thus, we compared our results to IUCN's available information on the classification of *C. caretta* in the SWA-RMU as "Least Concern" category status in the official IUCN Red List (Casale and Tucker, 2017). Accordingly to IUCN's classification system, species are considered to be on different extinction risk categories by presenting evidence of any met criteria (A to E) in that category related to risk factors, such as populational decrease, the number of mature individuals, geographic distribution, and generation length (IUCN, 2012). Here, we identified potential conflicts between the category in which SWA-RMU loggerheads are classified and criteria evaluation using our stranding data in addition to known populational parameters.

We assessed both criteria A and C of risk, focused on reductions in population size and population size of mature individuals, respectively. First, for criteria C evaluation, IUCN states the necessity of the number of adult loggerheads in the RMU, which can be derived from their own formula:

$$Adults\ = Nests * Nests\ per\ female^{-1}\ * Remigration\ interval$$
$$* Female\ proportion^{-1}$$

We obtained four scenarios of adult loggerheads population by repeating the equation using varying rates of nests per female and female proportion. The calculations considered the values of 9000 nests (available at https://www.tamar.org.br/tartaruga.php?cod=18), 3 or 5. 5 nests per female (Casale and Tucker, 2017), three years as remigration interval (Casale and Tucker, 2017) and 0.67 (this study) and 0.8 (Marcovaldi et al., 1997) as the female proportion. A higher number of nests per female and a higher proportion of females resulted in fewer estimated adults. Therefore, lower values in both factors increased the final estimate. The four obtained scenarios for adult loggerhead population in the SWA-RMU are 6136, 7327, 11,250, and 13,432 individuals.

While comparing these estimations with what is described in the Criteria C evaluation method, we can observe the possibility of a met criteria in the “Vulnerable” category (in global thresholds), as we estimated two possible scenarios in which adult loggerhead’s population in the SWA-RMU are below 10.000 individuals (IUCN, 2012). However, it is analyzing if subcriteria C.1 is met that we find really concerning patterns showcased by stranding data. IUCN describes the subcriteria C.1 as “An estimated continuing decline of at least 10% within ten years or three generations, whichever is longer (up to a maximum of 100 years in the future)” (IUCN, 2012). In our results, we observed 585 adult loggerhead strandings in the approximate 4.5 years period, an estimate of 130 per year. Considering that strandings may represent 5% to 20% of total in-water mortality (Peltier et al., 2012), our stranding rates may indicate that the annual mortality of adult loggerheads in the study region is between 650 and 2600 individuals (following methods proposed by Peltier et al., 2012). We must also highlight that although these rates seem to be already incredibly high, we did not add to them mortality rates from additional extensive areas within the SWA-RMU, including northern Brazil, Rio Grande do Sul, Uruguay, and Argentina (Carranza et al., 2006; López-Mendilaharsu et al., 2020b; Monteiro et al., 2016a; Tagliolatto et al., 2020; Vélez-Rubio et al., 2013). Even then, and in the best-case scenario (13.432 adult loggerheads and 650 annual mortality rates), we estimate massive declines in mature populations within 100 years (less than a three-generation period), with considerable *C. caretta* extinction risk in the SWA-RMU.

Regarding Criteria A, IUCN establishes the annual number of nesting females and nesting activities as the most appropriate proxy of populational abundance size for the taxa (IUCN, 2012). Therefore, we performed the estimates of nesting females for the SWA-RMU using, once again, their formula, but now without considering the female proportion factor. As a result, we obtained an estimate of 4909 and 9000 female adult loggerheads using 5.5 and 3 as the number of nests per female, respectively. In the stranding dataset, we detected 238 adult female loggerheads in total, an approximate 53 strandings per year that could indicate annual mortality rates in between 265 (20%) and 1060 (5%) individuals. Then, as we submitted the estimations through the criteria evaluation, we identified possible met Criteria A3 for the “Critically Endangered” category. IUCN describes Criteria A3 as “A population size reduction of ≥80%, projected or suspected to be met within the next 10 years or three generations, whichever is the longer (up to a maximum of 100 years), based on (and specifying) any of (b) to (e) under A1.” (IUCN, 2012). As we realized this projection based on an index of abundance appropriate to the taxon (item (b) under A1), the number of nesting females, we believe the massive estimated mortality of adult female loggerheads through the next 100 years (26.500 to 106.000 individuals) could seriously present extinction risk to the species in the SWA-RMU.

Finally, we assume that it is essential that we disclose our awareness of lacking important populational dynamic parameters in our comparisons and IUCN’s known sources of uncertainty for *C. caretta* data used in extinction risk assessments; thus understanding that our estimations are not robust or satisfactory to confirm a change in an extinction risk category for loggerheads in the SWA-RMU (Casale and Tucker, 2017). However, our findings do indicate the continuity of excessive mortality rates for the species maintenance in the region and bring concerns on the SWA-RMU conservation status, particularly for the *C. caretta* Brazilian population (Cantor et al., 2020a; López-Mendilaharsu et al., 2020b; Monteiro et al., 2016a; Tagliolatto et al., 2020). Therefore, considering the precaution principle, we suggest a new assessment regarding *C. caretta* conservation status in the SWA-RMU.

5. CONCLUSION

Since 2015, PMP-BS has produced a finely detailed stranding dataset on the Brazilian coast that must be thoroughly used in research to improve our public policies for species conservation and coastal/oceanic management. Our study uses these data to provide new insights on 1) the population structure of loggerheads, including primarily developing juveniles and inter-nesting adults, exploring foraging grounds and migratory corridors in the SWA-RMU; 2) the impact of overall habitat degradation on loggerhead mortality, particularly by fisheries bycatch; 3) the identification of stranding hotspots on SCSP, PC and NCSC mesoregions and the seasonal increases in July-October; 4) concerns on the current risk status of SWA-RMU.

The opportunity to simultaneously improve our understanding of several knowledge gaps for loggerheads cost-effectively assures the need for continuous, systematic stranding monitoring in the Brazilian coast. Furthermore, it highlights the contribution stranding data can have on future coastal management and conservation planning.

For the following steps, further investigation on the influence of environmental factors on strandings will be crucial to better understand loggerhead turtles' ecological and stranding patterns, getting the full benefit from this dataset (Cantor et al., 2020a; Hart et al., 2005; Monteiro et al., 2016a; Peltier et al., 2016, 2014; Peltier and Ridoux, 2015; Santos et al., 2018a; Tagliolatto et al., 2020).

As our closing remarks, we again call the precautionary principles and suggest that the observed mortality rates in this study urge a reevaluation of national and international conservation assessments. The threats to which loggerheads are exposed in the SWA-RMU could have a profound impact on their survival, but the long life cycle of the species and the biases generated by stranding data may difficult an immediate detection of altered population dynamics (Başkale et al., 2018; Cantor et al., 2020a; Casale et al., 2010; Hama et al., 2020; López-Mendilaharsu et al., 2020b; Monteiro et al., 2016a; Peltier et al., 2016; Tagliolatto et al., 2020; Wallace et al., 2010). Therefore, we suggest the integrative efforts of researchers, government, society, and decision-makers within the SWA-RMU to reassess *C. caretta* extinction risk category and design an effective conservation planning to guarantee population recovery.

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CAPÍTULO 2

Análise de padrão espacial pontual (*Spatial Point Pattern*) como um método alternativo para avaliar padrões de encalhe de *Caretta caretta* no sudeste e sul do Brasil

Spatial Point Pattern analysis as an alternative method to assess *Caretta caretta* stranding patterns in southeastern and southern Brazil

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Spatial Point Pattern analysis as an alternative method to assess *Caretta caretta* stranding patterns in southern Brazil

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Highlights

- **1 –** Aplicação inédita de *Point Process Models* para dados de encalhe de fauna marinha.
- **2 –** Definição de grids com 40 km² como mais precisos para modelar encalhes de *C. caretta*.
- **3 –** Estabelecimento de robusto método estatístico para conservação e manejo costeiro.
- **4 –** Indicação de modelos log-Gaussian Cox PPM para análise de encalhes de fauna marinha.

Resumo

Encalhes de animais marinhos podem ser uma ótima fonte de dados para o delineamento de medidas de conservação e mitigação de impactos, consequentemente, têm sido extensivamente analisados durante a última década. Entretanto, ainda não foi considerada a aplicação de metodologias de modelagem relacionadas à natureza *only-presence* de pontos espaciais que constituem bancos de dados de encalhes: os “Point Process Models”. Nesse estudo, apresentamos a primeira aplicação de PPMs para a modelagem de encalhes utilizando 2795 *Caretta caretta* obtidas pelo Projeto de Monitoramento de Praias da Bacia de Santos (PMP-BS)[1], entre 2015 e 2020, na área sudeste-sul brasileira. A partir de uma arquitetura Bayesiana, comparamos 20 diferentes modelos log-Gaussian Cox PPMs, a partir de seus índices DIC e relevância ecológica e conservacional. Como resultado identificamos tomadas-de-decisão analíticas mais apropriadas para o banco de dados analisado como o uso de células de 40 km². Além disso, estabelecemos índices de intensidade mínima, média e máxima de encalhes para diferentes pontos da costa brasileira, caracterizando múltiplos cenários quanto a

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[1] PMP-BS database; https://simba.petrobras.com.br

distribuição espacial dos dados. Dessa maneira, apresentamos a bem sucedida aplicação de PPMs para encalhes de *C. caretta,* um robusto embasamento para futuras e mais aprofundadas modelagens, e recomendamos o uso da metodologia para análises mais robustas de encalhes e ocorrência de espécies marinhas.

Palavras-chave

Point Process Model; Manejo costeiro; Tartaruga-cabeçuda; Ecologia da conservação.

Highlights

- **1 –** First application of Point Process Models for marine megafauna stranding data.
- **2 –** Providing adequate spatial grid resolution for data analysis as 40 km².
- **3 –** A novel use of a robust statistical tool to improve coastal management and conservation.
- **4 –** Indication of log-Gaussian Cox PPMs for marine megafauna stranding modeling.

Abstract

Marine megafauna strandings' can provide essential information for the development of conservation and impact mitigation actions. Therefore, they have been extensively studied during the last decade. However, even if stranding data is normally presented as only-presence information on spatial point locations, ecologists are yet to consider using Point Process Models for their analysis. In this paper, we present the first application of PPMs to modeling stranding data, using 2795 *Caretta caretta* obtained by the PMP-BS between 2015 and 2020 in south and southeastern Brazil. We aim to explore the PPMs viability in stranding modeling and to establish the appropriate spatial resolution for its modeling. Through a Bayesian framework, we compared 20 log-Gaussian Cox PPMs by their DIC indexes and ecological and conservational relevance. We identified models with 40 km^2 as cell spatial resolution to be the most appropriate for this loggerhead stranding dataset. We also determined minimum, mean and maximum stranding intensity values for models cells. Finally, we present the successful application of PPMs for loggerhead strandings, provide robust background for more complex stranding modeling, and encourage the use of PPMs for the stranding modeling of additional marine species.

Keywords

Point Process Model; Coastal management; Loggerhead; Conservation ecology.

1. INTRODUCTION

Analyzing presence-only data of megafauna strandings has been an exhausting statistical task during the last decade (Hart et al. 2006, Tomás et al. 2008, Wang et al. 2015, Moura et al. 2016, Meynecke and Meager 2016, Monteiro et al. 2016, Flint et al. 2017, Tagliolatto et al. 2020, Cantor et al. 2020, Dudhat et al. 2021). However, after several years of systematic monitoring in southern Brazil, a set of species distribution models (SDM) were applied to understand the responses and causes of the stranding of endangered species along the coast (Poli et al. 2014). Species distribution models (SDM) are important and powerful tools for ecology and conservation (Velázquez et al. 2016). By providing insights into the influence of environmental and biological factors on a species spatial distribution, SDMs allow for improved comprehension of occurrence patterns and predictions regarding response to habitat changes (Phillips and Dudík 2008a, Elith and Leathwick 2009, Warton and Shepherd 2010a, Renner et al. 2015a, Velázquez et al. 2016). Such information is key for conservation assessments, public policies, and co-management actions (Hays 2008, Wildermann et al. 2018). However, collecting data from highly migratory and endangered species on marine ecosystems can be troublesome and expensive, hindering a more extensive or complex application of SDMs on marine megafauna ecology (Pearce and Boyce 2006a, Renner et al. 2015a).

Therefore, marine researchers have developed several approaches integrating the best available dataset to spatial modeling through the years, pursuing reduced biases and errors as well as improved inferences and predictions for different types of data (Wiegand et al. 2013, Renner et al. 2015b). Amongst the well-known and used modeling methods are generalized linear models (GLM) (Warton and Shepherd 2010b); maximum entropy density estimations (MAXENT) (Phillips and Dudík 2008b); estimates of resource selection function (RSFs) (Aarts et al. 2012); and Point Process Models (Pearce and Boyce 2006b, Baddeley et al. 2015a, Renner et al. 2015b).

Although methods and model selections still rely primarily on researcher preference based on the obtained dataset, recently, there has been an increasing understanding of the Point Process Models (PPMs) applicability to analyze a set of individuals/species presence-only locations on a delimited area (Pearce and Boyce 2006b, Illian et al. 2008a, Warton and Shepherd 2010b, Baddeley et al. 2015a, Renner et al. 2015b). Datasets comprised only by presence reports, known as “Presence-only data“, are commonly found in museums, atlases, species lists, and online databases may represent the best available information on marine megafauna since accurate absence reports are challenging to detect in this environment (Pearce and Boyce 2006a, MacLeod et al. 2008). Furthermore, when the presence-only reports are random in both number and location, characterizing a “Point Process“ dataset, the PPM is considered better fitting as they may present some advantages over other methods due to its properties (Pearce and Boyce 2006a, Renner et al. 2015a).

Point Process Models are characterized by being primarily concerned with the spatial location of the points, using these locations and the number of points to obtain “Intensity”, an average number of points per unit area (Illian et al. 2008b, Warton and Shepherd 2010a, Baddeley et al. 2015b, Renner et al. 2015a). Conversely, Generalised Linear Models (GLM) aim at modeling the mean value of the interest object as a function of related covariates (Warton and Shepherd 2010b). They are commonly used in presence-only data analysis by generating a set of pseudo-absences in arbitrary spatio-temporal scales, randomly generated points simulating absences in the dataset to maintain the same functionality as when analyzing presence-absence data (Elith et al. 2008, Illian et al. 2008b, Warton and Shepherd 2010a, Renner et al. 2015a).

As a consequence, PPMs perform seemingly better than GLMs for presence-only data analysis concerning different factors. The first is regarding analysis transparency, as the response variable is a measure of abundance and not a probability (Aarts et al. 2012); the second is concerning the model construction, since pseudo-absences data does not need to be generated (Warton and Shepherd 2010b); the third is about model implementation, as there is no specification on creating pseudo-absences as in GLMs, while PPMs offer a choice possibility on the number and location of pseudo-absences (Warton and Shepherd 2010b, Renner et al. 2015b); the fourth is the opportunity to include spatial dependence of points when necessary (Renner et al. 2015b); and finally, the fifth is regarding ecological relevance, as PPMs can incorporate processes acting at the individual level (Pearce and Boyce 2006a, Warton and Shepherd 2010a, Renner et al. 2015a, Velázquez et al. 2016).

In the context of endangered species presence-only data, PPMs can fill knowledge gaps essential for management and conservation planning (Pearce and Boyce 2006a, MacLeod et al. 2008). For marine megafauna, standardized long-term monitoring might be the source of a detailed dataset, perfectly fitted for PPM analysis. In Brazil, the Santos Basin Beach Monitoring Project (PMP-BS), carried out in Rio de Janeiro, São Paulo, Paraná, and Santa Catarina, has been a systematic stranding monitoring program active since September 2015. The project is part of the environmental licensing conducted by IBAMA, related to evaluating potential impacts on marine tetrapods of oil and natural gas exploration at the Santos Basin by PETROBRAS, the largest oil company operating in the area. The PMP-BS collects daily stranding data of marine animals, covering more than 1700 km of the Brazilian coastline (Petrobras 2017). Considering its regularity and homogeneous coverage, this database consists of a massive presence-only dataset, including spatial, biological, and health-related parameters. Therefore, providing an excellent opportunity to apply SDM on threatened marine species.

Notwithstanding the above, we present the first assessment of PPM applied on the marine megafauna strandings dataset. Specifically, we aim to explore PPMs applicability by modeling the spatial distribution of 2795 stranded loggerhead sea turtles *Caretta caretta* obtained by PMP-BS along the south and southeastern Brazil between 2015 and 2020.

Additionally, we investigate the best-fit model for the species in this region, providing the adequate spatial grid resolution for data analysis, and indicating a novel use of a robust statistical tool to improve coastal management and conservation efforts regarding threatened marine species

2. STUDY AREA AND SAMPLING EFFORT

Stranding data was downloaded from the online database SIMBA used by the standardized monitoring program PMP – BS, available at https://simba.petrobras.com.br. Research teams from 13 institutions reproduced the systematic methodology in the study area encompassed between Saquarema (22° 93’ S, 42° 36’ W) and Laguna (28° 29’ S, 48° 45’ W), within the states of Rio de Janeiro, São Paulo, Paraná, and Santa Catarina, in daily procedures. The area comprises more than 1000km of coastline is monitored by foot or vehicles (mainly by cars, boats, and bicycles) during low tides (Figure 1). It presents varied oceanographic and geomorphological features, such as estuaries, islands, sand beaches, and vegetation areas covered by restinga, mangroves, and the Atlantic rainforest (de Castro et al., 2012; Mazzer and Gonçalves, 2012; Mendonça, 2015; Noernberg, 2002; Seeliger and Kjerfve, 2001).

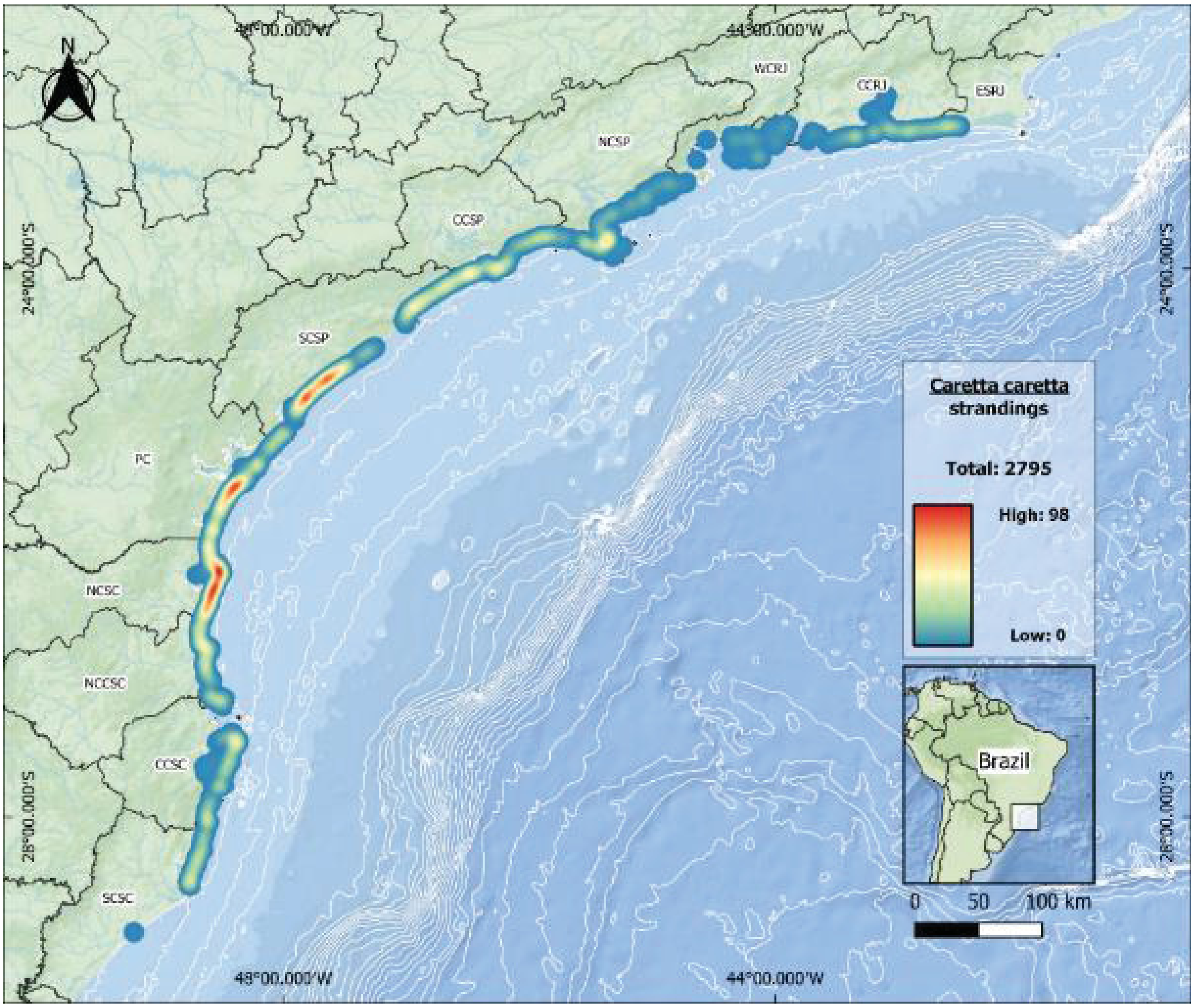


Figure 1: **Stranding distribution of *C. caretta*, loggerhead turtle, in the study area, in southern and southeastern Brazil.** We use a kernel density size of 2.4mm.

When a stranded animal is found, field monitoring teams determine its location, and these locations were used in our analysis. Stranded animals, dead or alive, were collected and transported to the field teams' respective laboratories for rehabilitation or necropsy. Veterinarians performed all necropsies with biologists, oceanographers and other correlated area professionals as team members.

3. POINT PROCESS MODEL DESIGN

We performed a log-Gaussian Cox Point Process Model to comprehend *C. caretta* strandings' spatial distribution while estimating the intensity of the process affecting the observed pattern of stranding locations. Our method selection was made under the assumption that the strandings follow an inhomogeneous Poisson Process; therefore, we understand that: strandings are random in number, each event is independent, and the observed intensity is a function of environmental variables and a stochastic Gaussian process, denoting that the events' present spatial dependence (Diggle 2013, Renner et al. 2015a, Moraga 2020a). We formulated and fitted the model in a Bayesian framework using the integrated nested Laplace approximation (INLA) approach, avoiding the computer-intensive and time-consuming Markov chain Monte Carlo method (Lombardo et al. 2018, 2019, Moraga 2020a). We constructed the maps and grids on R environment, version 4.0.3 (R Core Team, 2020), using packages *R-INLA*, *raster*, *sp*, *spdep*, *rgeos*, *rgdal*, and *tmap*.

We tested the applicability of the log-Gaussian Cox PPM analysis on stranding data by performing comparisons between a varying number of quadrature points, checking for optimal Deviance Information Criterion (DIC) regarding practical spatial grid resolution, and testing model fit for random spatially structured and unstructured effects (Spiegelhalter et al. 2002, Renner et al. 2015b, Moraga 2020b).

4. LOG-GAUSSIAN COX POINT PROCESS MODEL IMPLEMENTATION AND FITTING

During the study period, PMP-BS field teams recorded 2795 stranded *C. caretta* along the monitored coastline. Between September 3rd, 2015, and April 7th, 2020, daily monitoring of 782.91 Km occurred for all 1678 days and resulted in 81.19% of the 1.62 million total distance expected. Strandings were mostly comprised of dead juveniles and adults in advanced decomposition state, with a mean body size of 77.75 cm ± 10.82 (mean curved carapace length ± SD); however, information on occurrence, mortality, and stranding patterns was previously discussed (Chapter 1) and is available at Fonseca; Di Domenico; Domit. (2021 – *unpublished data*). Here we implemented and fit the Log-Gaussian Cox Point Process model to the strandings location data.

First, we obtained a map of the southeastern and southern Brazilian coast to create 20 rasters, each with a different cell resolution and, therefore, number of cells. The rasters are comprised of cells with resolutions ranging from 1 to 0.05 decimal degrees at 0.05 intervals, resulting in maximum and minimum cell areas of 111 x 111 and 5.55 x 5.55 Km, respectively. Then, we added the stranding data to the grids, providing the number of stranded loggerheads for each cell area, and removed all cells with no stranding event from the raster.

Next, we call inla () to specify our model formula:

```
formula <- Y ~ 1 +
f(id, model="rw2d", nrow = nrow, ncol = ncol) +
f(id2, model="iid")
```

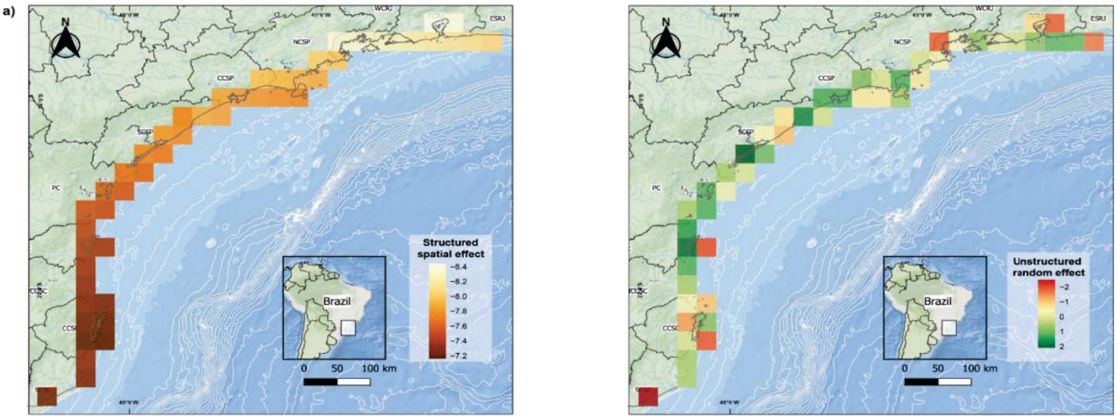
In the models, we used Y, the number of strandings in each cell, as the response variable to fixed (1 – the intercept) and random effects (*f*()). Using indice vector “id”, the first random effect represented the structured random spatial effect on intensity variability and was specified as a second-order two-dimensional conditional autoregressive model (“rw2d”). The second random effect, using indice vector id2, represents the unstructured random effects on the model, specified as “iid”. Both indice vectors are copies, therefore they have the same values, and id2 was created since each random effect needs its own indice vector for the model (Moraga 2020a).

Following the linear model specification, we use inla () to create a *res* object by providing the formula, the model family (“poisson”), the grid data for utilization, and the requirements for linear predictor computation. The *res* object contains essential information about the estimated model to detect model fitting (Lombardo et al. 2018, Moraga 2020a). Finally, we performed a model for each raster and compared the obtained results to determine the adequate spatial resolution for *C. caretta* strandings log-Gaussian Cox PPM.

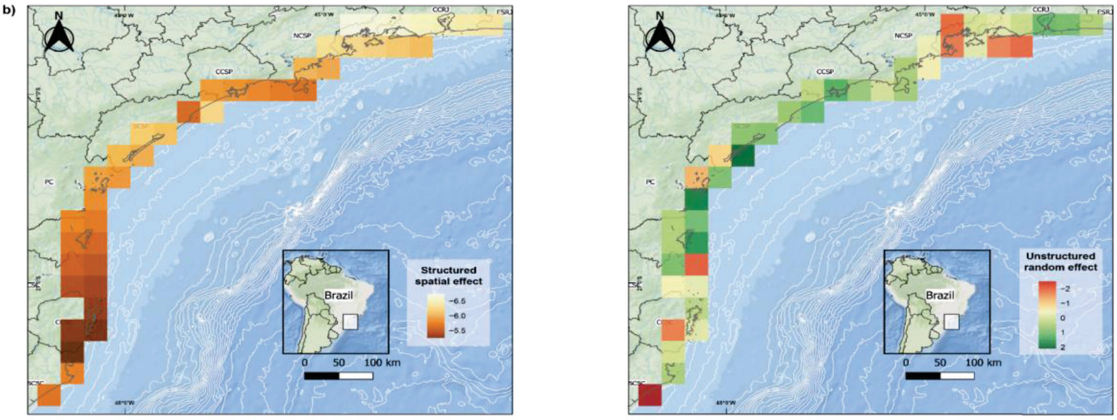
We obtained the variation of random spatially structured and unstructured effects for all rasters, and their spatial variation for the better fit models can be seen in Figure 2. Analyzing the patterns of the spatially structured random effects, we observe the influence of spatial factors on the intensity of the process responsible for stranding locations, indicating a higher number of strandings further south on the Brazilian coast. Additionally, analyzing the unstructured random effect provides an understanding of cells with independent intensity modification, as cells with higher values influence intensity individually.

Furthermore, our models allowed for the prediction of *C. caretta* strandings intensity in each cell of all rasters. We created the maps in Figure 3 by determining the average, minimum and maximum limits of 95% credible intervals for numbers of strandings in each cell area for the better fit models. Therefore, our models not only present the spatial variation in *C. caretta* strandings for southern and southeastern Brazil but also provide their intensities for each cell area during a period of 5 years.

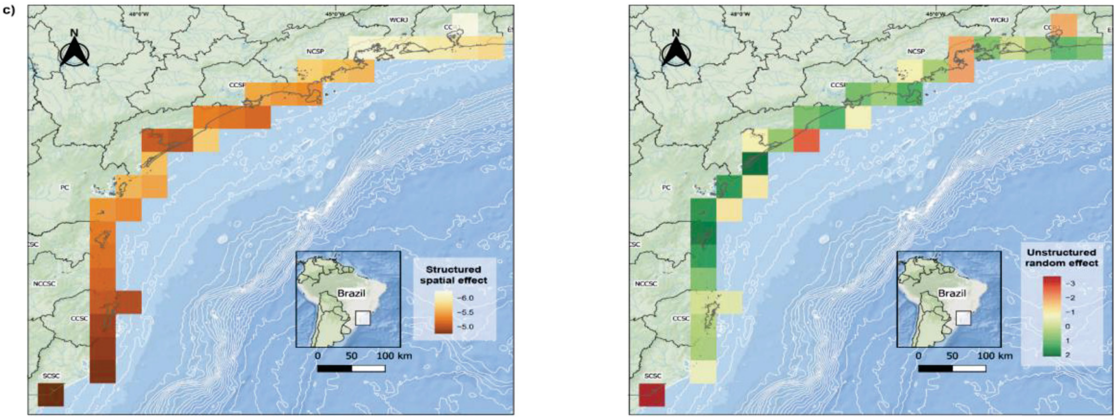
Structured and unstructured effects in cells with resolution of 0.3° decimal degrees



Structured and unstructured effects in cells with resolution of 0.35° decimal degrees



Structured and unstructured effects in cells with resolution of 0.4° decimal degrees



Structured and unstructured effects in cells with resolution of 0.45° decimal degrees

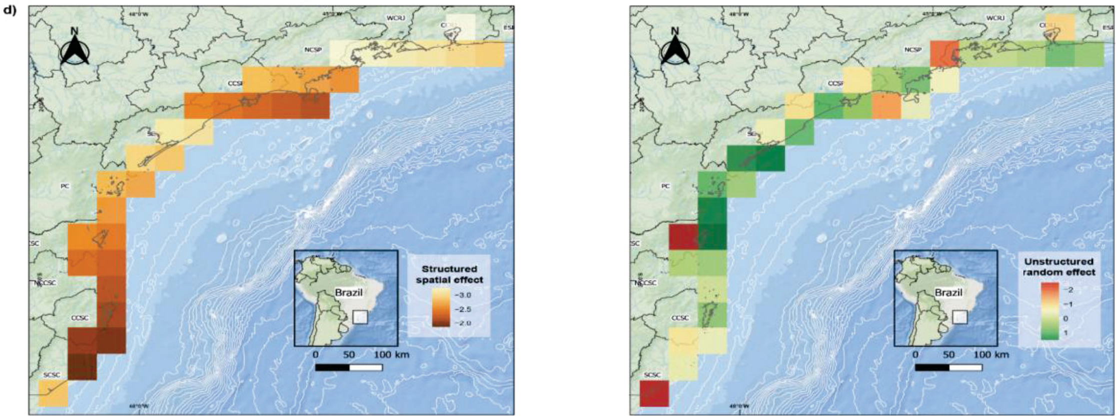
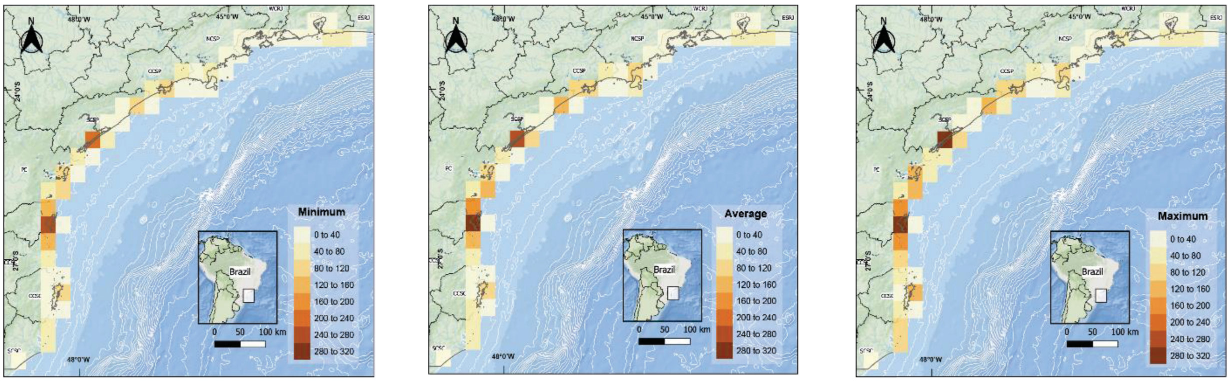


Figure 2: Structured and unstructured effects in log-Gaussian Cox Point Process Models. Patterns of spatially structured and random unstructured effects in Log-Gaussian Cox PPMs with cell spatial resolution from (a) 0.30°; (b) 0.35°; (c) 0.40° to (d) 0.45° decimal degrees.

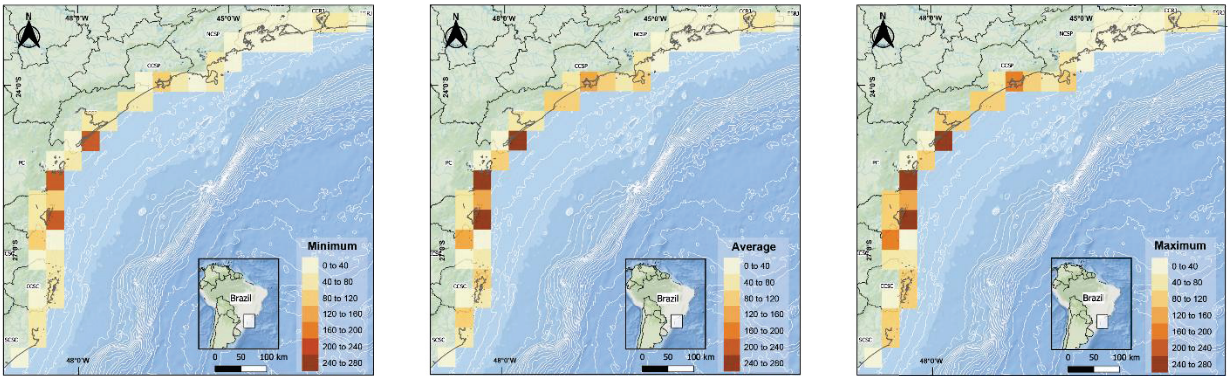
Predicted loggerhead strandings in cells with resolution of 0.3° decimal degrees

a)



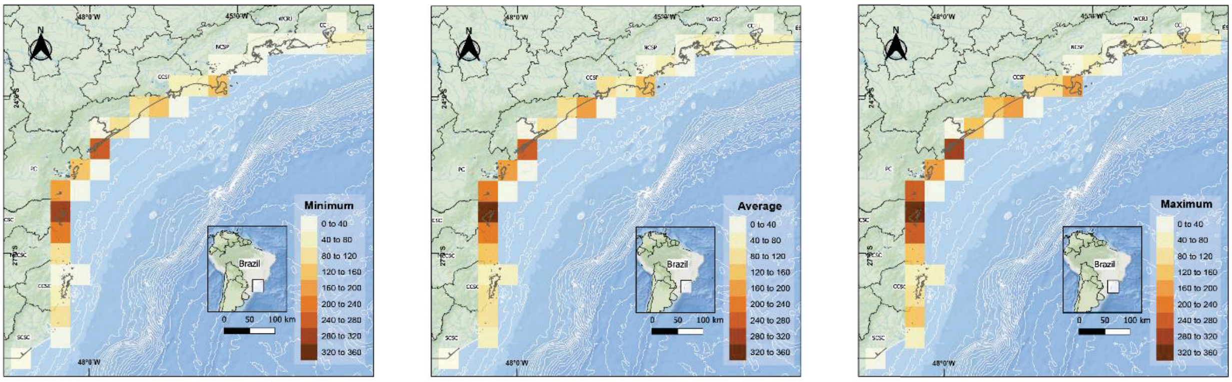
Predicted loggerhead strandings in cells with resolution of 0.35° decimal degrees

b)



Predicted loggerhead strandings in cells with resolution of 0.4° decimal degrees

c)



Predicted loggerhead strandings in cells with resolution of 0.45° decimal degrees

d)

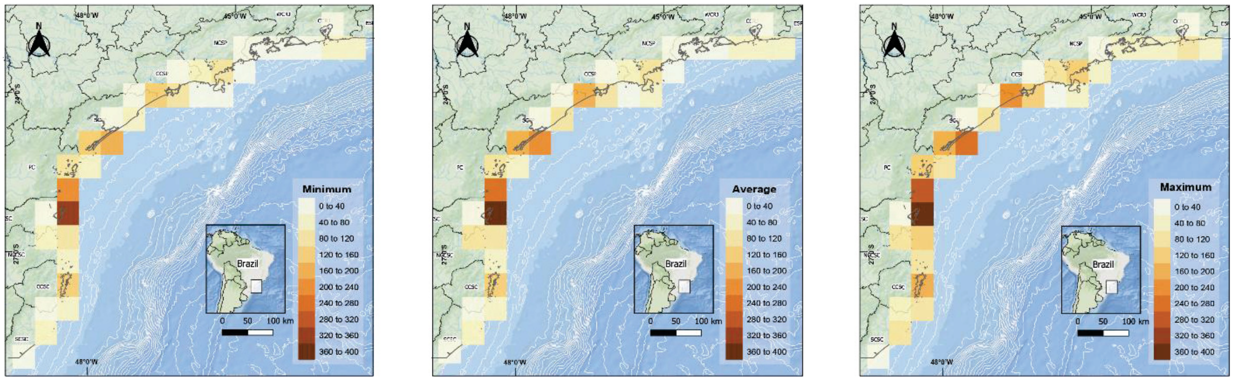


Figure 3: Predicted loggerhead strandings’ intensity in minimum, average and maximum values, along the south and southeast Brazilian coastal area. Predicted minimum, average, and maximum intensity of loggerhead strandings for the better fit models, with cell spatial resolution from 0.3° to 0.45° decimal degrees, for a period of 5 years. Variation predicted minimum, average, and maximum loggerhead stranding intensity in the model with cells’ spatial resolution at **a)** 0.3° decimal degrees **b)** 0.35° decimal degrees **c)** 0.4° decimal degrees. **d)** 0.45° decimal degrees.

Finally, in order to establish the raster with more appropriate cell resolution for log-Gaussian Cox PPM application on *C. caretta* stranding data, we selected the model with the higher number of cells that presented no significant change in fitting or prediction performance (Phillips and Dudík 2008a). In this Bayesian approach, we used the DIC values of each model to measure model fit, as lower values indicate the model that would best predict a replicate dataset with the same structure as as what was observed (*C. caretta* strandings) (Fong and Holmes 2020).

The variations in DIC regarding cells' spatial resolution (Figure 4), size (Figure 5), and number (Figure 6) denote that their values start to converge starting from the model using 0.35 decimal degrees as cell resolution. Even though statistically a DIC variation larger than 2 points indicates a less supported model, our selection also considered ecological, biological, and coastal management factors (Spiegelhalter et al. 2002). Consequently, for this dataset, we suggest that further spatial modeling should be performed using cells with a side size of approximately 40 Km (table 1).

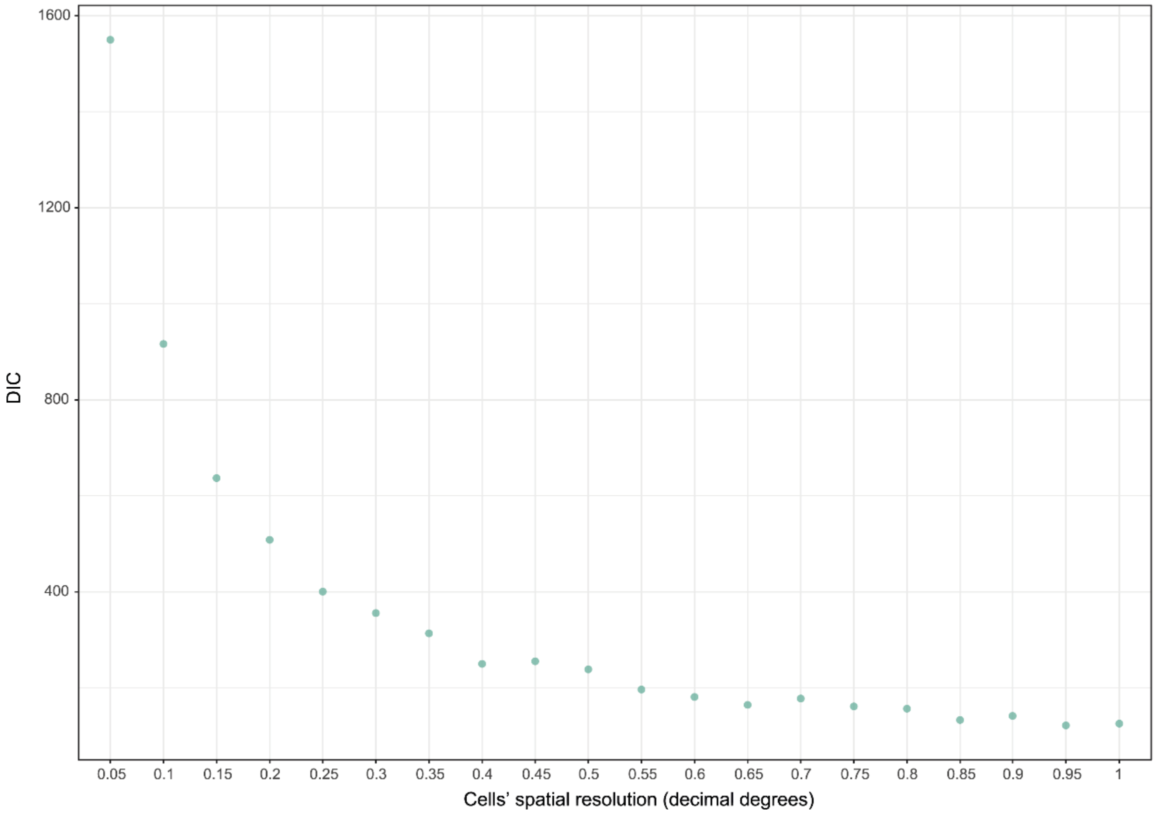


Figure 4: Variation in DIC with changes in model cells' spatial resolution in decimal degrees.

.

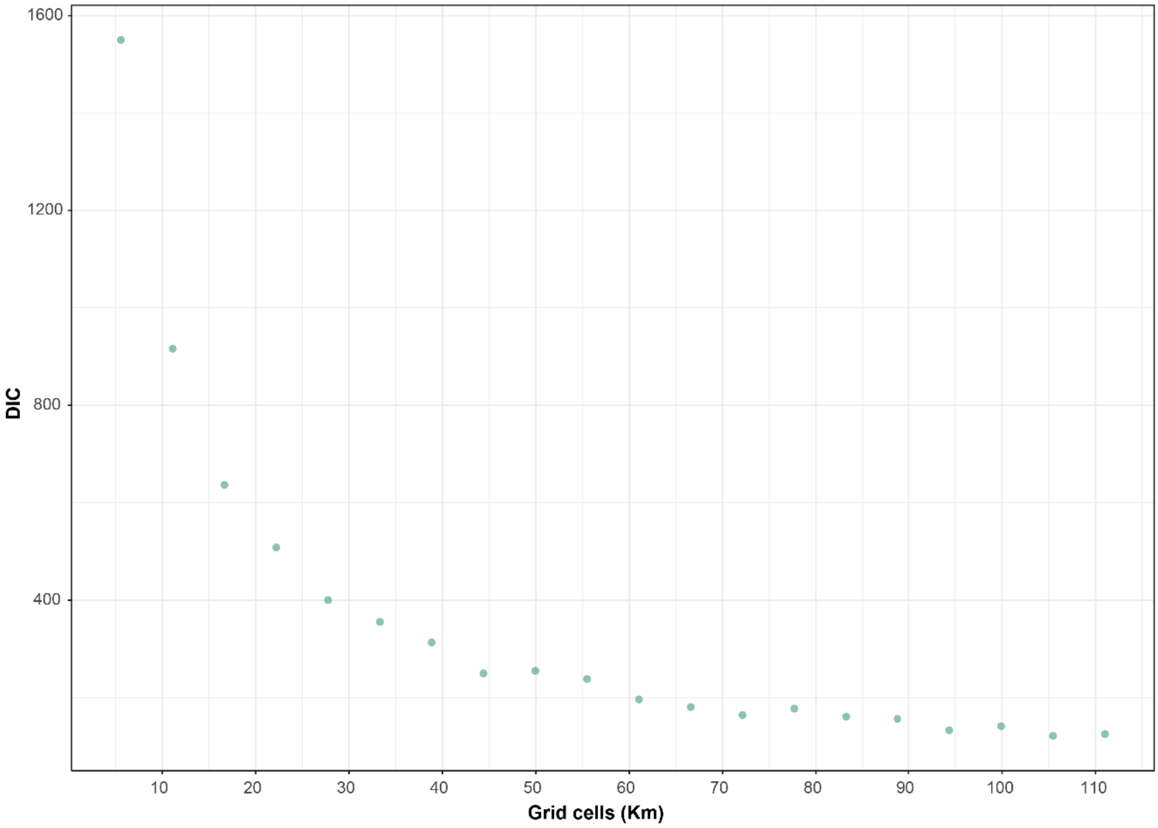


Figure 5: Variation in DIC with changes in model cells' size, in kilometres.

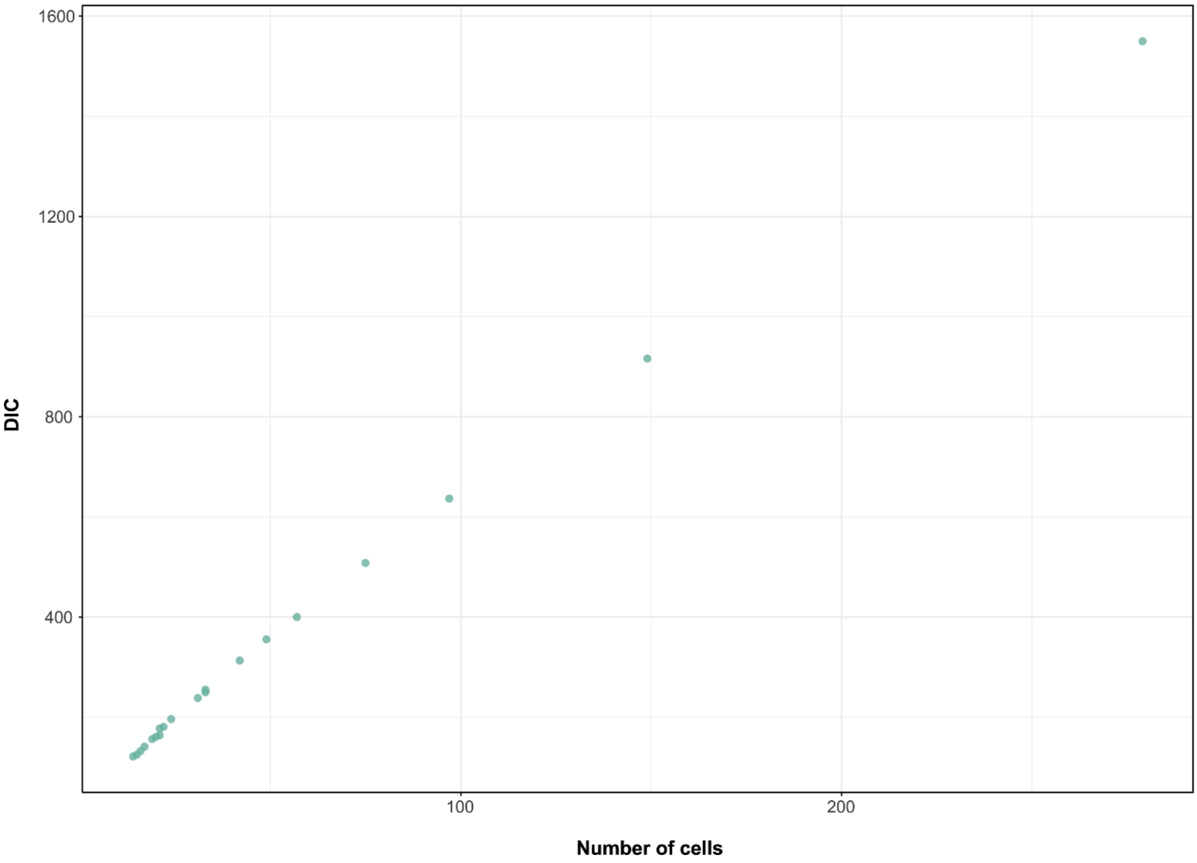


Figure 6: Variation in DIC with changes in models' number of cells.

Table 1: Variation in number of cells, cell size and DIC for all models.

Cell spatial resolution (Decimal degrees)	Expected number of cells	Expected number of cells standard deviation	Observed number of cells	Cell size (Km²)	DIC
1	14.79	0.054	15	111.0	125.41
0.95	13.84	0.075	14	105.45	121.71
0.9	16.77	0.06	17	99.9	141.44
0.85	15.63	0.097	16	94.35	132.9
0.8	18.71	0.071	19	88.8	156.49
0.75	19.64	0.089	20	83.25	161.2
0.7	20.62	0.119	21	77.7	177.62
0.65	20.57	0.099	21	72.15	164.39
0.6	21.57	0.093	22	66.6	180.97
0.55	23.48	0.114	24	61.05	196.44
0.5	30.21	0.166	31	55.5	238.44
0.45	32.11	0.172	33	49.95	255.19
0.4	32.09	0.174	33	44.4	249.89
0.35	40.59	0.251	42	38.85	313.39
0.3	47.12	0.313	49	33.3	355.63
0.25	54.48	0.387	57	27.75	400.35
0.2	70.89	0.54	75	22.2	508.27
0.15	89.96	0.839	97	16.65	636.84
0.1	135.03	1.3	149	11.1	916.34
0.05	229.45	6.21	279	5.55	1550.01

5. INFERENCES OF MODELING STRANDED LOGGERHEADS WITH LOG-GAUSSIAN COX POINT PROCESS MODELS

This paper has successfully applied log-Gaussian Cox PPM model development and fitting for a marine threatened species, the loggerhead *C. caretta*. Our results indicate that stranding data, especially when obtained by standardized monitoring programs, could provide crucial information on the spatial distribution of marine species for conservation management and strategic planning, improving public policies, impacting mitigation actions and decision-making. In this preliminary analysis, we were able to infer *C. caretta* stranding intensities for areas in the southern and southeastern Brazilian coast, identifying potential stranding hotspots that should be deeper carefully investigated in the future.

Additionally, determining grid cells with 40km² areas as optimal model spatial resolution provides a statistical foundation to future complex model constructions, allowing for the selection of environmental and biological data on adequate model resolutions. Therefore, reducing inference biases and indicating conservation priority areas at local levels.

Finally, our results demonstrate the importance of improving the stranding modeling with environmental, biological, and mortality factors not only for loggerheads, but primarily for threatened marine megafauna species with available stranding data. Thus, the application of PPMs may lead to advanced utilization of strandings as a cost-beneficial method for the betterment of conservation actions and coastal management.

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2. SUMÁRIO DE RESULTADOS E CONCLUSAO GERAL

Nessa dissertação, nós analisamos a variação espaço-temporal dos encalhes de *Caretta caretta* obtidos pelo PMP-BS, entre 2015 e 2020 na área entre os estados do Rio de Janeiro e Santa Catarina (25º05'S 42º35'W a 25º55'S 43º34'W), e apresentamos os resultados em dois capítulos. O primeiro capítulo apresentou a caracterização populacional de tartarugas-cabeçuda encalhadas como majoritariamente fêmeas (2:1 de proporção sexual) em estágios de desenvolvimento juvenil tardio ou adulto, com tamanho e idades médios de 77,75 cm ± 10,82 SD e 15,3 anos ± 3,95 SD, que utilizam a região como zona de forrageio e corredor migratório; assim como destacou o impacto provocado pela degradação ecossistêmica nas taxas de mortalidade de tartarugas-cabeçuda na região, principalmente por interações com pesca; e ainda identificou os *hotspots* de encalhes nas mesorregiões SCSP, PC e NCSC, com aumento de incidência sazonal entre julho e outubro. De maneira geral, este capítulo contribui com futuras medidas de conservação e mitigação de impactos para *C. caretta* na costa brasileira, incluíndo informações consideradas prioritárias para a conservação da espécie pelo Plano de Ação Nacional para a Conservação das Tartarugas Marinhas - PAN/ICMBio. Os resultados do capítulo contribuem com pelo menos 17 ações (1.1, 1.2, 1.4, 1.9, 2.1, 2.6, 5.1, 5.2, 5.3, 5.4, 5.5, 6.5, 7.2, 7.3, 7.5, 7.6, 7.10) descritas em cinco objetivos específicos (1, 2, 5, 6 e 7) do PAN.

No que diz respeito à classificação internacional de risco de extinção da população de tartarugas-cabeçuda da SWA-RMU, proposta pelo *Marine Turtle specialist group* da IUCN (https://www.iucnredlist.org/), atualmente como "quase-ameaçada", acreditamos que os cenários de mortalidade indicados pelos encalhes analisados no capítulo 1 ressaltam preocupações e a relevância de uma re-avaliação e do status atual com base, principalmente, nos princípios de precaução para a conservação desta RMU.

No segundo capítulo, os resultados demonstram a efetividade de utilização dos modelos Log-Gaussian Cox PPM para a análise de encalhes, indicando que as vantagens dos *Point Process Models* em relação a outras modelagens também se aplicam a avaliação de dados de encalhes. Além disso, estabelecemos a adequada resolução espacial para a modelagem de encalhes de tartarugas-cabeçuda na região, e valores preditos de intensidade de encalhes para cada célula dos modelos. Assim, encorajamos o uso destes modelos e resoluções de grid para a construção de modelos mais complexos, integrando múltiplos fatores, para tartarugas-cabeçuda e para demais espécies de megafauna marinha que apresentam bancos de dados de encalhes. Estes modelos podem resultar em cenários futuros promissores relacionados a contribuição dos encalhes no planejamento espacial marinho e na conservação de espécies ameaçadas.

Dessa maneira, acreditamos que de forma geral, esta dissertação tenha contribuído para a conservação de *C. caretta* ao resultar em conhecimento científico inédito e com potencial de embasar gestores, atores governamentais e sociais, tomadores de decisão e outros cientistas no delineamento de políticas públicas e ações direcionadas à conservação e mitigação de impactos que atingem a espécie.

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