UNIVERSIDADE FEDERAL DO PARANÁ

LORENA SILVA DO NASCIMENTO

REDES SOCIAIS COMO FONTE DE DADOS ALTERNATIVA NO MONITORAMENTO DE ÁGUAS-VIVAS

PONTAL DO PARANÁ

2023

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Tese apresentada em tutela pela Universidade Federal do Paraná, Programa de Pós-Graduação em Sistemas Costeiros e Oceânicos, Setor de Ciências da Terra, como pré-requisito para obtenção do grau de Doutora em Sistemas Costeiros e Oceânicos (UFPR)

Orientador: Dr. Maurício Almeida Noernberg
Coorientadores: Dra. Carmem Satie Hara
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ATA DE SESSÃO PÚBLICA DE DEFESA DE DOUTORADO PARA A OBTENÇÃO DO GRAU DE DOUTORA EM SISTEMAS COSTEIROS E OCEÂNICOS

No dia sete de abril de dois mil e vinte e tres às 09:00 horas, na sala Anfiteatro, Online, foram instaladas as atividades pertinentes ao rito de defesa de tese da doutoranda **LORENA SILVA DO NASCIMENTO**, intitulada**: Redes sociais com fonte de dados alternativa para monitorar águas-vivas**, sob orientação do Prof. Dr. MAURICIO ALMEIDA NOERNBERG. A Banca Examinadora, designada pelo Colegiado do Programa de Pós-Graduação SISTEMAS COSTEIROS E OCEÂNICOS da Universidade Federal do Paraná, foi constituída pelos seguintes Membros: MAURICIO ALMEIDA NOERNBERG (UNIVERSIDADE FEDERAL DO PARANÁ), CHARRID RESGALLA JUNIOR (UNIVERSIDADE DO VALE DO ITAJAÍ), RENATO MITSUO NAGATA (UNIVERSIDADE DE SÃO PAULO), AURORA TRINIDAD RAMIREZ POZO (UNIVERSIDADE FEDERAL DO PARANÁ). A presidência iniciou os ritos definidos pelo Colegiado do Programa e, após exarados os pareceres dos membros do comitê examinador e da respectiva contra argumentação, ocorreu a leitura do parecer final da banca examinadora, que decidiu pela APROVAÇÃO. Este resultado deverá ser homologado pelo Colegiado do programa, mediante o atendimento de todas as indicações e correções solicitadas pela banca dentro dos prazos regimentais definidos pelo programa. A outorga de título de doutora está condicionada ao atendimento de todos os requisitos e prazos determinados no regimento do Programa de Pós-Graduação. Nada mais havendo a tratar a presidência deu por encerrada a sessão, da qual eu, MAURICIO ALMEIDA NOERNBERG, lavrei a presente ata, que vai assinada por mim e pelos demais membros da Comissão Examinadora.

Pontal do Paraná, 07 de Abril de 2023.

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TERMO DE APROVAÇÃO

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 tese de Doutorado de **LORENA SILVA DO NASCIMENTO** intitulada: **Redes sociais com fonte de dados alternativa para monitorar águas-vivas**, sob orientação do Prof. Dr. MAURICIO ALMEIDA NOERNBERG, que após terem inquirido a aluna e realizada a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

A outorga do título de doutora está sujeita à homologação pelo colegiado, ao atendimento de todas as indicações e correções solicitadas pela banca e ao pleno atendimento das demandas regimentais do Programa de Pós-Graduação.

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Em todo samba que faço
Tem espaço, eu ponho o mar
Mãe Oxum, me dá licença
Que eu gosto de navegar

Teresa Cristina e Grupo Semente - Acalanto

E quando a dor vem encostar-se a nós, enquanto um olho chora,
o outro espia o tempo procurando a solução.

Conceição Evaristo – Olhos d'água

RESUMO

Na presente tese, foi investigada a utilidade das redes sociais em fornecer registros de observação de águas-vivas ainda pouco estudadas no Brasil. Inicialmente, é apresentada uma revisão sobre o uso da metodologia de ciência cidadã passiva para extrair observações de espécies marinhas usando redes sociais. Além disso, foram desenvolvidas metodologias sistematizadas para extrair e examinar postagens nas redes sociais para obter registros de ocorrências de águas-vivas. Com estas metodologias, foi obtido o primeiro registro da *Stygiomedusa gigantea*, bem como, o primeiro registro da maria-farinha (*Ocypode quadrata*) predando a caravela portuguesa (*Physalia physalis*) no Brasil. A partir dos dados das redes sociais, também foi possível obter novas observações da *Drymonema gorgo* e da *Physalia physalis* na costa brasileira. Comparativamente às outras fontes de dados, como literatura e ciência cidadã, as observações das redes sociais corresponderam a cerca de 85% dos dados obtidos para *D. gorgo* e 60% para *P. physalis*. As pesquisas com redes sociais oferecem uma nova fonte de dados complementares sobre a biodiversidade marinha, sobretudo para as espécies de grande tamanho, como as espécies de águas-vivas investigadas no presente estudo. Apesar da exploração das redes sociais como fonte de dados alternativa envolver desafios, com limitações nos dados, esta pesquisa mostra o potencial desta abordagem metodológica em contribuir para a gestão dos impactos negativos causados pelas águas-vivas, bem como seus serviços ecossistêmicos.

Palavras-chave: ciência cidadã; iEcologia; crowdsourcing; distribuição espaço-temporal; dados de observação.

ABSTRACT

In the present thesis, it was investigated the usefulness of social networks in providing observation records of jellyfish which are still little studied in Brazil. Initially, it is presented a review of the use of passive citizen science methodology to extract observations of marine species using social media. In addition, it was developed systematized methodologies to extract and examine posts on social media to obtain records of jellyfish occurrences. These methodologies provided the first record of *Stygiomedusa gigantea*, as well as the first record of the ghost crab (*Ocypode quadrata*) preying on the Portuguese man-of-war (*Physalia physalis*) in Brazil. Using data from social media, it was also possible to obtain new observations of *Drymonema gorgo* and *Physalia physalis* on the Brazilian coast. Compared to other data sources, such as literature and citizen science, observations from social media accounted for about 85% of the data obtained for *D. gorgo* and 60% for *P. physalis*. Surveys with social media offer a new source of complementary data on marine biodiversity, especially on large species such as the jellyfish investigated in the present study. Although exploring social media as an alternative data source involves challenges, with data limitations, this research shows the potential of this methodological approach in contributing to the management of negative effects caused by jellyfish, as well as their ecosystem services.

Keywords: citizen science; iEcology; crowdsourcing; spatiotemporal distribution; sightings data.

SUMÁRIO

PREFÁCIO

O primeiro contato que tive na vida com água-viva foi no início da minha graduação em Oceanografia. Eu estava banhando num mar de águas tranquilas quando percebi que um bicho translúcido em tons amarelados estava nadando ao meu lado. Fiquei tão encantada com a sua beleza e delicadeza que só quando saí da água que percebi que aquele bicho lindo tinha deixado algumas marcas bem doloridas na minha barriga e pernas. A partir deste dia, decidi aprender mais sobre as águas-vivas. Depois descobri que aquela água-viva era a hidromedusa *Olindias sambaquiensis*. Estudei a taxonomia e avaliei a distribuição dos gelatinosos e as suas relações com variáveis ambientais durante a iniciação científica, graduação e mestrado. Com o tempo, o meu interesse por estes animais só aumentou...

Durante o doutorado, num primeiro momento, pretendia rastrear águas-vivas com o uso de tags eletrônicas. Gostaria de entender mais sobre o seu movimento, ambiente e distribuição, mas devido às retrições financeiras infelizmente não foi possível adquirir os equipamentos. Consciente das grandes lacunas no conhecimento existentes sobre a distribuição destes animais no Brasil, fiquei pensando em outras estratégias para monitorá-los. Me lembrei que quando um evento ocorre, costumo seguir hashtags específicas nas redes sociais para acompanhar o que está acontecendo e a localização daquele evento em tempo real. Então fiz um levantamento preliminar das postagens publicamente disponíveis marcadas com hashtags relacionadas às águas-vivas nas redes sociais, como por exemplo #aguaviva e #caravelaportuguesa, e notei que haviam muitas postagens com observações destes animais acompanhadas de informações de onde e quando foram feitas. Sabe aquelas fotos de férias que você postou no Instagram? Foi a partir daí que nasceu a proposta do presente estudo. Neste estudo, não uso tags, mas uso hashtags para rastrear águas-vivas.

INTRODUÇÃO

O oceano é a força vital da Terra, cobrindo mais de 70% da superfície do planeta, impulsionando o clima, regulando a temperatura e sustentando todos os organismos vivos (NOAA 2021). Atualmente, cerca de 40% da população mundial vive a 100 km da costa (Resource Watch 2022), estando entre as regiões mais produtivas e biologicamente diversas do planeta (Ray 1988). De fato, transporte, alimentos e benefícios ecológicos estabeleceram precedência para que as populações migrassem naturalmente para as costas e para que as cidades se localizassem principalmente nestas regiões (Creel 2003). Além disso, os ambientes costeiros têm sido um grande atrativo desde os primórdios do turismo como uma atividade humana significativa (Gössling et al. 2018).

Os ambientes costeiros são áreas de transição, sujeitas a processos marinhos e continentais, com sistemas ecológicos turbulentos, mutáveis e complexos (McLusky e Elliott 2007). A rápida expansão das atividades humanas e a exploração em direção às costas aumentam o estresse ambiental, alterando as condições e benefícios costeiros nos próximos anos com grandes custos sociais, econômicos e ecológicos (Bruno et al. 2018). Neste contexto, o monitoramento ambiental é urgentemente necessário nos ecossistemas costeiros, sendo essencial para o desenvolvimento de estratégias de conservação de espécies e a plena incorporação de fatores de sustentabilidade no planejamento e gestão marinha (Curtin e Prellezo 2010; Pranzini et al. 2018). No entanto, a observação in situ de espécies marinhas é muitas vezes uma tarefa complicada.

Além dos aspectos logísticos e financeiros dos estudos de campo e expedições, as imensas dimensões espaciais e os volumes gigantescos com profundidades variadas podem representar barreiras às investigações marinhas (Marone et al. 2020). Pesquisas direcionadas em ambientes marinhos e costeiros requerem planejamento cuidadoso, são caras de executar e geralmente são conduzidas em escalas espaciais e temporais limitadas (Kelling 2008; Jovanovic e Vukelic 2015). Sendo que as lacunas nos dados de ocorrência de espécies causadas por dificuldades de detecção e levantamento inconsistente e inadequado, resultam em estimativas e descrições incompletas (Powney e Isaac 2015). Aliado a isso, o declínio no número de taxonomistas e pesquisas taxonômicas também favorece que as estimativas de espécies sejam incompletas (Hopkins e Freckleton 2002).

Para abordar as lacunas de conhecimento e adquirir uma ampla gama de dados (espacialmente, temporalmente e em quantidade), os cientistas estão cada vez mais utilizando a ciência cidadã, ou seja, o envolvimento de taxonomistas amadores e voluntários na ciência (Chandler et al. 2017; Garcia-Soto et al. 2021). Campanhas que incentivam a participação pública no processo científico de observação de espécies existem há anos em algumas regiões e são metodologias eficazes e colaborativas para obter informações geográficas em ambientes marinhos (Kelly et al. 2020; Sandahl e Tøttrup 2020). No entanto, essas campanhas geralmente exigem organização sistemática, marketing e habilidades especializadas, sendo ainda principalmente aplicadas em países ricos (Sandahl e Tøttrup 2020). Entretanto, o advento da web, juntamente com o uso crescente de smartphones equipados com Sistema de Posicionamento Global (GPS), câmeras de alta resolução e redes sociais, vêm revolucionando a ciência cidadã e a pesquisa de conservação (Newman et al. 2012; Aravind 2013; Toivonen et al. 2019). Uma fonte de dados cada vez mais interessante é o conteúdo gerado espontaneamente por usuários de várias plataformas de mídia social amplamente utilizadas, como Youtube, Facebook, Instagram e Twitter (Di Minin et al. 2015; Jarić et al. 2020).

Embora ainda sejam um terreno novo e desafiador para o desenvolvimento de técnicas de descoberta de conhecimento, as redes sociais são serviços baseados na web que permitem às pessoas criar perfis pessoais, formar uma comunidade virtual, articular conexões e interesses com outros usuários e postar e propagar multimídia. Com mais de 4,26 bilhões de usuários em todo o mundo em 2021 (Statista 2023a), as interfaces das redes sociais normalmente permitem o acesso a textos, fotos e vídeos, além de outros metadados, como onde e quando o conteúdo foi carregado. Como exemplo, informações geográficas de crowdsourcing podem ser fornecidas por fotos e vídeos marcadas geograficamente (ou seja, metadados de geolocalização) (Toivonen et al. 2019).

Tirar fotos tornou-se uma das principais atividades entre os usuários de smartphones e as redes sociais são muitas vezes utilizadas para capturar, postar e compartilhar memórias em tempo real. A regra “primeiro a imagem, depois o texto” presente em muitas plataformas de rede social cria uma robusta cultura de orientação visual (Lee et al. 2015). Sendo assim, as redes sociais tornaram-se plataformas para muitos entusiastas da vida selvagem, amantes do mar e profissionais compartilharem suas observações a qualquer momento, contribuindo para o monitoramento do ambiente marinho. Como exemplos, dados de rede social vêm fornecendo informações valiosas sobre registros de ocorrência de espécies (e.g., Pace et al. 2019), serviços dos ecossistemas marinhos (e.g., Ghermandi et al. 2020), poluição marinha (e.g., Hiemstra et al. 2021) e riscos costeiros (e.g., Wang et al. 2018). Por exemplo, a partir do Instagram, foi possível obter dados sobre serviços ecossistêmicos culturais em ambientes costeiros na Baía de Fundy, no Canadá, que estão sofrendo impactos cada vez mais severos do aumento do nível do mar e das mudanças climáticas, levando a desafios de gestão (Zhao et al. 2023).

Como pode ser uma fonte de informação alternativa eficiente em termos de custo e tempo, os dados de redes sociais podem ser especialmente relevantes nos trópicos e/ou regiões menos estudadas, onde as lacunas de conhecimento ainda são muito visíveis (Dylewski et al. 2017; Edwards et al. 2021), como é o caso do litoral brasileiro. Isso é potencializado pelo abrangente uso das redes sociais no Brasil. Os brasileiros estão entre as pessoas que mais usam redes sociais no mundo, estando na quinta colocação, com um total de 165,45 milhões de usuários em 2022 (Statista 2022a). O primeiro lugar é da China, com mais de 1 bilhão de usuários, seguida pela India, Estados Unidos e Indonésia, com 755, 302 e 217 milhões de usuários, respectivamente.

O presente estudo visa explorar o potencial das redes sociais para fornecer observações de espécies marinhas no Brasil. Consideramos as águas-vivas um modelo para explorar esse potencial porque: i) são difíceis de detectar e coletar, sofrendo com a falta de dados primários de biodiversidade e são historicamente negligenciadas em pesquisas (Raskoff 2003; Headlam et al. 2020), ii) tem havido um aumento no interesse do público, e consequentemente da mídia em geral, sobre as ocorrências de águas-vivas nos últimos anos (Condon et al. 2012; Vandendriessche et al. 2016); iii) ciência cidadã já é um paradigma no estudo da distribuição e ocorrências de águas-vivas (Magalhães et al. 2020; Marambio et al. 2021); iv) algumas espécies podem ter uma aparência conspícua e carismática, sendo facilmente identificáveis por imagens

(Martin-Abadal et al. 2020; Rizgalla e Crocetta 2020); e v) Grandes Ecossistemas Marinhos (GEMs) são afetados pela ocorrência de águas-vivas em todo o mundo, podendo impactar negativamente diversas atividades humanas; mas também fornecer inúmeros serviços ecossistêmicos (Brotz et al. 2012; Graham et al. 2014; Bosch-Belmar et al. 2020). No território brasileiro, estudos que exploraram dados espontaneamente criados nas redes sociais para obter informações sobre espécies marinhas estão principalmente focados em vertebrados ameaçados de extinção (por exemplo, Di Beneditto et al. 2021; Dualibe et al. 2021; Leitão et al. 2022), e ainda não foram realizadas investigações com águas-vivas.

1.1 DEFININDO “ÁGUA-VIVA”

Uma vez que não há uma predefinição sobre o que é “água-viva”, é importante identificar claramente quais grupos são considerados no presente estudo. Água-viva geralmente se refere à fase de medusa de alguns cnidários cifozoários (Classe Scyphozoa), também conhecida como “água-viva verdadeira”. Entretanto, as águas-vivas geralmente se referem aos organismos trasnparentes do zooplâncton gelatinoso. Zooplâncton gelatinoso é o termo técnico para se referir ao grupo de organismos marinhos zooplanctônicos frágeis, transparentes e com uma grande porcentagem de água em seus tecidos, sendo que em geral seu peso seco representa no máximo 5% do peso úmido (Larson 1986; Thiebot e McInnes 2020). Animais que pertencem ao filo Cnidaria (Cubozoa, Hydrozoa e Scyphozoa), Ctenophora (Beroida e Tentaculata) e Tunicata (Salpida) são comumente citados como representativos do zooplâncton gelatinoso (Boero 2013).

Considerando todas as fases do ciclo de vida e estágios coloniais, o zooplâncton gelatinoso tem uma ampla variação de tamanho, de poucos milímetros a até vários metros (Boltovskoy et al. 1999). Eles possuem adaptações únicas, que lhes permitem atingir altas densidades populacionais quando enfrentam condições ambientais favoráveis, mas também para se adaptar rapidamente às condições desfavoráveis no ecossistema pelágico marinho (Gibbons e Richardson 2013). No presente estudo, foram estudados os animais do filo Cnidaria, mais especificamente as espécies *Stygiomedusa gigantea* (Classe Scyphozoa), *Drymonema gorgo* (Classe Scyphozoa) e *Physalia physalis* (Classe Hydrozoa), pois são águas-vivas conspícuas, que podem ser facilmente observadas e identificadas, facilitando o compartilhamento de registros nas redes sociais.

1.2 ÁGUAS-VIVAS E CIÊNCIA CIDADÃ

Há uma carência histórica de informações sobre a dinâmica espaço-temporal das águas-vivas em todo o mundo (Raskoff 2003), e questões ainda não resolvidas relacionadas à sua biologia, distribuição, dinâmica de comunidade e influência do ambiente sobre as populações. Diante disso, métodos de coleta não tradicionais, como ciência cidadã, têm sido utilizados para preencher estas lacunas e promover programas de monitoramento das ocorrências de águas-vivas (Gatt et al. 2018; Terenzini et al. 2023).

As contribuições dos cidadãos para obter dados de informação geográfica podem ser ativas (ou intencionais) ou passivas (ou não intencionais) (See et al. 2016). Na ciência cidadã com águas-vivas, os registros geralmente são obtidos pelo método ativo, por meio de iniciativas de educação, campanhas e guias de identificação. Nestas campanhas, o público é comumente encorajado a contar e identificar espécies populares, e as fotografias geradas intencionalmente são geralmente compartilhadas por e-mail, aplicativo, site ou rede social (por exemplo, Boero 2013; Marambio et al., 2016; Record et al. 2018; Tiralongo et al. 2022). Até o momento, a ciência cidadã com águas-vivas foi aplicada em muitos locais, como a África do Sul (Gibbons et al. 2021), Hong Kong (Terenzini et al. 2023) e em toda a Europa (Garcia-Soto et al. 2021).

Aplicativos dedicados que contam com a colaboração dos cidadãos são exemplos de iniciativas eficazes e bem-sucedidas para monitorar águas-vivas (Magalhães et al. 2020; Gutiérrez-Strada et al. 2021). Por exemplo, MedusApp é um software espanhol para smartphones que permite o registro de águas-vivas com abundância e coordenadas pelos cidadãos; o aplicativo conta com descrições e imagens que podem ser usadas para identificar diversas espécies (Yanez-Dobson et al. 2022). Neste aplicativo, também é possível usar inteligência artificial para identificar automaticamente os registros de espécies compartilhados pelos cidadãos. Implementado em 2017, mais de 13.000 avistamentos de águas-vivas foram compartilhados neste aplicativo até maio de 2023 (https://www.medusapp.net/).

Por outro lado, registros não intencionais de águas-vivas compartilhados em redes sociais populares também forneceram informações valiosas e promissoras sobre ocorrências e distribuição de águas-vivas e estão sendo recentemente aplicados para monitoramento de águas-vivas e alerta precoce sobre florações e invasões (Jovanovic e Vukelic 2016; Kienberger and Pietro 2017; Laudy et al. 2017, 2020; Rizgalla e Crocetta 2020; Ruiz-Frau et al. 2022).

A iniciativa pioneira de ciência cidadã passiva usando redes sociais e Sistema de Informação Geográfica (SIG) para monitorar em tempo real as ocorrências de águas-vivas foi proposta em Malta, no Mediterrâneo, comparando e combinando os resultados de diferentes fontes de dados online (Twitter, Google+, blogs e notícias) e ciência cidadã ativa (Jovanovic e Vukelic 2016). Embora os registros fossem limitados, os autores encontraram tendências correspondentes nas ocorrências de águas-vivas invasoras entre as fontes de dados, especialmente quando os eventos ocorreram no período de "pico".

Em 2020, Jellytoring, um sistema automático de detecção e quantificação para monitoramento em tempo real e de longo prazo de águas-vivas com base em uma rede neural profunda para a detecção de objetos, foi inicialmente proposto para *Pelagia noctiluca*, *Rhizostoma pulmo* e *Cothyloriza tuberculata* (Martin-Abadal et al. 2020). Posteriormente, esta iniciativa foi estendida para outras águas-vivas utilizando imagens extraídas do Youtube, totalizando 15 espécies (Ruiz-Frau et al. 2022). Os resultados revelaram que o Jellytoring 2.0 teve um bom desempenho na identificação das 15 espécies com valores médios de precisão variando entre 90% e 99% para a maioria das espécies, mostrando que é uma maneira eficiente de monitorar as águas-vivas globalmente e pode ser usado para o desenvolvimento dos primeiros sistemas de alerta (Ruiz-Frau et al. 2022).

Também em 2020, no projeto H2020 ODYSSEA, um modelo biofísico de deriva combinando registros do Twitter e ciência cidadã ativa para prever ocorrências de águas-vivas foi publicado na costa do Mediterrâneo (http://odysseaplatform.eu/) (Laudy et al. 2020). Dados do Twitter, especificamente textos dos tuítes e caixas de comentários ou descrições, foram coletados usando várias hashtags e palavras-chave (invasão de água-viva, praia) em três idiomas (inglês, francês e espanhol) e analisados em conjunto com dados extraídos de um aplicativo dedicado de ciência cidadã na plataforma InSyTo. Os autores afirmaram que os dados da rede social cobriram uma área mais ampla do que o aplicativo dedicado, e é possível usar quando e onde nenhuma outra fonte de informação estiver disponível. No entanto, ainda são necessárias outras fontes de informação, mais confiáveis, detalhadas e amplamente utilizadas pelos cidadãos.

Apesar de possuir características morfológicas marcantes, como tamanho, formato e cores, este estudo é pioneiro ao propor uma metodologia para obtenção de informações espaço-temporais sobre as águas-vivas *Stygiomedusa gigantea* (Classe Scyphozoa), *Drymonema gorgo* (Classe Scyphozoa) e *Physalia physalis* (Classe Hydrozoa) a partir dos dados gerados espontaneamente nas redes sociais. Até onde sabemos, apenas um estudo anterior investigou menções de espécies marinhas em grupos de Facebook sobre fauna marinha, incluindo *Physalia physalis*, obtendo cinco postagens com imagens desta espécie, das quais três apresentavam informações geoespaciais (Chamberlain 2014, 2018; https://www.purpleoctopus.org/groupsourcing/).

Projetos de ciência cidadã focados em águas-vivas na América do Sul ainda estão sub-representados na literatura (por exemplo, Canepa et al. 2020). No Brasil, não há registro de nenhuma campanha de ciência cidadã passada ou atual procurando especificamente por águas-vivas, mas existe o Programa BioGeoMar, um projeto científico dedicado ao mapeamento da biodiversidade marinha no Brasil, incluindo algumas espécies de águas-vivas (SiBBr 2023). O Grupamento de Bombeiros de Santa Catarina, no sul do Brasil, também disponibiliza o aplicativo de smartphone Praia Segura para informar os banhistas sobre os riscos costeiros observados pelos salva-vidas, incluindo ocorrências de águas-vivas (https://www.cbm.sc.gov.br/index.php/noticias/blog-noticias-institucionais/praia-segura-aplicativo-do-cbmsc-ajuda-a-escolher-melhor-praia). Desenvolvido em 2016, esse aplicativo fornece informações em tempo real sobre segurança e acessibilidade nas praias catarinenses, mas não traz informações mais detalhadas sobre a ocorrência de águas-vivas, como espécie e abundância. Além disso, investigações sobre ocorrências de águas-vivas extraídas de registros espontâneos compartilhados em redes sociais nunca foram feitas antes em águas brasileiras. No entanto, dados sobre avistamentos e florações de águas-vivas são comumente relatados e encontrados em portais de mídia populares, como jornais online e redes sociais (por exemplo, Instagram e Youtube).

1.3 PERGUNTA DE PESQUISA

Os dados gerados espontaneamente nas redes sociais são úteis para monitorar águas-vivas ao longo da costa brasileira?

1.4 HIPÓTESE DE PESQUISA

As postagens das redes sociais permitem a coleta de observações de águas-vivas no Brasil, complementando as informações existentes e potencialmente contribuindo para a gestão dos seus impactos negativos e serviços ecossistêmicos.

1.5 OBJETIVOS

A tese está estruturada e formatada como artigos científicos, onde cada capítulo representa um objetivo específico. O objetivo principal desta tese foi avaliar a utilidade das redes sociais em fornecer observações de águas-vivas na costa do Brasil.

1.5.1 Capítulo I – Ciência cidadã passiva com redes sociais para observação da fauna marinha: oportunidades e desafios

Objetivo: Apresentar uma revisão sobre o uso da metodologia de ciência cidadã passiva para extrair observações de espécies marinhas usando redes sociais, bem como analisar suas oportunidades e desafios.

1.5.2 Capítulo II – A água-viva de mar profundo *Stygiomedusa gigantea* (Scyphozoa: Semaeostomeae) encontrada no Brasil por meio de mineração de dados em rede social

Objetivo: Fornecer o primeiro registro de *Stygiomedusa gigantea* no Brasil com base em postagem feita na plataforma Instagram.

1.5.3 Capítulo III – Afinal, não é uma espécie tão rara? Descobertas sobre *Drymonema gorgo* Müller, 1883 (Cnidaria, Scyphozoa), uma água-viva grande e pouco conhecida do Brasil

Objetivo: Revisar registros históricos da água-viva *Drymonema gorgo* na costa brasileira e fornecer novas observações a partir de dados da rede mundial de computadores.

1.5.4 Capítulo IV – Redes sociais a serviço da ecologia marinha: novas observações da maria-farinha *Ocypode quadrata* (Fabricius, 1787) predando caravela-portuguesa *Physalia physalis* (Linnaeus, 1758)

Objetivo: Documentar a maria-farinha (*Ocypode quadrata*) predando a caravela portuguesa (*Physalia physalis*) em Sergipe e Bahia, Brasil tropical (11° e 14° Lat. S), com base em postagens do Instagram.

1.5.5 Capítulo V – Instagram como fonte de dados alternativa no monitoramento da #caravelaportuguesa *Physalia physalis* (Linnaeus, 1758)

Objetivo: Avaliar a utilidade das mídias sociais como fonte de dados para a obtenção de observações da caravela portuguesa (*Physalia physalis*) no Brasil, bem como a distribuição dos riscos à saúde humana causados por esta espécie.

INTRODUCTION

The ocean is the lifeblood of Earth, covering more than 70% of the planet's surface, driving weather, regulating temperature, and supporting all living organisms (NOAA 2021). Presently, about 40% of the world's population lives within 100 km of the coast (Resource Watch 2022), amongst the most productive and biologically diverse regions on the planet (Ray 1988). In fact, transport, food, and ecological benefits have set a precedence for populations naturally migrating toward the coasts and cities have been located on coastlines (Creel 2003). In addition, coastal environments have been a major drawcard since the very beginning of tourism as a significant human activity (Gössling et al. 2018).

Coastal environments are transitional areas, subject to marine and continental processes, with turbulent, changing, and complex ecological systems (McLusky and Elliott 2007). The rapid expansion of human activities and overexploitation toward the coasts add to environmental stress, changing coastal conditions and benefits in the next years at great social, economic, and ecological costs (Bruno et al. 2018). In this context, environmental monitoring is urgently required on coastal ecosystems, being essential for the development of species conservation strategies and the full incorporation of sustainability factors into marine planning and management (Curtin and Prellezo 2010; Pranzini et al. 2018). However, in situ observation of marine species are many times a complicated task.

Besides the logistical and financial aspects of field studies and expeditions, the immense spatial dimensions, and gigantic volumes with varying depths may represent barriers to marine investigations (Marone et al. 2020). In fact, directed surveys require careful planning, are expensive to execute, and are generally conducted on limited spatial and temporal scales (Kelling 2008; Jovanic and Vukelic 2015). Gaps in species occurrence data caused by species detection difficulties and inconsistent and inadequate surveying results in incomplete estimates and poor descriptions (Powney and Isaac 2015). In addition, the decline in the number of taxonomists and taxonomic research also favors incomplete species estimates (Hopkins and Freckleton 2002).

To address knowledge gaps and acquire a wide range of data (spatially, temporally, and in quantity), scientists are increasingly utilizing citizen science (i.e. involvement of volunteers in science) (Chandler et al. 2017; Garcia-Soto et al. 2021). Campaigns that encourage public participation in the scientific process of species observation have existed for years in some regions and are effective and collaborative methodologies to obtain crowdsourcing information on marine environments (Kelly et al. 2020; Sandahl and Tøttrup 2020). However, these campaigns usually require systematic organization, marketing, and skills and still is mostly applied in the richest countries (Sandahl and Tøttrup 2020). But the advent of the web along with the overgrowing usage of smartphones equipped with Global Positioning System (GPS), high-resolution cameras, and social media, have revolutionized citizen science and conservation research (Newman et al. 2012; Aravind 2013; Toivonen et al. 2019). An increasingly interesting source of data is user-generated content produced spontaneously via various widely used social media platforms, such as Youtube, Facebook, Instagram, and Twitter (Di Minin et al. 2015; Jarić et al. 2020).

Although it still is a challenging new ground for developing knowledge discovery techniques, social media platforms are web-based services allowing people to create personal profiles, form a virtual community, articulate connections and interests with other users, and post and propagate multimedia. With more than 4.26 billion users worldwide in 2021 (Statista 2023a), social media interfaces usually allow access to text, photos, and videos, as well as other metadata such as where and when the content was uploaded. For example, crowdsourced geographic information can be provided by geotagged photos and videos (ie geolocation metadata) (See et al. 2016; Toivonen et al. 2019).

Taking photos has become one of the major activities among smartphone users and social media are many times used to capture, post, and share real-time memories. The “image first, text second” rule present in many social media platforms creates a robust visual-oriented culture (Lee et al. 2015). Social media have become platforms for many wildlife enthusiasts, sea lovers, and professionals to share their observations in marine environments at any time, contributing to environmental monitoring. For example, social media data already provided valuable information on species occurrence records (e.g, Sullivan et al. 2019), marine ecosystems services (e.g., Ghermandi et al. 2020), marine pollution (e.g., Hiemstra et al. 2021), and coastal hazards (e.g., Wang et al. 2018). For example, from Instagram, it was possible to obtain data about cultural ecosystem services in coastal environments in Canada's Bay of Fundy, which are experiencing increasingly severe impacts from sea level rise and climate change, leading to management challenges (Zhao et al. 2023).

As it may be a cost and time-efficient alternative source of information, social media data may be especially relevant in the tropics and/or less studied regions where gaps in knowledge are still very noticeable (Dylewski et al. 2017; Edwards et al. 2021); such as the Brazilian coast. This potential is enhanced by social media usage in Brazil. Brazilians are among the people who use social networks the most in the world, remaining in fifth place, with a total of 165.45 million users in 2022 (Statista 2022a). In the first place is China, with more than 1 billion users, followed by India, United States, and Indonesia, with 755, 302, and 217 million users, respectively.

The present study aims to explore the potential of social media to provide observations of marine species in Brazil. We consider jellyfish a model to explore this potential because: i) they are difficult to detect and collect, suffering from a lack of primary biodiversity data and being historically overlooked in research (Raskoff 2003; Headlam et al. 2020), ii) there has been an increase in public and media interest on jellyfish occurrences in recent years (Condon et al. 2012; Vandendriessche et al. 2016); iii) citizen science is already a paradigm in the study of the distribution and occurrence of jellyfish (Marambio et al. 2016; Magalhães et al. 2020); iv) some species may have a conspicuous and charismatic appearance, being easily identifiable by images (Martin-Abadal et al. 2020; Rizgalla and Crocetta 2020); and v) Large Marine Ecosystems (LME) are affected by jellyfish occurrences worldwide, negatively impacting diverse human activities; but also providing numerous ecosystems services (Brotz et al. 2012; Graham et al. 2014; Bosch-Belmar et al. 2020). In the Brazilian territory, studies that have explored data spontaneously created on social media to obtain information on marine species are mainly focused on endangered vertebrates (e.g., Di Beneditto et al. 2020; Dualibe et al. 2021; Leitão et al. 2022), and investigations with jellyfish have not been carried out yet.

1.1 DEFINING “JELLYFISH”

Since there is no preset of what “jellyfish” is, it is important to clearly identify which groups are considered in the present study. Jellyfish generally refers to the medusa stage of some cnidarians, commonly scyphozoans (Class Scyphozoa), also known as "true jellyfish". However, jellyfish usually refer to the transparent gelatinous zooplankton organisms. Gelatinous zooplankton is the technical term to refer to the group of marine zooplankton organisms that are fragile, transparent, and have a large percentage of water in their tissues, in general their dry weight represents a maximum of 5% of their wet weight (Larson 1986; Thiebot and McInnes 2020). Animals belonging to the phylum Cnidaria (Cubozoa, Hydrozoa, and Scyphozoa), Ctenophora (Beroida and Tentaculata), and Tunicata (Salpida) are commonly cited as representatives of gelatinous zooplankton (Boero 2013).

Considering all phases of the life cycle and colonial stages, gelatinous zooplankton has a wide range in size, from a few millimeters to several centimeters (Boltovskoy et al. 1999). They have unique adaptations that allow them to reach high population densities when faced with favorable environmental conditions, but also to adapt quickly to unfavorable conditions in the marine pelagic ecosystem (Gibbons and Richardson 2013). In the present study, we will study the animals of the phylum Cnidaria, more specifically the species *Drymonema gorgo* (Class Scyphozoa), *Stygiomedusa gigantea* (Class Scyphozoa), and *Physalia physalis* (Class Hydrozoa), as they are conspicuous jellyfish, which can be easily observed and identified, facilitating the sharing of records on social media.

1.2 JELLYFISH AND CITIZEN SCIENCE

There is a historical lack of information about the spatiotemporal dynamics of jellyfish worldwide (Raskoff 2003), and still, unresolved questions related to its biology, distribution, community dynamics, and influence of the environment on populations. On this, non-traditional collection methodologies, such as citizen science, have been used for filling these gaps and promote monitoring programs of jellyfish occurrences (Pontin et al. 2011; Gatt et al. 2018; Terenzini et al. 2023).

Citizens' contributions to geographic information can be active (or intentional) or passive (or non-intentional) (See et al. 2016). In jellyfish citizen science, records are usually obtained by active citizen science, through education initiatives, campaigning, and identification guides. In these campaigns, the public is commonly encouraged to count and identify popular species, and photographs intentionally generated are usually shared by email, app, website, or social media (e.g., Boero 2013; Marambio et al. 2016; Record et al. 2018; Tiralongo et al. 2022). To date, jellyfish citizen science has been applied in many locations, such as South Africa (Gibbons et al. 2021), Hong Kong (Terenzini et al. 2023), and across Europe (Garcia-Soto et al. 2021).

Dedicated apps that rely on citizen collaboration are examples of effective and successful initiatives to monitor jellyfish (Magalhães et al. 2020; Gutiérrez-Estrada et al. 2021). For example, MedusApp is a Spanish software for smartphones that allows the record of jellyfish in abundance and coordinated by citizens; the app counts with descriptions and images that can be used to identify diverse species (Yanez-Dobson et al. 2022). In this app, it is also possible to use artificial intelligence to automatically identify species shared by citizens. Implemented in 2017, over 13,000 jellyfish sightings have been shared until May 2023 (https://www.medusapp.net/).

On the other hand, non-intentional jellyfish records shared on popular social media have also provided valuable and promising information into jellyfish occurrences and distribution, and are being recently applied for jellyfish monitoring and early warning about blooms and invasions (Jovanovic and Vukelic 2016; Kienberger and Pietro 2017; Laudy et al. 2017, 2020; Rizgalla and Crocetta 2020; Ruiz-Frau et al. 2022).

The pioneer attempt of passive citizen science using social media and Geographic Information System (GIS) to gather real-time monitoring of jellyfish occurrences was proposed in marine waters of Malta, in the Mediterranean, by comparing and combining the results of the different online data sources (Twitter, Google+, blogs, and news) and active citizen science (Jovanovic and Vukelic 2016). Although records were limited, the authors found corresponding trends in occurrences of invasive jellyfish among the data sources, especially when the events were at the 'peak' period.

In 2020, Jellytoring, an automatic detection and quantifying system for real-time and long-term monitoring of jellyfish based on a deep object detection neural network was initially proposed for *Pelagia noctiluca*, *Rhizostoma pulmo*, and *Cothyloriza tuberculata* (Martin-Abadal et al. 2020). Later, this initiative was extended to other jellyfish using images extracted from Youtube, totaling 15 species (Ruiz-Frau et al. 2022). The results revealed that Jellytoring 2.0 performed well in identifying the 15 species with average precision values ranging between 90% and 99% for most species, showing that it is an efficient way to monitor jellyfish globally and can be used for the development of the early-warning system (Ruiz-Frau et al. 2022).

Also in 2020, a biophysical drift model combining Twitter records and active citizen science to predict jellyfish occurrences was published in the H2020 ODYSSEA project off the Mediterranean coast (http://odysseaplatform.eu/) (Laudy et al. 2020). Twitter data, specifically tweet texts and comments or description boxes, was collected using various hashtags and keywords (jellyfish invasion, beach) in three languages (English, French, and Spanish) and analyzed along with data extracted from a dedicated citizen science app on the InSyTo platform. The authors stated that the social media data covered a wider area than the dedicated app, and it is possible to use when and where no other source of information is available. However, it is necessary other sources of information, more reliable, detailed, and widely used by citizens.

Despite having remarkable morphological characteristics, such as size and colors, this study is a pioneer in proposing a methodology to obtain spatiotemporal information about the jellyfish *Stygiomedusa gigantea* (Classe Scyphozoa), *Drymonema gorgo* (Classe Scyphozoa), and *Physalia physalis* (Classe Hydrozoa) from data generated spontaneously in social media. To our knowledge, only one previous study investigated mentions of marine species in Facebook groups about marine fauna, including *Physalia physalis*, finding five posts with images of this species, of which three presented geospatial information (Chamberlain 2014, 2018; https://www.purpleoctopus.org/groupsourcing/).

Citizen science projects focused on jellyfish in South America are still underrepresented in the literature (e.g., Canepa et al. 2020). In Brazil, there is no record of past or current citizen science campaign looking specifically for jellyfish, but the Program BioGeoMar, a scientific project dedicated to mapping the marine biodiversity in Brazil, include some jellyfish species (SiBBr 2023). The Firemen Group of Santa Catarina State, in the south of Brazil, also provides the smartphone app Praia Segura to inform beachgoers about coastal risks observed by lifeguards, including jellyfish occurrences (https://www.cbm.sc.gov.br/index.php/noticias/blog-noticias-institucionais/praia-segura-aplicativo-do-cbmsc-ajuda-a-escolher-melhor-praia). Developed in 2016, this app provides real-time information about safety and accessibility on Santa Catarina beaches, but it does not provide more detailed information about jellyfish occurrences, such as species and abundance. Moreover, investigations about jellyfish occurrences extracted from spontaneous records shared on social media have never been done before in Brazilian waters. However, data about jellyfish sightings and outbreaks are commonly reported and found in popular media portals, such as online newspapers and social media (e.g., Instagram and Youtube).

1.3 RESEARCH QUESTION

Is the spontaneously generated social media data useful for monitoring jellyfish along the Brazilian coast?

1.4 STUDY HYPOTHESIS

Posts on social media allow the collection of jellyfish observations, complementing existing information and potentially contributing to the management of negative impacts and ecosystems services.

1.5 OBJECTIVES

The thesis is structured and formatted as scientific articles, where each chapter represents a specific objective. The main objective of the thesis was to evaluate the usefulness of social media in providing observations of jellyfish off the coast of Brazil.

1.5.1 Chapter I – Passive citizen science with social media for marine wildlife observation: Opportunities and challenges

Objective: Present a review about the use of the methodology of passive citizen science to extract observations of marine species using social media, both by analyzing its opportunities and challenges.

1.5.2 Chapter II – The deep-sea jellyfish *Stygiomedusa gigantea* (Scyphozoa: Semaeostomeae) found in Brazil through social media data mining

Objective: Provide the first record of *Stygiomedusa gigantea* from Brazil based on a posting made on the Instagram platform.

1.5.3 Chapter III – Not such a rare species after all? Insights into *Drymonema gorgo* Müller, 1883 (Cnidaria, Scyphozoa), a large and little-known jellyfish from Brazil

Objective: Review the historical records of the jellyfish *Drymonema gorgo* on the Brazilian coast and provide novel observations from the World Wide Web data.

1.5.4 Chapter IV – Social media in service of marine ecology: new observations of the ghost crab *Ocypode quadrata* (Fabricius, 1787) scavenging on Portuguese man-of-war *Physalia physalis* (Linnaeus, 1758)

Objective: Document the ghost crab (*Ocypode quadrata*) scavenging on stranded Portuguese man-of-war (*Physalia physalis*) at Sergipe and Bahia, tropical Brazil (11° and 14° Lat. S), based on Instagram posts.

1.5.5 Chapter V – Instagram as an alternative data source for the monitoring of #portuguesemanofwar *Physalia physalis* (Linnaeus, 1758)

Objective: Evaluate the usefulness of social media as a data source for obtaining observations of the Portuguese man-of-war (*Physalia physalis*) in Brazil, as well as the distribution of human health problems caused by this species.

CAPÍTULO I

Passive citizen science with social media for marine wildlife observation: Opportunities and challenges

Intended journal: Wildlife Research (Online ISSN: 1448-5494, impact factor 2.178, Qualis CAPES A3)

Abstract

Worldwide, decision-makers and nongovernment organizations are increasingly using citizen science to enhance their ability to monitor and manage marine wildlife. Social media is widely used and its data and metadata may represent a low-cost, real-time, long-term, and refreshable source of information about species (i.e. passive citizen science). We reviewed the use of passive citizen science to extract marine species observations from social media, both by analyzing its opportunities and challenges. Popular social media platforms are relevant as complementary data sources in marine biodiversity databases. But the exploitation of social media data involves challenges mainly related to ethics, filtering processes, and inherent biases. This technology offers researchers a new opportunity to gather biodiversity data and it is expected that social media research will continue to expand, transforming the future of marine ecology in the Information Age.

Keywords. iEcology; Marine Species; Crowdsourcing; Spatiotemporal distribution; Sightings data

1. Introduction

A key component of managing and conserving biodiversity is the ability to monitor species occurrences at both local and global scales in a timely and cost-efficient strategy (Dickman and Wardle 2012; Sullivan et al. 2017). These datasets and predictions of species distribution provide information on species' response to the environment, conservation status, spatiotemporal changes, invasion potential, and human impacts and conflicts on ecosystems (Elith et al. 2006; Dickman and Wardle 2012; Marshall and Strine 2019).

Given that gathering biodiversity data takes a considerable amount of time, effort, and resources, citizen science campaigns that encourage people in the scientific processes of species recording, collecting, and interpreting data are successful examples of alternatives to obtain information on a number of attributes difficult to monitor through conventional scientific methods, such as field samplings (Bonney et al. 2009). The data in voluntary citizen science usually involves at least three elements: observation (many times in photograph format), date, and geographic location (Resch 2013). These initiatives are usually designed to answer scientific questions linked to public demands and management decisions, and can effectively crowdsource data, so amassing large volumes of species observations (Garcia-Soto et al. 2021).

Besides the scientific benefits in solving data scarcity issues, there are added benefits to involving people in the process of species and environmental observation, for example: i) it can give people direct access to environmental information relevant to them; ii) it exposes a wider audience to the scientific process; and iii) it helps to construct a more science-friendly public; increasing participant knowledge, awareness, and empowerment (Bonney et al. 2015; Kieslinger et al. 2018; Sandahl and Tøttrup 2020). In other words, everybody wins!

Nowadays, digital technologies play an important role in knowledge transfer and e-learning, motivating and retaining people involved in, or engaged with science conservation (van der Wal et al. 2016; Marambio et al. 2021). For example, the species information and photography may be emailed to the researcher (Acorn 2017; Record et al. 2018), or uploaded through an online portal (Worthington et al. 2012; Silvertown et al. 2015) or dedicated mobile app (Lee and Nel 2020; Gutiérrez-Estrada et al. 2021). Often, there is little or no expertise required in providing information about species observation, as systems rely on common sense and general types of human observations, helping to collect the relevant data (Becken et al. 2019). Further, new technology and computational techniques allow for some data to be automatically identified and transferred to professional scientists (Cooper et al. 2012; Terry et al. 2020).

Voluntary participation in citizen science may be done through planned campaigns (Garcia-Soto et al. 2021) or opportunistic contributions (Pocock et al. 2018), with differences in the data collection. Citizen science campaigns usually follow directed and structured survey protocols guided by researchers, differently from opportunistic contributions (Cooper et al. 2012; Kelly et al. 2020; Sandahl and Tøttrup 2020). An example of opportunistic databases is the iNaturalist community (https://www.inaturalist.org/), one of the most popular biodiversity databases of species images shared by users and validated by experts (Callaghan et al. 2022). Although iNaturalist allows the creation of voluntary campaigns with specific taxa, places, and periods (e.g., Terenzini et al. 2023), the observations in this platform have many times an unstructured format without formal survey methods or guidance from researchers (e.g., Roberts et al. 2022). Moreover, in citizen science campaigns it is common the collection of data on species observation (presence) but also the non-observation (‘true’ absence), helping to analyze and model when a species both was and was not encountered in space and time, while opportunistic contributions usually provide only the presence of the species (Callaghan et al. 2021).

Besides emails, websites, and dedicated and opportunistic platforms for smartphones, social media platforms are other examples of digital technologies which have provided networking opportunities for the public to collaborate and co-create scientific studies with professional research, facilitating communication between all parties involved (Kelly et al. 2020). In voluntary citizen science, social media is commonly used for recruiting volunteers to share species observations or respond to questionnaires (Record et al. 2018; Cerri et al. 2020), and sharing data and results with citizens (Magalhães et al. 2020). In fact, the social media element already revolutionized citizen science projects (Aravind 2013), being consistently incorporated in campaigns in marine ecosystems (Garcia-Soto et al. 2021), but also many of them are based solely on these platforms (Krželj et al.

2020; Carvalho et al. 2022). Among the advantages, there is easy, wide, and free access to social media (Lodi and Tardin 2018). Indeed, social media may represent a low-cost citizen science monitoring strategy for marine species if compared to a dedicated website or mobile app (Encarnação et al. 2021).

Along with deliberately planned citizen science campaigns, content produced involuntarily via various social media platforms may also be an interesting source of data on ecology and conservation (Di Minin et al. 2015; Edwards et al. 2021). There are millions of internauts who have spontaneously created a huge databank inside the web, containing real-time observations of species (Di Camillo et al. 2017). Web Ecological Knowledge (WEK) and Digital Accessible Knowledge (DAK) are examples of terms commonly used to refer to the impressive amount of information that the web can offer to scientists (Barve 2014; Di Camillo et al. 2017). iEcology (Jarić et al. 2020), passive crowdsourcing (Ghermandi and Sinclar 2019), or passive citizen science (Edwards et al. 2021) are other examples of terms present in the literature to refer to the research approach focused on collecting, collating, and exploring data about wildlife species passively, spontaneously or unintentionally generated online by human society. Here, we will refer to this research approach as ‘passive citizen science’.

Similar to voluntary citizen science, the dataset in passive citizen science is citizen-generated, but it is opportunistic and presence-only species observations are collected without the organization and conduction of specific campaigns or restrictions on species observations and time-frames (Edwards et al. 2021). Instead, it consists of a process of crowdsourcing in which data are retrieved from web resources to which members of the public have uploaded observations such as annotated images of wildlife (Edwards et al. 2021, 2022).

Passive citizen science constitutes a promising research approach, which can contribute to conservation and science and may allow examining specific ecological hypotheses. In the present study, we reviewed and analyzed the use of passive citizen science to extract observations of marine wildlife from social media.

2. Opportunities

Marine wildlife tourism is increasingly popular, being one of the fastest-growing areas with a focus on wildlife, and representing an opportunity for public involvement in marine conservation (Davenport and Davenport 2006; Burgin and Hardiman 2015). In this context, the capture and sharing of images of marine animals on social media have become a major component of the tourism experiences in the twenty-first century (Pagel et al. 2020; Lin et al. 2023).

Swimmers, snorkelers, divers, underwater photographers, kayakers, and recreational fishers are examples of typical contributors (Di Camillo et al. 2017; Hermoso et al. 2019). For example, monitoring the Great Barrier Reef in Australia, Becken et al. (2017) observed that the social media data volume was greatly enhanced by tourists visiting the region, which highlighted the importance of non-resident sensors in marine environments and the potential value of social media analysis in tourist destinations that are otherwise relatively sparsely populated.

On social media platforms, hashtags or keywords of the Latin and common names of the species can be observed along with photos and videos; locations where it can be found (as a wide area or as specific as the GPS coordinates); captions; comments; and likes, which may provide rich and valuable species occurrence databases (Figure 1; Di Camillo et al. 2017). Each post many times also contains information about “when” (day, hour, minute) the content was created or shared on social media (di Minin et al. 2015). Then, the information about species observation may be present in data entry (i.e. metadata, data about that photo), and in text and image format. Besides spatiotemporal information, posts may also contain details about “what” and “why” the users posted about and “who” the users are (Ghermandi and Sinclair 2019).

2.1. Applications

Previous studies already showed the growing potential of social media data to supplement datasets on marine biodiversity; by detecting and monitoring marine invasions (Rizgalla and Crocetta 2020; Laudy et al. 2020; Ragkousis et al. 2023); discovering new species (Pfingstl et al. 2022); providing observations of rare and episodical species (McDavitt and Kyne 2020); obtaining long-term and large scale spatiotemporal data (di Camillo et al. 2017; Boldrocchi and Storai 2021); extending (Deidun et al. 2017) and delimiting (Kovačić et al. 2023) species distribution ranges; tracking animal movement (Nathan et al. 2022; Outhwaite and Stockin 2022); providing insights into habitats (Pace et al. 2019); and evaluating biodiversity hotspots (Di Camillo et al. 2017).

A review of some studies that applied passive citizen science techniques using social media to study marine wildlife is presented in Table 1. For example, Twitter helped in the discovery of a new marine species by the record of the marine mite *Ameronothrus retweet* sp. n. in Japan which also represented the first report of an ameronothroid taxon from the Sea of Japan coast (Pfingstl et al. 2022). Moreover, the invasive jellyfish *Phyllorhiza punctata* was firstly recorded in Lybia by Facebook data mining (Rizgalla and Crocetta 2020).

Besides spatiotemporal data, other relevant data may be extracted from social media posts, such as the number of individuals, sex, life stage, and animal behavior, as well as, human disturbance, human-wildlife conflicts, and public perceptions (Di Camillo et al. 2017; Sullivan et al. 2019, Todd et al. 2020; Papafitsoros 2022). For example, videos published on Youtube and Facebook provided additional information on the distribution of purple and yellow-purple colonies of *Paramuricea clavate* on the Central-Eastern Mediterranean Sea but also provided information about the presence of fishing lines and signs of damage in the corals (Di Camillo et al. 2017). In Brazil, videos and photos posted on Instagram were used to record diver–sea turtle interactions in shipwrecks, which were classified as ‘abrupt approach, chase, touch, and pose’ (Leitão et al. 2022). Moreover, the fishing, consumption, and market of marine species can also be investigated using social media (Albarico et al. 2021; Pytka et al. 2023). In Phillipines, new mud lobster behaviors was discovered using Youtube videos, such as surfacing during the rainy season and cospecific repulsion, but they also discovered the use of toxic chemicals for illegal fishing activity of mud lobster (Albarico et al. 2021).

Data mining through social media techniques in marine ecology and conservation has the potential to assist in the development of policy documents, advisories, and recommendations for sustainable actions for the protection of species and ecosystems (Dualibe et al. 2021). These datasets and predictions of species distribution provide information on species' response to the environment, conservation status, spatiotemporal changes, invasion potential, and human impacts and conflicts on ecosystems (Elith et al. 2006; Dickman and Wardle 2012; Marshall and Strine 2019).

2.1.1. Species

Some marine animals are more charismatic and easy to find and identify than others or are physically more common and well distributed, therefore there will be more images of these posted on social media platforms (Chamberlain 2018). In fact, studies conducted with terrestrial species also showed that species that call public attention and generate some feelings seem to be most well represented on social media (Roberge et al. 2014; ElQadi et al. 2017; August et al. 2020).

Larger, charismatic, easy-identifiable, threatened, or endangered megafauna seems to be common target in marine wildlife investigations using social media; such as cetaceans (e.g., Pace et al. 2019; Gibson et al. 2020; Morais et al. 2021), sea turtles (e.g. Rizgalla 2021; Papafitsoros et al. 2021, Papafitsoros et al. 2023), and sharks and rays (e.g. Taklis et al. 2020; Pytka et al. 2023). Big fishes are among the most well-represented study subjects because the sharing of fisheries caught may represent substantial sources of species occurrence records (e.g. Boldrocchi and Storai 2021; Sbragaglia et al. 2021). Moreover, beautiful and photogenic animals such as sea horses (Heard et al. 2019), marine worms (Krželj et al. 2020), and jellyfish (Rizgalla and Crocetta 2020) are other examples of target species. Despite this, a study also showed the potential of social media to provide records of tiny and inconspicuous animals, such as marine mites (Pfingstl et al. 2022).

2.1.2. Platforms

Facebook, Youtube, and Instagram are examples of platforms commonly used in passive citizen science investigations for marine species, also being the most popular social media worldwide (Statista 2023b). Instagram, for example, gives users easy access to upload images (photos and videos) directly from their smartphones, commonly in real-time (Leaver et al. 2020), providing valuable spatiotemporal information on marine species (e.g., Sullivan et al. 2019; Morais et al. 2021; Leitão et al. 2022). In these platforms, the data generated by taking photographs or uploading a video, and the metadata, add to the usefulness of the image as valuable information about species occurrence that can be added to, compared with, and analyzed with other data (Figure 1).

2.1.3. Data search and filtering

The standardization of posts classification and sampling effort is commonly essential for filtering social media data. For example, users may use multiple hashtags to identify the post, such as the common and scientific name of species, then, researchers should consider this and cull duplicates accordingly (Pace et al. 2019; Sullivan et al. 2019). Then, it is important to define data quality criteria for filtering the social media data to reduce the impact of Type I error (i.e. reject the null hypothesis when it is true), guarantee reliability, reduce variability, and eliminate outliers, duplicates, and double entries (Barve 2014; Becken et al. 2019).

It is common that the minimum requirements to classify a post or comment as an occurrence record include at least taxonomic identification, and date and location of observation (Pace et al. 2019). For taxonomic identification, only the photographs and video footage in which the diagnostic features of the taxa are clearly visible are commonly selected (Di Camillo et al. 2017; Pace et al. 2019).

Studies that used social media to retrieve marine wildlife observations mainly focused on a single species or a few species, searched the occurrences through specific hashtags or keywords about the study subject or objective, and filtered the records manually. But there are also investigations that filtered and collected marine species observations from social media automatically. Computational and automatic techniques are improving the ability to search, detect, classify, and process texts and images in a less time-consuming way (Di Minin et al. 2018; Blount et al. 2022; Edwards et al. 2022), also helping to create a centralized open-source data system (Blount et al. 2022).

In automatic data extraction, API (Application Programming Interface) may be accessed to download social media search results via programming language packages (Barvi 2014; Chamberlain 2018). APIs are hooks provided by the web service that allows developers to build on the features provided by the service. These APIs are similar to manual searches that one might run on any website, but the data returned are machine-readable (Barve 2014). In addition, the automatic classification may help to compile a large volume of data from several species or big geographical areas in content analyses and filtering processes by ‘big data’ classification techniques (Menon et al. 2017; Edwards et al. 2021; Blount et al. 2022). In this technique, machine learning is used to understand and classify images and determine the likelihood that a mention of a species represents a given species (Chamberlain 2018; Edwards et al. 2021).

Artificial intelligence and computer vision tools also allow the provisioning of common data models for collaboration between researchers, saving significant time and money (Menon et al. 2017). For example, the global citizen science platforms present in the Wildbook project (https://www.wildme.org/platforms) combine voluntary contributions and public images to provide marine species observations through computer vision and deep learning (Berger-Wolf et al. 2017). This project developed a software ecosystem using intelligent agents or web-crawling bots designed to extract relevant observation data from publicly available posts on social media, including photos and video captures (Blount et al. 2022). Moreover, they also provide an authoritative catalog of the individual animals who might appear in this content, linked to the researchers who would be interested in these observations (Blount et al. 2022), such as the Flukebook and Sharkbook.ai platforms, which assist the conservation of different species of whales, dolphins, and sharks by automating individual identification (Berger-Wolf et al. 2017; Blount et al. 2022).

2.2. Advantages

Passive citizen science would not undertake volunteer efforts, however, data from the web are many times publicly and easily accessed, geo-referenced, real-time, long-term, and refreshable, and are rapidly increasing in volume and scope (di Minin et al. 2015). In fact, the observations provided by sea users on social media have already become a source of species and environmental information, especially in the context of budgetary restrictions and a lack of institutional resources (Becken et al. 2019; Azzuro and Tiralongo 2020).

Spontaneously generated social media data may represent a cost and time-efficient method for collecting wildlife on a larger scale and for a wider time span than field sampling and voluntary citizen science campaigns (Edwards et al. 2021), also occasionally providing information that scientists would have no other way of acquiring (Vyas et al. 2017; Naumov et al. 2020). For example, social media platforms can dramatically increase the knowledge about the distribution and ecology of poorly studied species that can accurately be identified through an image, providing missing information about species distributions (Heard et al. 2019).

People also tend not to download apps due to their need to empty space in their smartphones, which also represent one advantage of spontaneously generated data from popular social media in relation to dedicated apps from voluntary citizen science, since the data source are platforms that people are already using widely. In 2022, 4.59 billion people were using social media worldwide, a number projected to increase to almost six billion in 2027 (Statista 2023a). Due to the widespread, broad scope and gratuity of most social media, passive citizen science raises as a promising methodology, which will become increasingly established in marine investigations.

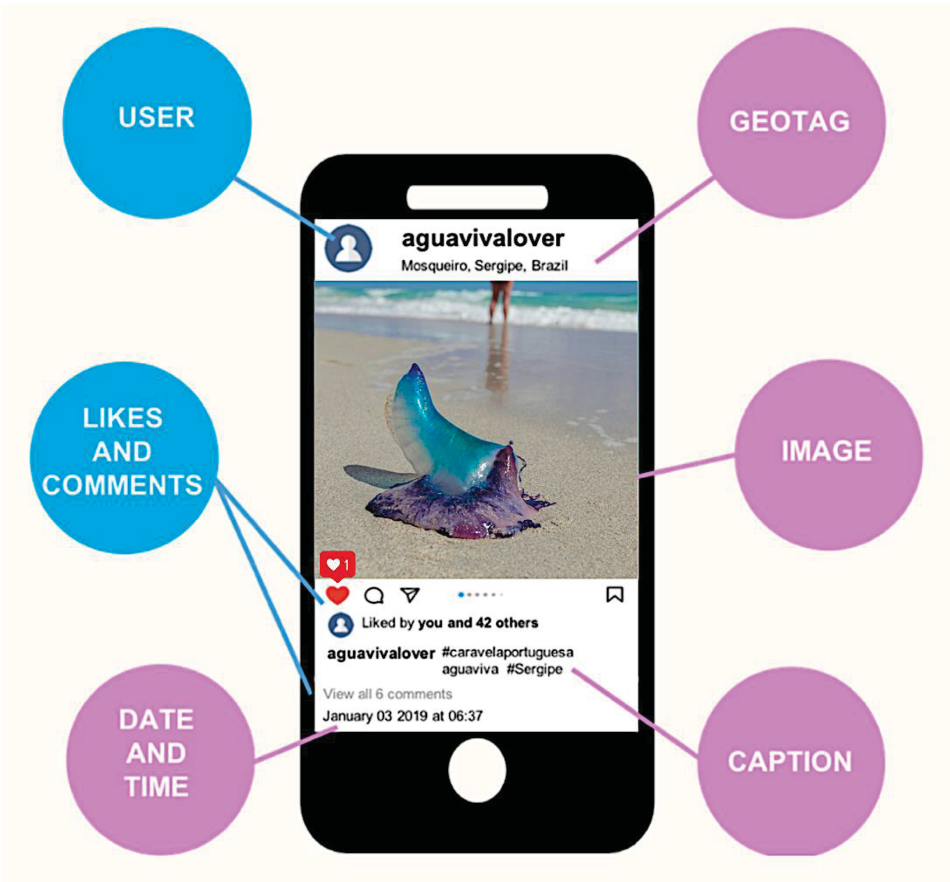


Figure 1. Examples of data present in image-based social media. In pink, is the main data commonly used for obtaining information about species occurrence.

Table 1. Examples of studies that applied the passive citizen science approach using social media data for marine species. A brief description of the initiatives is given, as are some details regarding data sources and data collection. SS = scientific surveys; CS = voluntary citizen science; BL = blogs; NW= news; LIT = literature review; PC = personal communications; IW = interviews; WB = other web data; Na = no data or not assessed; / = not applicable.

Marine wildlife	Social media data								Other data		References
	Where	When	Platform	Search method	Filtering method	Data collected	N spp.	N obs.	Sources	N obs.	
Coral reefs	Central-Eastern Mediterranean	2009 - 2015	Youtube and Facebook	Keywords (locations + common names) and dive centers	Manual	Location, date, depth, dive spot name, chromatic variations, occurrence of fishing lines, substrates preferences and damage	9	138	SS, CS	1119	Di Camillo et al. 2017
	Great Barrier Reef, Australia	Mar - Dec 2016	Twitter	Keywords (locations + marine activities + marine life + aspects of water quality + and coral condition)	Manual and automated	Location, date, and sentiment	Na	434	CS, WB	8857	Becken et al. 2019
Jellyfish	Malta, Mediterranean	1 Jul - 15 Aug 2015	Twitter and Google+	Keywords (locations + common names)	Automated	Location and date	Na	230	CS, BL, NW	100	Jovanovic and Vukelic 2015

	Alboran Sea, Mediterranean	1993-2015	Flickr, Panoramio, Youtube and Facebook	Na	Manual	Location and date	1	16	SS, CS, LIT, NW, WB	149	Kienberger and Pietro 2017
	Mediterranean	Na	Twitter	Keywords (common names + general descriptors)	Automated	Location, date and number of individuals	Na	Na	CS	Na	Laudy et al. 2017; 2020
	Lybia	21 Sep 2015	Facebook	Na	Manual	Location, time and depth	1	1	/	/	Rizgalla and Crocetta 2020
	Global	Na	Youtube	Keyword (common name)	Automated	Location	15	226	/	/	Ruiz-Frau et al. 2022
Marine worms	Croatia	2000 - 2019	Youtube	Keywords (locations + common and species names) and dive centers	Manual	Location, date, circumstances of the observation, depth and behaviour	1	30	LIT, SS, CS	110	Krzelj et al. 2020
Marine mites	Japan	Na	Twitter	Na	Manual	Na	1	Na	SS	Na	Pfingstl et al. 2022
Crab	Central Mediterranean	19 June 2016	Na	Na	Manual	Location and date	1	1	SS, CS	12	Deidun et al. 2017
Mud Lobster	Philippines	2015 - 2021	Youtube	Keywords (locations +	Manual	Location, date, main	Na	30	/	/	Albarico et al. 2021

				common names)		content, fishing method, gear design, catch rate, price, surrounding environment, cooking method/ menu, sex, size, maturity and behavior					
Seahorses	Taiwan	2017 - 2019	Facebook and Instagram	Keywords (common name) and groups of underwater photography and marine biodiversity	Manual	Location, date and depth	5	Na	/	/	Heard et al. 2019
Groupers	Northeastern Brazil	1995 - 2021	Youtube, Facebook , and Flickr	Keywords (locations + common and species names)	Manual	Location, date, environment, fishing gear and vessel	1	17	NW, BL, PC, WB	16	Dualibe et al. 2021
	Italy	2011 - 2017	Youtube	Keyword (common name)	Manual and automated	Location, date, depth, mass of fish, and fishing method	4	262	/	/	Sbragaglia et al. 2021

Sharks and rays	Indo-West Pacific	Feb - Mar 2019	Instagram, Facebook, Youtube and Twiter	Keyword (common name)	Manual	Location, date, and user name	1	53	/	/	Araujo et al. 2020
	Southeastern Brazil	2013 - 2018	Youtube and Facebook	Na	Manual	Location and date	1	4	LIT, NW, PC, IW	15	Di Beneditto et al. 2020
	Indonesia	Jul 2019 - Feb 2020	Instagram, Twitter and Facebook	Keywords (locations + common names + general descriptors)	Manual	Location, date, user name, common name or search term, context and animal usage	1	1219	WB	Na	McDavitt and Kyne 2020
	Greece	2017 - 2019	Facebook, Twitter and Youtube	Keywords (common names)	Manual	Location, date, circumstances of the observation, fate of the sharks, sex, maturity stage, size, weight and depth	19	116	/	/	Taklis et al. 2020
	Italy	2011 - 2020	Instagram, Facebook	Keywords (locations + common	Manual	Location, date, type of record,	1	146	NW	Na	Boldrocchi and Storai 2021

			and Youtube	names + general descriptors) and groups of diving, fishery, and marine biodiversity		number of individuals, sex, life stage and biological and/or ecological observations					
	Thailand	Jun-Jul 2020	Facebook, Twitter and Instagram	Keywords (locations + common and species names)	Manual	Location of seller, location of buyer, sale date, year first posted, site type, product type, size of thorn, price in local currency, cultural relevance, legality of trade, reference to other potentially illegal wildlife items	1	Na	WB	Na	Pytka et al. 2022
Other fishes	Mediterranean	1 Mar 2020	Facebook	Fish group	Manual	Location, date, depth, size and	1	1	/	/	Azzuro and Tiralongo 2020

						fishing artfacts					
	Mediterranean Egypt	2020	Facebook	Fishing groups	Manual	Location, date, depth and fishing method	5	5	LIT	48	Al Mabruk et al 2021
	Italy	2009-2019	Youtube	Keywords (common name + technique and gear of recreational angling and spearfishing)	Manual and automated	Location, mass of the fish, positive and negative feelings	/	376	/	/	Sbragaglia et al. 2022
	Turkya	Jan 2017 – Dec 2019	Youtube	Keywords (common name)	Manual	Location, date, duration, angling method, number of catches, bycatch species and their number, number of escaped bluefish, number of bluefish caught as	1	929	/	/	Eryaşar and Saygu 2022

						juvenile or adult					
	Mediterranean	Aug-Sep 2022	Facebook	Na	Manual	Location, date, species, identification method, observer, source category, source link and photographer	2	9	LIT, CS	1015	Kovačić et al. 2023
Sea turtles	Libya	Jan 2019 - May 2020	Facebook and Youtube	Keywords (common and species names)	Manual	Location, date, time, size, sexual maturity, cause for live and dead stranding and carcass decomposition stage	3	232	SS, IW	42	Rizgalla 2021
	Zakynthos, Greece	1 Apr - 30 Nov 2018 and 2019	Instagram	Keywords (common and species names)	Manual	Location, date and risk of trauma	1	3789	/	/	Papafitsoros et al. 2021
	Zakynthos, Greece	1 - 31 Oct 2021	Instagram	Keywords (common	Manual	Location and date, carapace	1	1	SS	Na	Papafitsoros 2022

				and species names)		length, life stage and foraging behaviour					
	New Caledonia	2013 - 2019	Instagram	Keywords (common and species names + location + popular diving sites + general descriptors)	Manual and automated	Location and date	3	946	/	/	Rean and Jean 2021
	Pernambuco, Brazil	2010-2020	Instagram	Keywords (shipwreck +dive + location)	Manual	Location, date, species, dive-turtle interaction	3	220	/	/	Leitão et al. 2022
Monkseals	Hawaiian Islands	1 Oct 2014 - 30 Sep 2015	Instagram	Keyword (common name)	Manual	Location, date, behaviour, human disturbance and public perceptions	1	2392	CS	7655	Sullivan et al. 2019
Dugongs	New Caledonia	Na	Instagram, Facebook and Youtube	Keywords (common name + drone + aerial)	Manual and automated	Location and species	1	1325	SS	218	Mannocci et al. 2021

Cetaceans	Tyrrhenian Sea	2008 - 2017	Youtube and Facebook	Keywords (locations + common and species names)	Manual	Location and date or season	10	557	LIT, SS, NW	717	Pace et al. 2019
	North Ireland	2007 - 2016	Facebook, Twitter and Flickr	Na	Manual	Location, date and estimated group size	1	Na	CS	Na	Gibson et al. 2020
	South Portugal	2008 - 2020	Instagram and Facebook	Whale-watching companies	Manual	Location, date and number of individuals	16	1403	CS	82	Morais et al. 2021
	Southeast Asia	2009-2019	Facebook	Keywords (location + common names + stranding + plastic + ingestion + entanglement	Manual	Location; date; cause of death and whether a necropsy was carried out	15	163	/	/	Coram et al. 2021
	New Zealand	Apr 2015 – Jul 2016	Facebook	Whale and dolphin groups	Manual	Location, date, time, species, physical description of dolphins, group size, group composition,	3	260	SS	/	Outhwaite and Stockin 2022

						behavior, and their direction of travel					
	New Zealand	2013-2021	Facebook	Cetacean groups	Manual	Location, date and species, group composition, life stage,	Na	45	SS, CS, WB	71	Cranswick et al. 2022
Marine megafauna	Global	May 1998 - Jul 2019	Youtube	Keywords (common names + general descriptors)	Manual	Location, date, time, depth, offshore operation type, project, equipment and structure	28	46	CS	36	Todd et al. 2020
	Global	Na	Youtube and Twitter	Na	Automated	Location, date, and species	doze ns	thous ands	CS, WB	thous ands	Berger-Wolf et al. 2017; Blount et al. 2022
	Sydney, Australia	Jun 2018-Sep 2021	Instagram	Drone shark page	Manual	Location, species, behaviour (e.g., feeding, swimming), interspecies association and	15	678	/	/	Pirotta et al. 2022

						specifically for sharks swimming with humans (swimmers and surfers)					
	Gaza Strip-Palestine	Na	Na	Na	Manual	Na	26	Na	SS, IW, WB	Na	Abd Rabou et al. 2023
	Phillipines	2011-2018	Facebook	Marine conservation and pollution pages	Manual	Location, date, and species	17	32	/	/	Abreo et al. 2019
Top predators	North Aegean Sea	2017 - 2020	Na	Na	Manual	Location, date, and species	11	Na	SS, IW	Na	Kesici et al. 2021
Cryptogenic and alien species	Greece	Na	Instagram and Facebook	Diving centers pages	Manual	Location, date, and species	60	268	SS, CS, LIT, PC, WB	5210	Ragkousis et al. 2023
Marine wildlife	Worldwide	Na	Facebook	Marine biodiversity groups	Automated	Location, date, species, and species interaction	Na	Na	/	/	Chamberlain 2014; Chamberlain 2018

3. Challenges and possible solutions

Despite the cited advantages and benefits, it is important to be aware of the challenges in exploring social media data before starting any project in marine ecology and conservation science that will rely on primary occurrence information. Below we present common challenges, related to ethics, data search and filtering, and inherent biases of such data (Figure 2).

3.1. Ethics

Ethical issues may be a challenge in passive citizen science investigations mainly because these data are people. In general, ethical concerns must be considered in 'big data' research, maximizing the good while minimizing harm (Zook et al. 2017). Although little still is understood about the ethical implications underpinning social media data, researchers have a professional duty to weigh benefits against risks, thinking critically about the ethics of the project, data collection, analysis, and publication (Zook et al. 2017).

It is recommended only use public data and follow the recommendations and regulatory expectations and legal demands associated with the rules and protection of privacy within the dataset from the used social media platform. Then, the ethics of research are needed to access on a case-by-case basis and the need for regular reassessment during the research as social media are rapidly evolving (Monkman et al. 2018; Ghermandi and Sinclair 2019).

When it is obtained only one or few observations it is possible to contact the user to obtain more information along with permission to use the post to illustrate the findings (Azzuro and Tiralongo 2020). However, gaining informed consent is virtually impossible when data from hundreds and thousands of social media users are used. Therefore, it is of foremost importance that all identifiable content of social media users is removed to protect user privacy in these cases (Di Minin et al. 2021). The data mining of publicly accessible social media content for research purposes in order to serve a larger public good generally receives special dispensation in law when correctly anonymized (Monkman et al. 2018; Ghermandi et al. 2023). If there is a need to contact or identify the user, it would be suitable to submit the study to an Ethics Committee, since it involves human rights.

There are also ethical issues related to animal rights in ecological and conservation research using social media, for example, when the investigation is conducted with endangered species (Lindenmayer et al. 2017; Jarić et al. 2020). The sharing of the geolocation of the observation and the disturbance caused by human presence may put the species even more at risk (Jarić et al. 2020; Pagel and Lück 2022). If the research is carried out with endangered or threatened animals, it is also advisable to submit the study to an Ethics Committee, since it involves animal rights.

3.2. Data search and filtering

The mistakes in species identification are a challenging issue related to the social media database in marine biodiversity, such as for cryptogenic species with similar morphological characteristics (Abreo et al. 2019). It is possible to observe social media posts with errors in species identification by non-experts. Further, the quality of images may also difficult the identification of some species. These limitations may affect the results, because the species distribution analysis can be sensitive to false positives (Fernandes et al. 2018). Possible solutions to reduce errors in species identification are to standardize the data collection and promote the online training of citizen science observers through social media (Abreo et al. 2019). It is still possible that the accuracy of the storage data to be checked by one or more researchers to verify and validate the data and ensure data quality (Pace et al. 2019).

The manual filtering process to obtain species occurrence records may be very time-consuming, especially in the investigation of many species. A possible solution is to use machine learning to develop automated classification systems (Chamberlain 2018; Edwards et al. 2021; Blount et al. 2022). However, the automation in species classification it is not an easy task and eliminating false positives currently requires manual verification by the researchers (Wäldchen and Mäder 2018; Chamberlain 2018; Toivonen et al. 2019).

The restrictions in the download of data from some social media are also challenges in the filtering processes of species occurrences. For example, in the aftermath of the Cambridge Analytica controversy, social media platform providers such as Facebook and Twitter have severely restricted access to platform data via their Application Programming Interfaces (APIs), which had a critical effect on social media research (Bruns 2019). A possible solution is to use open source APIs developed by independent programmers, such as the Instaloader https://instaloader.github.io/), a python package to download posts with various parameters.

3.3. Biases

Since the “social” in “social media” denotes the relation of these platforms to human social behavior which is complex, variable, and not necessarily aligned with the goals of any ecological study, the biases associated with social media datasets are also common challenges in ecological investigations (ElQadi et al. 2017; Peter et al. 2022). Social media data are nonrandom and not generated systematically, with a significant variance in content generation among different users, regions, cultures, and time frames, with inherent risks of biases (Ghermandi and Sinclar 2019; Jarić et al. 2020), which may affect the sample size and distribution results when using occurrence data (Jiménez-Valverde et al. 2019; Foglio et al. 2019).

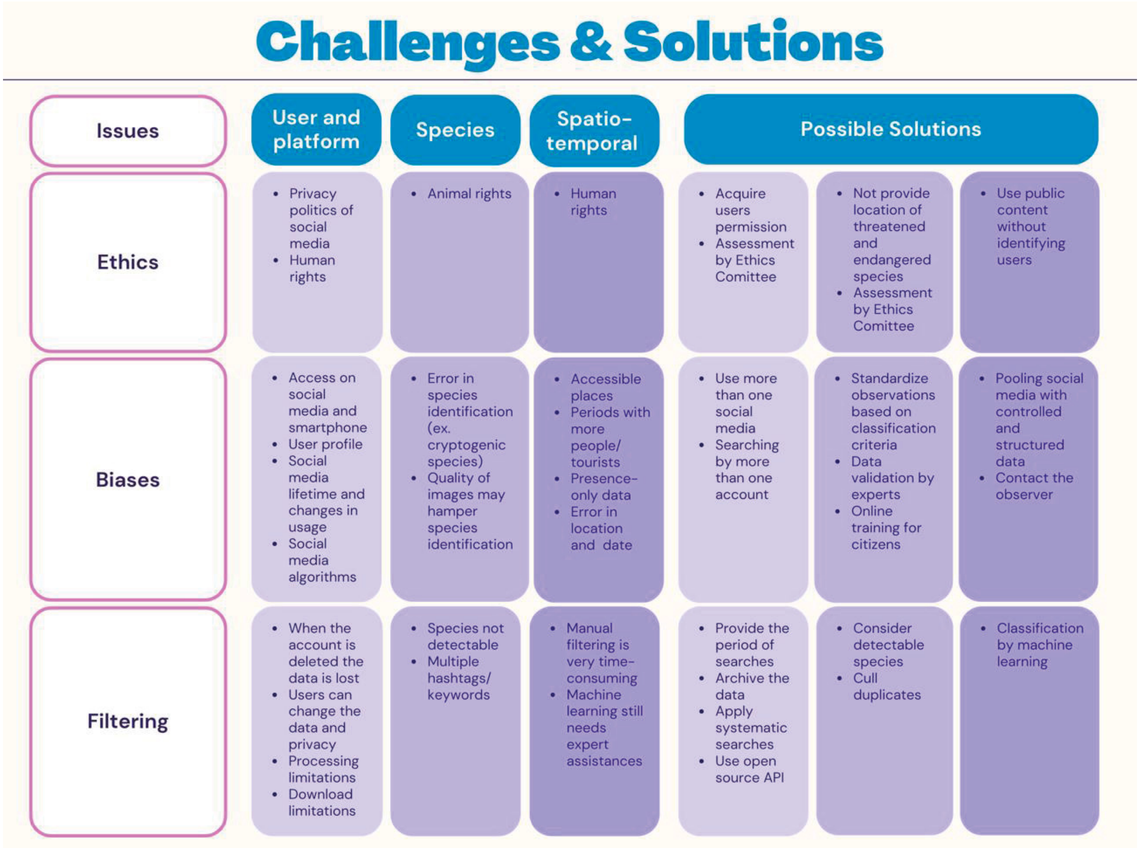
People upload images according to their tastes and experiences, then, it is doubtful, whether the population density of species should be inferred directly from this data, because the density of images on social media may be dependent on user activity levels, rather than on the abundance of the photographed subject (ElQadi et al. 2017). Social media data may be influenced by human-populated coastal areas, travel routes, and common holiday destinations, with a degree of variability connected to the presence of harbors and to seasons (summer is more suitable for recreational activities at sea (Pace et al. 2019). The bias associated with wildlife observations towards attractive or easily accessible places may hamper accurate characterization of how a species responds to ecogeographical factors, may reduce accuracy, and generally may devaluate the data for conservation and ecological research (Jiménez-Valverde et al. 2019).

The increase in social media usage in recent years may also represent biases in the data generation and volume. A staggering 64.2 zettabytes were created on the web in 2020 since the pandemic restrictions (Statista 2022b). This is an impressive number, but it is projected that the volume could grow to about 100 zettabytes in 2022 and 180 in 2025, which certainly influence the data about species observations retrieved from social media.

The benefits of social media to supplement biodiversity databases may also be highly variable between species and minimal for species with low detectability (Marshall and Strine 2019). Furthermore, for easy-to-identify taxa, automatic systems may achieve comparable results to that of experts; however, more difficult groups may present problems for species identification done by both, computer and expert (Chamberlain 2018).

It has been suggested that a convenient way to address such issues and reduce biases associated with human behavior in social media involves pooling heterogeneously distributed data from social media with controlled and structured data (e.g., ground truth, such as scientific survey data based on a predefined protocol), when available (Pagel et al. 2014; Pace et al. 2019). In fact, many studies that applied social media to obtain information about marine species compared and validated their findings with other data sources, such as scientific field research, voluntary citizen science, online databases, literature review, or their combination (e.g., Barve 2014; Jovanovic and Vukelic 2015; Hart et al. 2018; Ghermandi and Sinclar 2019; Jiménez-Valverde et al. 2019; Pace 2019). In most cases, the authors reported a satisfying to excellent level of consistency among data sources. By comparing data sources, it is also possible to measure the contribution of the social media dataset in the database (Sullivan et al. 2019; Morais et al. 2021). Further, distribution and abundance analyses are more difficult if starting from presence-only data, such as those traditionally generated by museum records and many opportunistic citizen science projects to gather photographs of living organisms, such as iNaturalist (Callaghan et al. 2021) and social media platforms (Becken et al. 2019). But previous study argued that if social media data is used along with other data sources, as a complementing or ground truth data source, the biases associated with presence-only records may not be an urgent issue (Becken et al. 2019).

Besides the advantages of complementing and validating social media databases, the use of other data sources along with unstandardized data is recommended because the increased sample sizes are less sensitive to false positives/negatives and locational error (Marshall and Strine 2019; Jiménez-Valverde et al. 2019). On the other hand, it is also a challenge to compile different data sources, because they usually have differences in characteristics and issues related to data quality (Jiménez-Valverde et al. 2019). Moreover, the insufficient information from existing scientific literature and the absence of unbiased data from a well-designed and standardized survey may also hamper appropriate results comparison and validation (Jiménez-Valverde et al. 2019).



Challenges & Solutions

Issues	User and platform	Species	Spatio-temporal	Possible Solutions		
Ethics	• Privacy politics of social media • Human rights	• Animal rights	• Human rights	• Acquire users permission • Assessment by Ethics Comittee	• Not provide location of threatened and endangered species • Assessment by Ethics Comittee	• Use public content without identifying users
Biases	• Access on social media and smartphone • User profile • Social media lifetime and changes in usage • Social media algorithms	• Error in species identification (ex. cryptogenic species) • Quality of images may hamper species identification	• Accessible places • Periods with more people/ tourists • Presence-only data • Error in location and date	• Use more than one social media • Searching by more than one account	• Standardize observations based on classification criteria • Data validation by experts • Online training for citizens	• Pooling social media with controlled and structured data • Contact the observer
Filtering	• When the account is deleted the data is lost • Users can change the data and privacy • Processing limitations • Download limitations	• Species not detectable • Multiple hashtags/ keywords	• Manual filtering is very time-consuming • Machine learning still needs expert assistances	• Provide the period of searches • Archive the data • Apply systematic searches • Use open source API	• Consider detectable species • Cull duplicates	• Classification by machine learning

Figure 2. Review of common challenges in passive citizen science investigations through social media in ecology and some possible solutions.

4. Conclusions

Although modern communications, smartphones, and the enabling of citizen science have created a broad resource base for social media to provide information on the monitoring of marine species, the investigation of the potential of data from social media for answering ecological questions related to the occurrence and distribution of marine wildlife still is incipient and has not been explored in depth, with few recent studies conducted in the emerging field of passive citizen science. But these studies already recognized the role of social media as a complementary data source for varied research hypothesis, as well as the challenges in explore this data source. We expect that social media research will continue to expand, transforming the future of marine ecology in the Information Age.

Declarations

Funding
This study is part of LSN PhD thesis and was supported by the Coordination for the Improvement of High Education Personnel – CAPES, grant no. 88882.382983/2019-01.

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

Data availability
We compiled data for this study through the inspection of published studies available in the web.

CAPÍTULO II

The deep-sea jellyfish *Stygiomedusa gigantea* (Scyphozoa: Semaeostomeae) found in Brazil through social media data mining

Intended journal: Journal of Sea Resarch, ISSN 1385-1101, impact factor 2.287, Qualis CAPES A3)

Abstract

We provide the first record of the giant deep-sea jellyfish *Stygiomedusa gigantea* (Browne 1910) from tropical Southwestern Atlantic, based on a posting made on Instagram social media. The jellyfish was seen already dead on the water surface off Bahia, Northeast Brazil (12°34′39″S, 38°00′19″W), on 23rd August 2016. Pygmy killer whales (*Feresa attenuata*) were swimming around and apparently interacting with the jellyfish. Observations of *S. gigantea* usually come from submersibles and ROVs. This is the first record extracted from social media, highlighting its potential use to complement information based on traditional scientific methods, and expanding considerably the known geographic distribution of this jellyfish. With the growth and development of social media in the coming years, we highlight its potential as data-source from passive citizen science. We also expect that social media will increasingly contribute to the knowledge of remarkable but poorly known species such as *S. gigantea*.

Keywords medusae, iEcology, passive citizen science, Instagram

Introduction

The giant *Stygiomedusa gigantea* (Browne, 1910) is a jellyfish of the family Ulmaridae Haeckel 1880 (Cnidaria: Scyphozoa: Semaeostomeae), and the unique species currently recognized in the genus (Matsumoto et al., 2003; Benfield and Graham, 2010; Collins et al., 2022). *S. gigantea* is popularly known as the 'giant phantom jellyfish'. It has a dark red-brown coloration and a large disc-shaped bell that can reach more than 1 m in diameter. Such coloration probably helps *Stygiomedusa* to stay visually undetectable against the dark background of the deep sea, where the species is recurrently found (Russell and Rees, 1960; Herring, 2002; Johnsen, 2005). Differently from most Semaeostomeae, this species does not have tentacles, but its four highly flattened oral arms can extend more than 10 m in length (Russell and Rees, 1960; Benfield and Graham, 2010; MBARI, 2022). Two individuals observed in the Gulf of Mexico clinging to underwater structures lead to the hypothesis that the jelly uses its long oral arms for the retention and digestion of plankton and small fishes (Benfield and Graham, 2010).

Stygiomedusa gigantea has a cosmopolitan distribution, probably occurring in the mesopelagic and upper bathypelagic zones of all oceans, with a global average recorded depth of 657.6 m, but reaching more than 6,600 m (Larson, 1986; Benfield and Graham, 2010; MBARI, 2022). Very little is known about its distribution, ecology, and behavior (Benfield and Graham, 2010). This jellyfish was recorded over a hundred times since its first sighting in 1899, most of them as a single individual (Russell, 1959; Benfield and Graham, 2010; Schnabel et al. 2021). In South America, this medusae was only previously recorded in Argentina at ~45°S (Oliveira et al., 2016; Schiariti et al., 2018). Within the framework of an ongoing investigation of jellyfish occurrences through internet data-mining, here we provide the first record of *S. gigantea* from Brazil, based on a posting made on the Instagram platform, highlighting the great potential of social media to complement traditional methods on conspicuous marine species.

Material and methods

The whale watcher Adriano Paiva posted an underwater image of Stygiomedusa gigantea on July 06th, 2019 on Instagram (Figure 1A). The image was found during social media data mining, using the hashtag #aguavivagigante (in English, #giantjellyfish) on Instagram. The hashtag is a word or phrase preceded by a hash sign (#) used on social media platforms to identify digital content on a specific topic. The whale watcher was then contacted via Direct Instagram messenger for additional images, more detailed information, and permission to use images and information for a specific publication illustrating the finding.

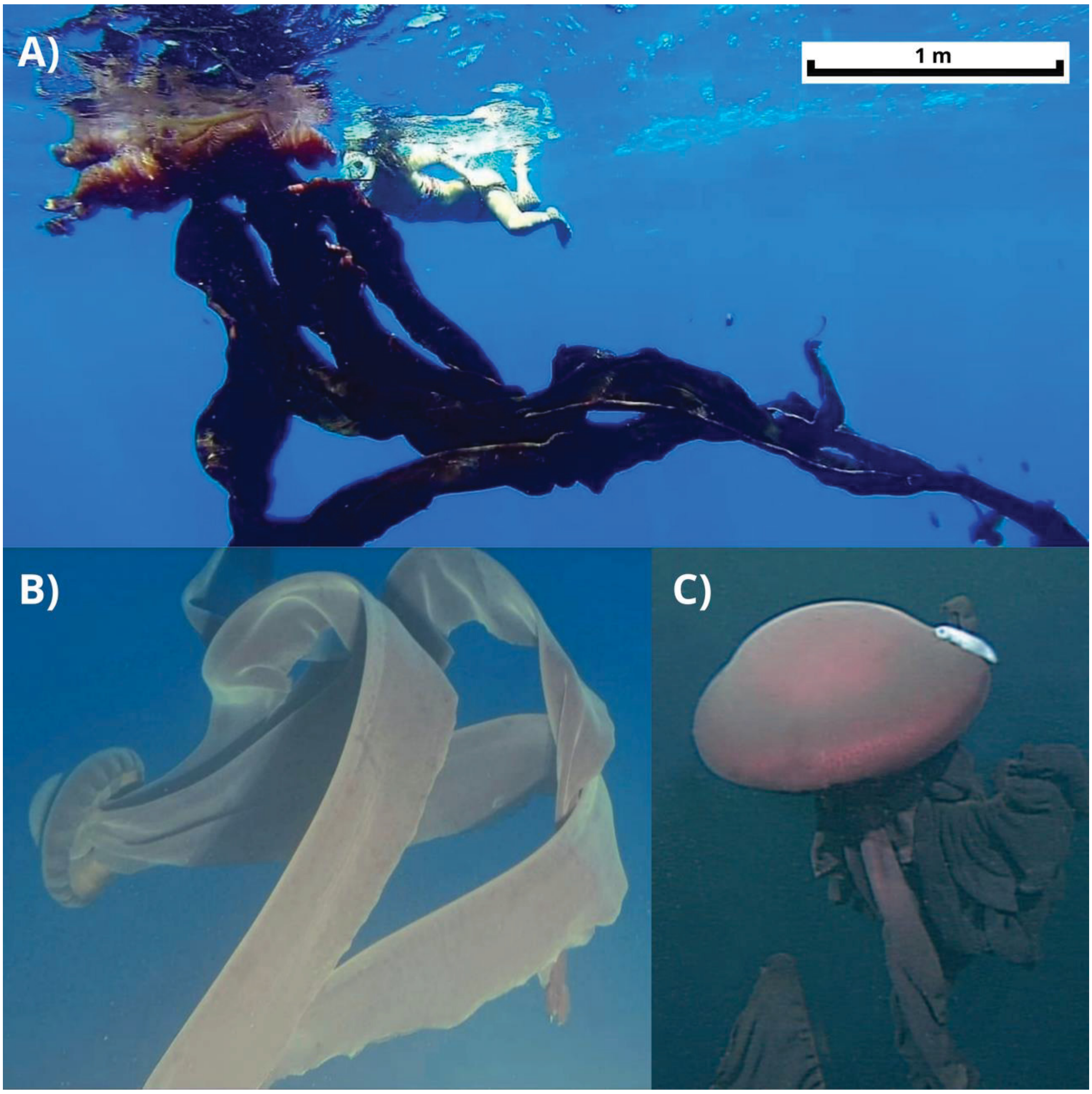


Figure 1. Image of *Syigiomedusa gigantea* individuals observed in the A) Praia do Forte, Bahia, Brazil (12°34’39” S, 38°00’19” W) at the water surface (this study), B) Antarctic Peninsula at Georges Point, Rongé Island (64°39’9” S, 62°38’7” W) at 87 m (from Moore et al., 2023), and C) Farallon Basin, Gulf of California, Mexico (25°27.220” N, 109°50.170” W) at 1300 m (from Drazen and Robinson, 2004). The scale is only applicable for (A).

Results and discussion

Adriano Paiva sent via Direct Instagram more detailed information and a video of the encounter with the giant *Stygiomedusa gigantea* (Supplementary material 1). The observation was made on 23rd August 2016, during a research cruise coordinated by the Instituto Baleia Jubarte (Humpback Whale Project – Brazil). The vessel was off Praia do Forte, Bahia (12°34′39″S, 38°00′19″W), at the continental slope, about 1000-2000 m in bottom depth (12°34′39″S, 38°00′19″W; Figure 2). According to the whale watcher, the jellyfish was already dead at the moment of observation and pygmy killer whales (*Feresa attenuata*, Delphinidae) were swimming around the jellyfish at the water’s surface, apparently “nibbling” on it. From the images shared by Adriano Paiva, it is possible to observe that the individual was damaged.

We could not obtain a sample of the whole animal for adequate morphological examination, or a sample of tissue for molecular analysis, but the organism observed in Brazil had macro-morphological characteristics consistent with *S. gigantea* (Figure 1). This species is very distinctive, with easy identification due to its large size and typical macro-morphology (Benfield and Graham, 2010), such as about 1 m in bell diameter, four long and flattened oral arms extended about 5 m in length, absence of marginal tentacles, and typical red-brownish coloration pattern (Russell and Rees, 1960; Benfield and Graham, 2010).

This record in Brazil is the first of *S. gigantea* from tropical Southwestern Atlantic. Previous records in the South Atlantic include in the Gulf of Guinea at 5°S (Repelin, 1967) and seven records from near the Subantarctic Oceanic Domain (~50°S) (Larson, 1986; Mianzan and Cornelius, 1999; Schiariti et al., 2018). *Stygiomedusa gigantea* was seen about a hundred times worldwide with greatest number of records of this jellyfish from the Antarctic Ocean while observations at low latitudes are particularly rare (Figure 2), highlighting the relevance of the present finding. Nowadays, almost nothing is known about this giant medusae aside from its morphological description and sporadic sighting notes (Russell and Rees, 1960; Harbison et al., 1973; Benfield and Graham, 2010).

It is not possible to determine if the higher number of records of this species in the Antarctic Ocean and the lack in other regions actually represent the distribution of *S. gigantea* or if it is due to disproportions in the explorations (Benfield and Graham, 2010). The disproportions in the explorations must be true for tropical regions, since studies are in fact limited in these regions (Menegotto and Rangel, 2018). However, temperate regions are generally well studied and the challenges of accessing the deep-water habitat of *S. gigantea* must also be considered. This species is known to inhabit mostly the mesopelagic and bathypelagic zones, although can also be found in shallower waters (Larson, 1986; Benfield and Graham, 2010; MBARI, 2022). It has porphyrin pigments, commonly occurring in low light levels due to the phototoxic effects of light exposure on the pigment (Herring, 1972; Benfield and Graham, 2010). When exposed to daylight photo decomposition can convert these porphyrins into toxic compounds (Herring, 1972). But, at high latitudes, the low angle of incidence of the sun may permit the jellyfish to ascent to shallower depths without damage to porphyrin pigments, which may facilitate the record of this species (Benfield and Graham, 2010). On the other hand, migration into surface waters could bring adverse consequences in lower latitudes (Benfield and Graham, 2010), contributing to the relative scarcity of sightings for such a large species in these regions. In the present study, the *S. gigantea* observation was made at the water surface at 12°S, perhaps because the specimen was dead.

The majority of published *S. gigantea* records are from trawl or net samples, and direct observations of this large jellyfish come from submersibles and ROVs (Drazen and Robinson, 2004; Benfield and Graham, 2010; Tarling et al., 2012; Moore et al., 2023). This is the first record of this species extracted from social media. Although the investigations are still incipient, social media is already recognized a useful tool in obtaining rare observations, including for jellyfish (Rizgalla and Crocetta, 2020; Nascimento et al., 2022). The expanding and developing of social media and its usage as data-source from passive citizen science is expected to help increasing the knowledge of poorly known remarkable species as *S. gigantea*.

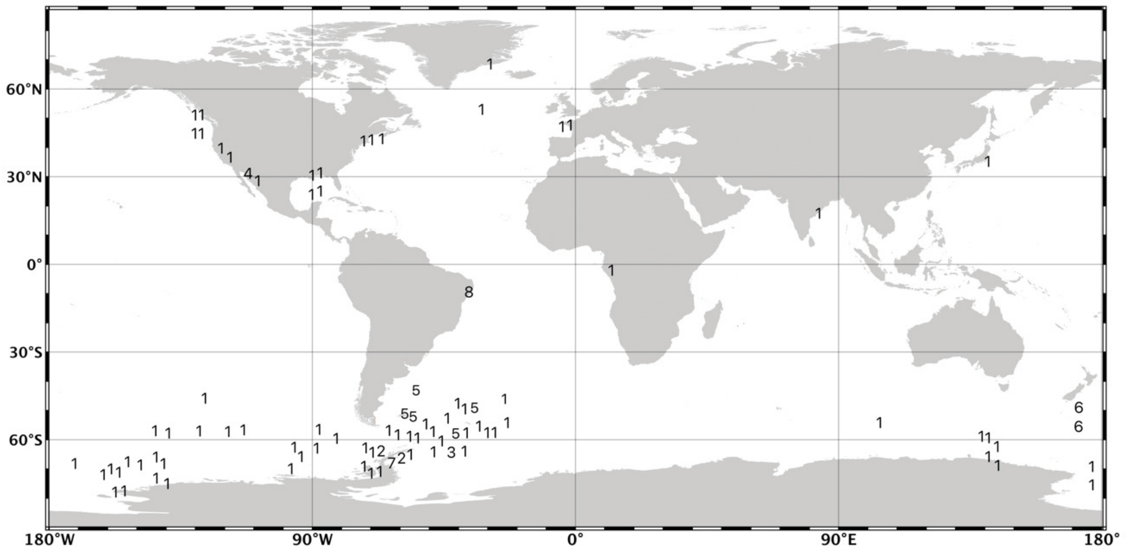


Figure 2. Global distribution of documented records of Stygiomedusa gigantea in the literature. Sources: 1 = Benfield and Graham (2010); 2 = Parker et al. (2011, 2015); 3 = Tarling et al. (2012); 4 = Gasca and Loman-Ramos (2014); 5 = Schiariti et al. (2018); 6 = Schnabel et al. (2021); 7 = Moore et al. (2023); 8 = this study.

Declarations

Funding

This study is part of LSN PhD thesis and was supported by the Coordination for the Improvement of High Education Personnel – CAPES, grant no. 88882.382983/2019-01.

Ethical approval

The Human Research Ethics Committee of Federal University of Paraná (CEP/UFPR) manifests itself by the approval of Research Project number 4.751.477 on 02.06.2021, CAAE: 46505721.7.0000.0102. No animal testing was performed during this study.

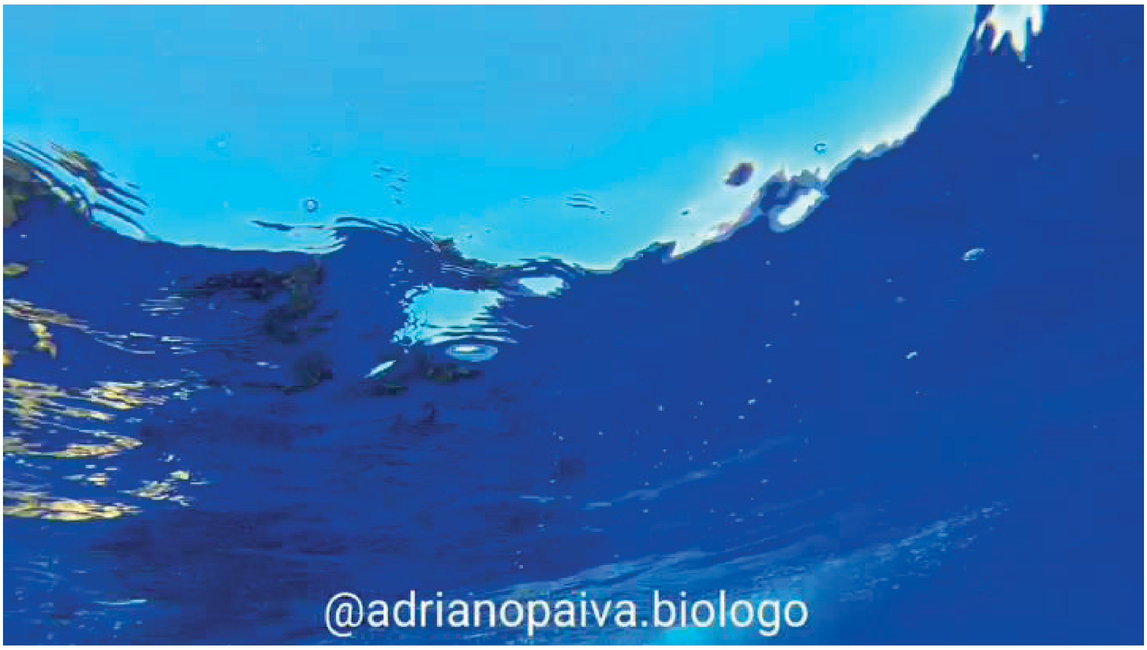
Informed consent

A Free and Informed Consent Form (FICF) was presented to the author of the post on social media before a quick interview focused on animal observation, as directed by the CEP/UFPR.

Data availability

We compiled data for this study through the inspection of publicly available images on Instagram®: [https://www.instagram.com/p/BzlnDMxht0y/?hl=pt-br/].

Supplementary material



Online resource 1. Video of *Syigiomedusa gigantea* from Praia do Forte, Bahia, Brazil, on 6 July 2019.

CAPÍTULO III

Not such a rare species after all? Insights into *Drymonema gorgo* Müller, 1883 (Cnidaria, Scyphozoa), a large and little-known jellyfish from Brazil

Intended journal: Aquatic ecology (ISSN 1573-5125, impact factor 2.218, Qualis CAPES A2)/ Special issue 'Social media in service of aquatic ecology'
Deadline: 31 March 2023

Abstract

Despite jellyfish's ecological and socio-economic impacts, they are still an understudied component of marine ecosystems. Even with its conspicuous size, reaching ~1 m in bell diameter, *Drymonema gorgo* has been rarely observed, with only a few occurrences in the literature, suggesting it is not a common species. Here, we gathered historical records from literature and novel data from the World Wide Web (WWW) to obtain records of *D. gorgo* along the Brazilian coast. A total of 63 observations from 1857 to 2022 were compiled, of which 57 were extracted from the web. Observations on this jellyfish concentrated between 22°S and 27°S, especially in the Cabo Frio region in Rio de Janeiro. It was reported throughout the year, except in August and October, with the highest concentrations in March (late summer). Based on the notable complement in information about its occurrence in the last ten years, we hypothesize that *D. gorgo* is probably not as rare as suggested by the near absence of previous literature records. In addition, biological associations of *D. gorgo* with other species were also discovered such as 1) predation on the jellyfish *Aurelia* sp. and *Chrysaora lactea*; 2) food item for the green turtle *Chelonia mydas*; and 3) association with fishes. This study provides evidence on the potential use of WWW to obtain ecological data about conspicuous marine species occurrence, such as *D. gorgo*, helping to fill knowledge gaps and overcome difficulties in its detection using traditional methodologies.

Keywords Biodiversity monitoring, Social media, iEcology, Web-based images, Citizen science

Introduction

The scyphomedusae, commonly referred to as true jellyfish, represents one of the earliest diverging lineages of pelagic metazoans (Rigby and Milsom 2000). They are amongst the most conspicuous in the gelatinous zooplankton taxa due to their common large size and vivid colors, beyond extensive distribution (Helm 2018). In addition, scyphomedusae have worldwide importance in ecosystems' health, functioning, productivity, and services (Doyle et al. 2014; Graham et al. 2014). For example, some species may interfere with fisheries, being significant predators and competitors of commercially important fishes (Brodeur et al. 2008; Decker et al. 2018) and altering the energy pathways (Brodeur et al. 2011; Robinson et al. 2014).

Despite jellyfish' ecological and socio-economic impacts, they are still an understudied component of most marine ecosystems (Gibbons and Richardson 2013; Nogueira Júnior et al. 2022). The lack of adequate knowledge is primarily due to difficulties in detecting and sampling (Raskoff 2003). Net samplings and scuba diving are examples of the early techniques applied to study jellyfish in their natural environment in the 1970s, 1980s, and 1990s (e.g., Hamner et al. 1975; Burke 1976; Omori and Hamner 1982; Costello et al. 1998). The advancements in technology over the past decades have also provided observing and tracking tools (satellite and recorder tags, acoustic systems, and in situ imaging) that can measure GPS locations, animal depth, orientation in the water column, habitats, populations, and physical oceanographic features. These datasets have led to an increase in the understanding of jellyfish movement, association, and interaction between individuals of the same and different species, the influence of the environment, and species distribution, for example (e.g., Graham et al. 2003; Benfield and Graham 2010; Hays et al. 2012; Schaub et al. 2018; Zhang et al. 2019). Moreover, regular surveys and visual counts on coastal environments have also provided valuable information about jellyfish ecology and distribution (e.g., Doyle et al. 2007; Houghton et al. 2007; Bastian et al. 2011). However, these investigations are often expensive and limited in space and time.

Drymonema species are among the lesser-known jellyfish (Varela et al. 2010; Malej et al. 2014; Öztürk 2020). These species belong to the order

Semaeostomeae, family Drymonematidae (Bayha and Dawson 2010), being shallow-water jellyfish (Hale 1999). There are three valid *Drymonema* species (WoRMS 2022): *D. dalmatinum* from the Mediterranean (Haeckel 1880), *D. larsoni* from the Caribbean (Bayha and Dawson 2010), and *D. gorgo* from the Brazilian provinces (Müller 1883). The jellyfish *D. gorgo* is known to occur in the states of Santa Catarina, São Paulo, and Rio de Janeiro in Brazil, between 22°S and 27°S (Müller 1883; Morandini et al. 2005; Oliveira et al. 2016), being also found on the coast of Argentina (Mianzan 1989; Oliveira et al. 2016; Schiariti et al. 2018). In addition, there is speculation if the specimens described from the west coast of Africa (Kramp 1959) are *D. gorgo* or an undescribed species (Bayha and Dawson 2010).

The specific name *gorgo* is associated with the mythological creature Gorgona, represented as a ferocious, feminine-looking monster with large fangs (Müller 1883). *Drymonema gorgo* is amongst the largest medusae found on the Brazilian coast, with a bell diameter of up to 1 m (Morandini et al. 2005). Despite its conspicuous size and coastal habits, this jellyfish has been rarely observed, with little information about its occurrences reported in the literature (Müller 1883; Cornelius and Silveira 1997; Morandini et al. 2005). This lack of records would suggest that the species is not a common dweller on the Brazilian coast. However, during data exploration for Brazilian jellyfish records on the World Wide Web (WWW) we came across many records of this species that would suggest the opposite.

The online content produced involuntarily by human society via various WWW platforms may be an interesting source of data in ecology and conservation (Di Minin et al. 2015; Edwards et al. 2021). Despite the investigations still being incipient, Web Ecological Knowledge (WEK) (Di Camillo et al. 2017), iEcology (Jarić et al. 2020), and passive citizen science (Edwards et al. 2021) are terms commonly used to refer to the impressive amount of information that can be collected, collated, and explored from the WWW for ecological studies. In the present contribution, we review the historical records of the jellyfish *Drymonema gorgo* on the Brazilian coast and provide novel observations from WWW data. Based on these recent observations, we hypothesize that *D. gorgo* is not such a rare species as the absence of previous records would suggest.

Methodology

Data on *Drymonema gorgo* along the Brazilian coast were obtained by combining information from three data sources: literature (LIT), personal communication (PCO), and the World Wide Web (WWW). We annotated at least the location and date of observation or posting from each occurrence record.

Data from LIT were collected by reviewing published information since Müller's first description of this species in 1883. We performed scientific literature searches through specific keywords and its combination: '*Drymonema*', 'Brazil', '*Drymonema gorgo*', '*Drymonema dalmatinum*', '*Drymonema dalmatina*', 'Atlantic', 'South America' on the websites Google Scholar and SciELO. We also followed citations present in the published papers to search for records of this species. Data from WWW were obtained by searching specific keywords on public internet-based platforms. On Instagram, Facebook, Youtube, Twitter, TikTok, iNaturalist, and Google Image Search, we used the terms 'água viva' (jellyfish), 'água viva gigante' (giant jellyfish), and 'medusa gigante' (giant medusae), and the Latin name of the genus and species '*Drymonema*' and '*Drymonema gorgo*'. Moreover, we obtained one record from a personal communication (PCO).

We only selected photographs and videos from the WWW with specimens clearly identifiable as *Drymonema*, following morphological characteristics defined in the literature (Müller 1883; Mianzan and Cornelius 1999; Morandini et al. 2005; Bayha and Dawson 2010). Besides its conspicuous size, the macro-morphological characteristics typical of *Drymonema* most seen included A) bell markings of a central circle with red/brownish bifurcating radiating lines, B) oral arms foliaceous and elongated, and C) tentacles toward the center of the subumbrella (Figure 1). It was impossible to identify at the species level morphologically since characters such as the number of tentacles by octant or subumbrelar furrows could not be clearly observed from the images. Nevertheless, the specimens here were identified as *Drymonema gorgo* Müller 1883 based on the type locality of this species in southern Brazil (Müller 1883) and since it is the only species of the family considered valid in the South American coast (Oliveira et al. 2016).

The searches on the WWW started on November 01 2020 and ended on December 31, 2022. We obtained observation records from February 2013 to June 2022 from WWW. To maximize the efficiency and quality of data retrieval, storage, and analysis, the WWW search and collection were standardized. We followed the search results chronologically from the most recent until the oldest until no-load more results. For Facebook, Youtube, Twitter, TikTok, iNaturalist, and Google Image Search all the results were investigated for all keywords used, but for Instagram, we could not access results prior to 2020 for the keyword ‘aguaviva’ (jellyfish) due to a large number of posts, which made it difficult for the system to process and hampered access to older data. For Facebook, three different user accounts were used in order to broaden potential search results due to Facebook’s algorithm (Heard et al. 2019). Records were filtered and collected by one scientist and were checked by a second experienced researcher before inclusion in the database to verify and validate the data. Doubtful records were excluded. Reposts, double entries, different fragments of the same footage, and pictures of the same observation were used only once to ensure that each jellyfish encounter was represented exclusively by a unique video or set of photographs in the final analysis.

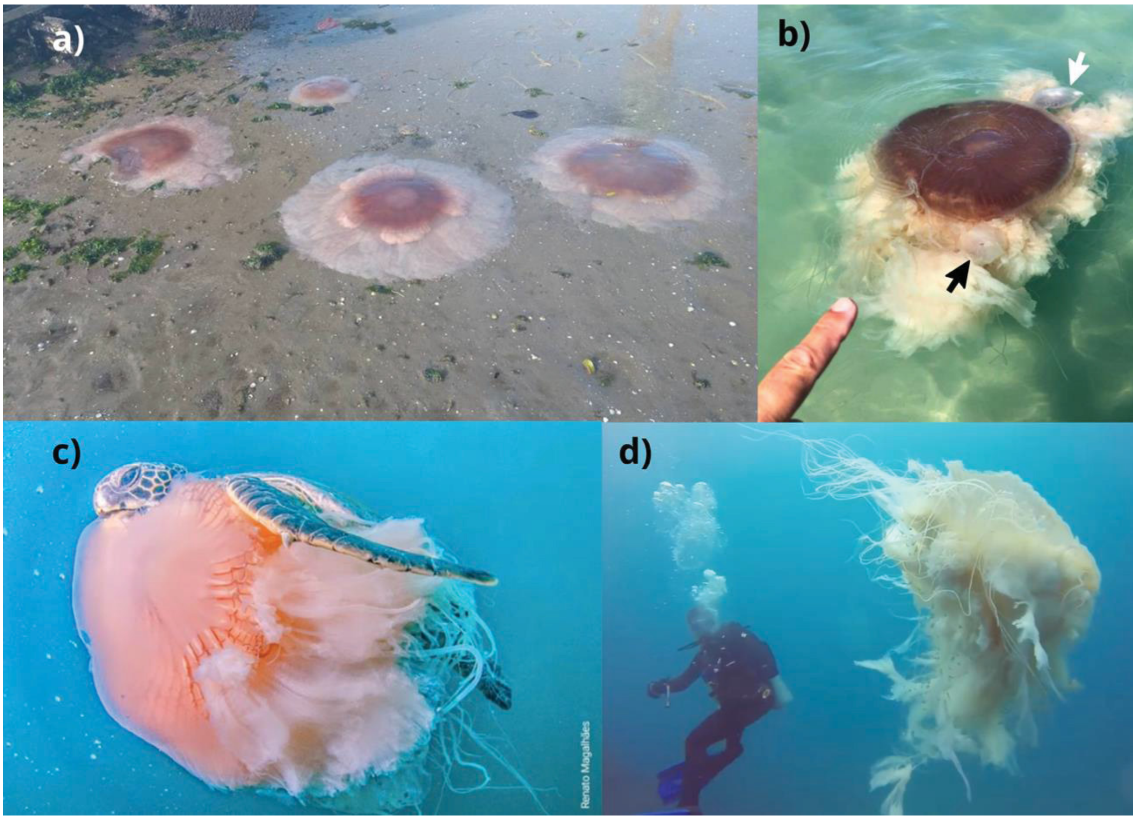


Figure 1. Examples of images of *Drymonema gorgo* on the Brazilian coast extracted from the World Wide Web (WWW): a) Photo posted on 19/09/2017 on Facebook showing four individuals of the jellyfish stranded in Cabo Frio (Rio de Janeiro); b) Photo posted on Facebook on 14/02/2020 showing someone pointing to the jellyfish in Florianópolis (Santa Catarina), the arrow indicates the jellyfish *Aurelia* sp. (white arrow) and *Chrysaora lactea* (black arrow), potential food items for *Drymonema*; c) Photo posted on Instagram on 04/04/2022 showing the jellyfish being eaten by a green turtle geolocated at Arraial do Cabo (Rio de Janeiro); and d) Video frame from Youtube posted on 11/12/2014 showing a scuba diver next to the jellyfish in Arraial do Cabo (Rio de Janeiro).

Results

We compiled 63 records of *Drymonema gorgo* from 1857 to 2022, concentrated between 22°S and 27°S, 57 from WWW, 5 from LIT, and 1 from PCO (Figure 1; Online Resource 1).

Drymonema gorgo was described in Brazil by Müller (1883) from three specimens collected in the 1860s in Florianópolis, State of Santa Catarina, Brazil (27° 35' 49" S 48° 32' 56" W; Figure 2). Then, two exemplars were reported from Ilhabela, São Paulo (23° 46′ 43″ S 45° 21′ 30″ W) in 1997 (Cornelius and Silveira 1997; Morandini et al. 2005). In the review of Medusozoa of Brazil published in 2002, records of *D. gorgo* were also mentioned in the State of Rio de Janeiro (Migotto et al. 2002). However, until now, we have not been able to access the material and detailed information about the Rio de Janeiro occurrences from the literature. Three specimens were also caught through deep gill fishing operations in Southeast/South Brazil between July 2008 and May 2011 (Schroeder et al. 2014; Rutkowski et al. 2018), but we also did not include this information in the LIT database because the geolocation and timeframes are not detailed.

In the present study, most occurrences were recorded in the State of Rio de Janeiro (total of 52 observations), especially in the Cabo Frio region: Cabo Frio (22º 52' 46" S, 42º 01' 07" W; 9 on map) with 19 observations, followed by Arraial do Cabo (22° 57′ 58″ S, 42° 1′ 44″ W; 8 on map) with 14 observations, and Armação dos Búzios (22° 44' 53" S, 41° 52' 53" W; 10 on map) with 13 observations (Figure 2 and 3). Most observations are based on a single animal, but there are four records in which more than one individual was observed (Figure 3).

The observations concentrated in the late summer, and March was the month with the highest number of records, totaling 25 observations (Figure 3). WWW data was retrieved from 2013 to 2022 from different platforms and localities, occurring every year except in 2016, 2018, and 2019 (Figure 4). The year 2022 had the highest number of observations, with a total of 22 observations. Followed by 2017 with 17 and 2021 with 9 observations.

Since social media platforms had an expressive contribution in the *D. gorgo* observations extracted from the WWW, representing about 95% of the total (Table 1), we obtained information about the social media penetration in Brazil from the website Statista (2022c) in order to visually compare the number of records with social media usage (Figure 4).

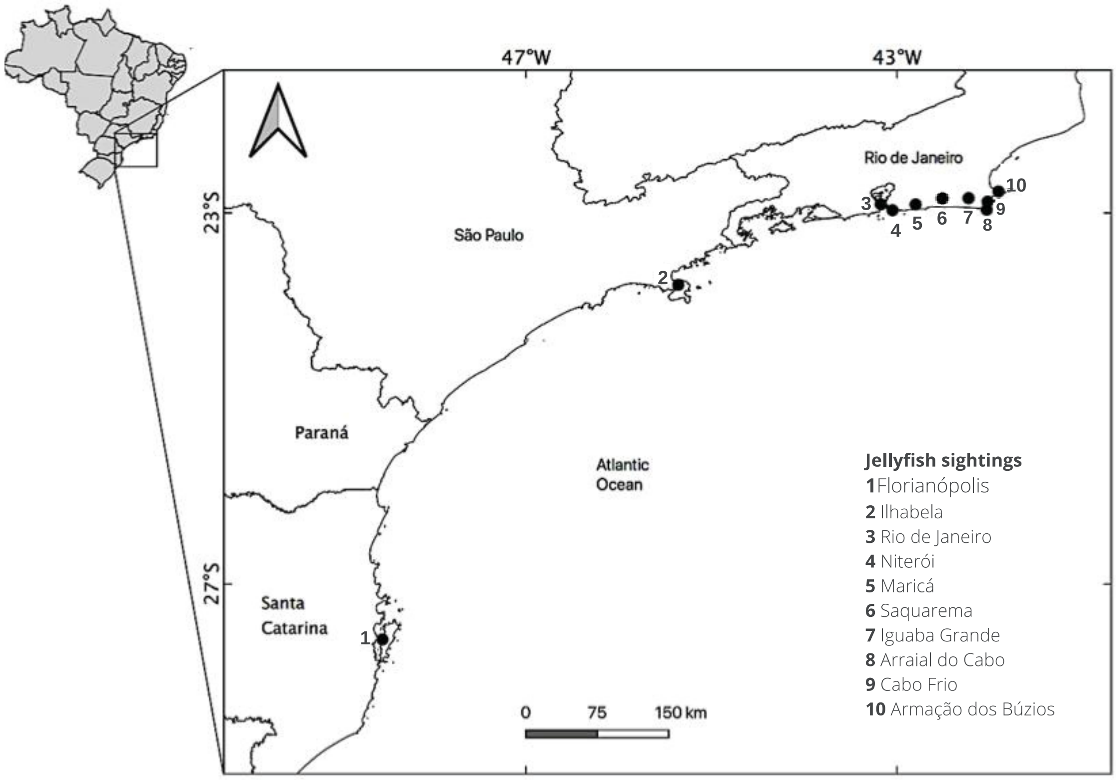


Figure 2. Map of all geographical locations (1-10) with observations of *Drymonema gorgo* compiled in this study for the Brazilian coast for the state of Santa Catarina (SC), São Paulo (SP), and Rio de Janeiro (RJ). From the literature, we obtained records in Florianópolis (SC) and Ilhabela (SP) (Müller 1883; Cornelius and Silveira 1997; Morandini et al. 2005).

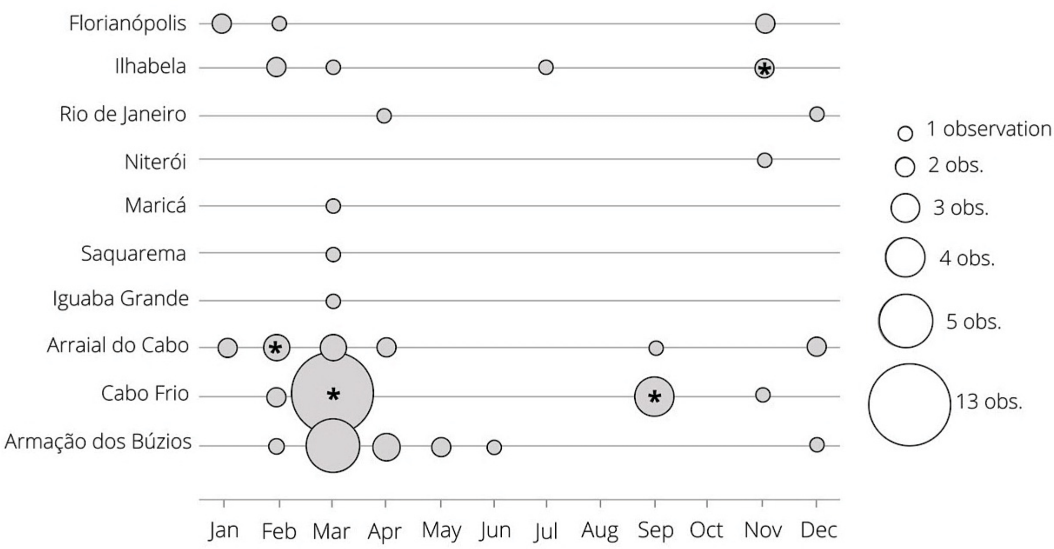


Figure 3. Monthly occurrence of *Drymonema gorgo* observations from 1957 to 2022 in the different geographic areas on the Brazilian coast. The accumulative number of observations is relative to the size of the bubble in the legend. Bubbles with an asterisk (*) indicate one observation record with more than one individual. From the literature, we obtained one record in Florianópolis in January and two in November and one in Ilhabela in February and July (Müller 1883; Cornelius and Silveira 1997; Morandini et al. 2005).

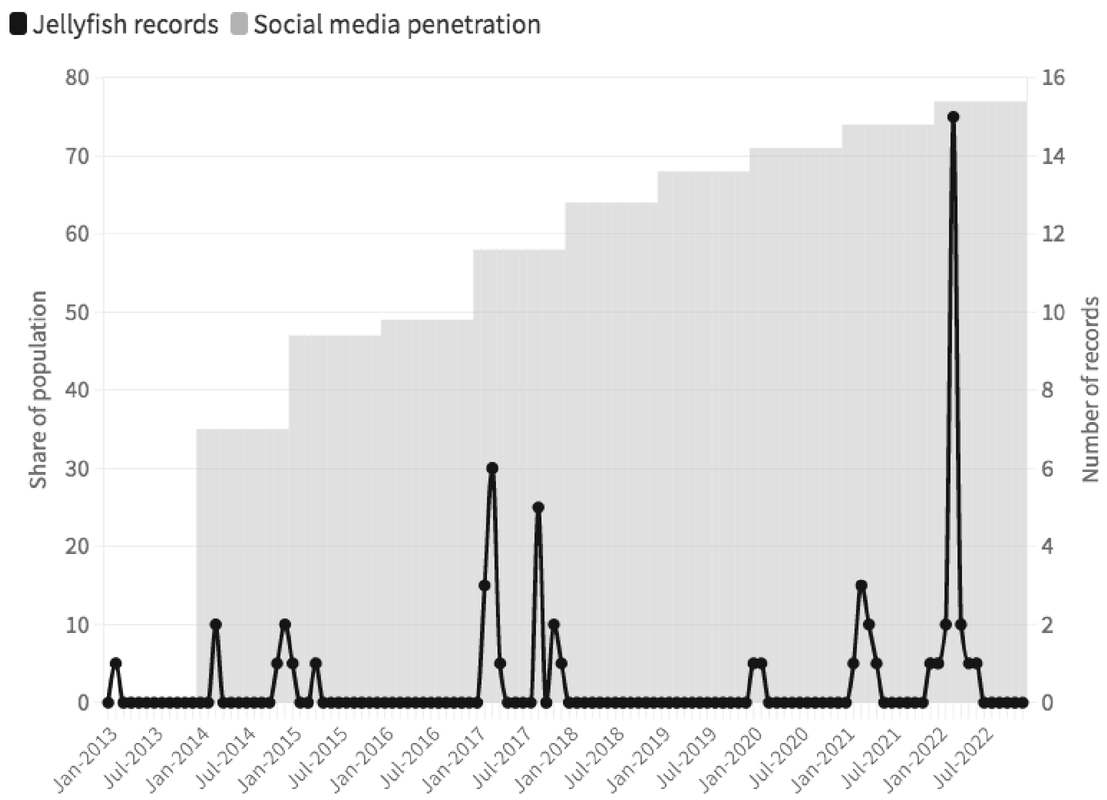


Figure 4. Monthly observation records from WWW of the jellyfish *Drymonema gorgo* between 22°S and 27°S in Brazilian waters from January 2013 to December 2022, and percentage of annual social media user penetration in Brazil from 2014 to 2022 (Source: Statista 2022c).

Table 1. Number of observations of *Drymonema gorgo* in Brazil from WWW platforms from January 2013 to December 2022. These data only include public content.

Platform	Observations
Facebook	22
Instagram	21
Youtube	8
News portals	3
iNaturalist	1
TikTok	1
Twitter	1
Total	**57**

Discussion

Data from WWW had a powerful role in obtaining information about *Drymonema gorgo*, totaling 57 observations on the Brazilian coast over the past ten years, representing more than 90% of total records of this species along the Brazilian coast. Based on the notable complement in information about its occurrence obtained here, we hypothesize that *D. gorgo* is probably not such rare as the near absence of previous records suggests. Previous researchers already argued that it was not possible to determine whether the absence of records of the large and conspicuous *D. gorgo* in Brazil is, in fact, because it is rare or just overlooked (Cornelius and Silveira 1997). Since then, academic attention towards Brazilian scyphomedusae increased considerably (see reviews in Haddad and Marques 2009; Schiariti et al. 2018; Nogueira and Brandini 2018) with only a few additional specimens of *D. gorgo* reported (Morandini et al. 2005; Schroeder et al. 2014; Rutkowski et al. 2018). The large size and associated low densities of this medusa species may pose sampling difficulties using traditional trawling methods and partly explain the scarcity of reports. The use of alternative methods such as visual surface counts and collection, scuba-diving, video profiles, and the citizen science used here, have been increasingly employed to gather data and monitor large and conspicuous jellyfish (Hamner et al. 1975; Graham et al. 2003; Bastian et al. 2011; Schaub et al. 2018; Nascimento et al. 2022), such as *Drymonema* (Öztürk et al. 2020).

The small sample size obtained here, along with the scarcity of information available about *Drymonema* biology and ecology (e.g., Bayha and Dawson 2010; Bayha et al. 2012), hamper the assessments of detailed trends in *D. gorgo* distribution. *Drymonema gorgo* was recorded all over the year in the present study, except in August and October, with the highest concentration in March. On the coast of Argentina, *D. gorgo* was also found over a wide temporal period (February, March, April, May, and August) (Schiariti et al. 2018).

The spatial distribution of recent observations in Brazil was similar to previous studies, with specimens being recorded in the states of Santa Catarina, São Paulo, and Rio de Janeiro (Oliveira et al. 2016). However, the great number of observations in the Cabo Frio region (more than 80% of total observations), may be related to the onshore intrusion of the nutrient-rich South Atlantic Central Water (SACW; $T < 20$ °C; $35 < S < 36$) (Emilsson 1961; Piola et al. 2018). The western boundary current transports this water mass in the continental slope of the South Brazilian Bight (SBB) (Emilsson 1961). In spring and summer, when the Cabo Frio region (23°S) is under intense and persistent easterly and northeasterly winds, intermittent coastal upwelling events of SACW have been observed (Miranda 1985; Franchito et al. 2008). Besides the Cabo Frio region, SACW coastal upwelling also occurs in Santa Catarina at 28°40′S also caused by persistent easterly-northeasterly winds and the narrow continental shelf (Campos et al. 2013; Brandini et al. 2018). The SACW plays a significant role in the fertilization of the SBB (Castro et al. 2006), allowing high phyto and zooplankton productivity (Brandini et al. 2014; Nogueira Júnior and Brandini 2018), and creating trophic conditions adequate for the occurrence of diverse species (e.g., Gadig et al. 2003; Pessoa et al. 2020), including gelatinous zooplankton (Nogueira Júnior et al. 2014). We have not recorded *D. gorgo* observations in latitudes lower than 22ºS and in the embayment between São Paulo and Santa Catarina (points 1 and 2 in the map), where there are no upwelling events close to the coast due to the wide shelves and gentle slopes (Brandini et al. 2018). However, the absence of records in this region may also be related to the spatial bias from the WWW observations. This region has a remarkable presence of large estuaries (Diegues and Rosman 1998) which can make it difficult to observe the specimens due to the water turbidity. Moreover, if *D. gorgo* indeed is associated with the SACW intrusions, it would be expected to occur in more offshore waters less accessible to most people.

Here, we observed *D. gorgo* both as predator and prey, highlighting its ecological importance in ecosystem functioning. One specimen of the moon jellyfish *Aurelia* sp. and one specimen of *Chrysaora lactea* were recorded near *D. gorgo* tentacles (Figure 1b), probably indicating predation. Besides the few reports of *Drymonema* preying on *Aurelia* spp., the predation of this species on others has been rarely studied. The genus *Drymonema* is unique among the Semaeostomeae in that adult jellyfish obligately eat the moon jellyfish *Aurelia* sp. (Larson 1987; Bayha and Dawson 2010; Bayha et al. 2012), with adults developing adaptations to soft prey as they grow (Larson 1987; Bayha and Dawson 2010). For example, the jellyfish *D. larsoni* and *D. dalmatinum* are voracious predators of *Aurelia* sp. (Williams et al. 2001; Bayha et al. 2012; Malej et al. 2014). In the Gulf of Mexico, for instance, predation by *D. larsoni* medusae could reduce moon jellyfish blooms, possibly alleviating predation pressure on lower trophic levels ecologically and economically important utilized by *Aurelia* sp., such as copepods and fish eggs/larvae (Larson 1987; Bayha et al. 2012). Isotopic analysis showed that approximately 85% of the *D. larsoni* diet in the northern Gulf of Mexico was *Aurelia* spp. (D'ambra et al. 2015), with the presence of *D. larsoni* apparently being related to the biomass of *Aurelia* spp. (Aleksa

2017). In addition, in the Adriatic and eastern Mediterranean Sea, it has been speculated that *D. dalmatinum* occurrence has been more frequent in the last decades due to the proliferation of their *Aurelia* prey (Malej et al. 2014). In fact, we observed many observation records of *Aurelia* sp. and *C. lactea* in the Cabo Frio region in the summer of 2022 on Instagram, where and when *D. gorgo* observations were concentrated in the present study.

It was also recorded a green turtle *Chelonia mydas* preying on *D. gorgo* (Figure 1c). Similarly, *D. larsoni* is the preferred prey item of the leatherback *Dermochelys coriacea* (Aleksa 2017). A diet containing *D. larsoni* provides the opportunity for jellyfish predators, like the leatherback, to possibly consume multiple species at one time if *Aurelia* spp. are captured in oral arms or digestive tissue of *Drymonema* spp. (Aleksa 2017). In the Gulf of Mexico, the location and density of jellyfish coincided with the movements and foraging of leatherback, suggesting the search for prey and sustained foraging efforts (Aleksa 2017).

Still, in the present study, it was possible to observe eight records of the medusae *D. gorgo* associated with fishes, especially the largest medusae. Such fish-jellyfish association is common and well-known (Nogueira Júnior et al. 2022), and school of fish swimming around *Drymonema*, especially in its oral arms, was already recorded (Larson 1987). Because several ecologically and economically important fish species live in association with jellyfish, the scyphomedusae *D. larsoni* and *Aurelia* sp. contributed on average ~90% to the assimilated diet from the early life stage of the fish *Chloroscombrus chrysurus*, calling the attention of jellyfish importance for fish diet and marine food web (D'Ambra et al. 2015).

It is impossible to ensure that the same individual was not accounted for more than once in some of the records obtained here. Exceptions may be the observations obtained on 06 and 08 December 2014 in Arraial do Cabo, and on 21 February 2017, 21 and 22 September 2017, and 08 March 2022 in Cabo Frio, which may be the same individual due to the spatiotemporal proximity of records. The spatiotemporal discontinuity of most observations and the occurrence of more than one individual in some records indicates that most observations here correspond to different specimens. Actually, in the periods with higher concentrations, in March and September 2017 and March 2022, it was common for social media users and news portals to mention sightings of 'many' individuals. In addition, although most observations were solitary individuals, four exemplars with different sizes were observed on 19 September 2017 in Cabo Frio (Figure 1a), two larger ones on 04 November 2017 in Ilhabela and on 28 February 2022 in Arraial do Cabo, and more three individuals with 3-5 kg on 07 March 2022 in Cabo Frio.

Besides the difficulties in identifying individuals, other confounding biases in our data surround the number of beach users (including residents and tourists) and the number of web and social media users. The number of beach users is directly related to the accessibility of the coastline and the summer/vacation season. In the same way, most WWW observations of *D. gorgo* were created in the last few years, with the highest number recorded in the year 2022 (Figure 4). The usage and access of the web and social media in Brazil may significantly influence these results. Big data statistics report a sudden increase in data/information created, captured, copied, and consumed worldwide in the last years, allied to increased social media user penetration. A staggering 64.2 zettabytes (10^{21}) were created on the web in 2020 since the pandemic restrictions (Statista 2022b). This is an impressive number, but it is projected that the volume could grow to about 100 zettabytes in 2022 and 180 in 2025. On the other hand, in 2020, during the COVID-19 crisis infection, only two observations were recorded. This year, many cities closed their beaches, making it difficult to observe marine fauna, which may have also influenced the collected data.

The social media data are usually posted nearly real-time (di Minin et al. 2015). In fact, in our investigations, 21 records of *D. gorgo* extracted from WWW were accompanied by the date provided by the observer. In most of them, the observation date was the same day or just a few days before the posting date. But it still is a possible error in the date of observation for those social media posts from which we only extracted this information by the posting date.

Another challenge we faced in our investigation of jellyfish records on social media was the limitation in the system processing. Since the hashtag #aguaviva (jellyfish) has huge data on Instagram (more than 150,000 posts), it was not possible to investigate posts before 2020, because the system did not load. In addition, in our attempts to load older results, the platform blocked our users several times. Before blocking, we received the message: “Are you a computer?”, with a challenge-response test to determine whether the user is human. We believe that this hashtag could provide even older records of jellyfish in Brazil.

In the present study, Facebook and Instagram mainly contributed to obtaining *D. gorgo* observations (Table 1). Both social media are amongst the most popular in the world, with more than 2.95 billion monthly active users on Facebook and more than 2 billion on Instagram in January 2023 (Statista 2023b), with great potential to provide marine biodiversity records (Sullivan et al. 2019; Cranswick et al. 2022). In a survey with respondents from different backgrounds and all continents, Facebook was rated as the most popular social media platform for posting nature-based content, followed by Instagram and YouTube (Di Minin et al. 2015).

While this methodological approach has been relatively more used on plants, mammals, fishes, and birds, its usage for invertebrates is still scarce (Jaric et al. 2020), which is particularly true for jellyfish. In this sense the present study sums up with a few previous ones, highlighting the usefulness of social media to obtain jellyfish observations (Kienberger and Pietro 2017; Rizgalla and Crocetta 2020; Nascimento et al. 2022). From Facebook, for example, it was possible to obtain the first record of the invasive *Phyllorhiza puncata* in Libya through an underwater image posted by a recreational fisherman (Rizgalla and Crocetta 2020).

The jellyfish observations in the present study were mainly associated with touristic activities, such as sea bathing, diving, and canoe trips (Figure 1d). SCUBA divers, for example, select destinations based on the water clarity, water temperature, and diversity of marine life, contributing to biodiversity observation (Uyarra et al. 2009). The jellyfish *D. gorgo* is large and beautiful, favoring professional and amateur photographers and videographers sharing images on the web. Its size draws a lot of attention from observers which makes people want to share this experience on social media. It was common to observe records with reports "I have never seen a jellyfish this size before". Further, besides *D. gorgo*, *Aurelia* spp., and *Chrysaora lactea* previously cited in the present study, we also observed many occurrences in Brazil for other large scyphomedusae on social media, such as *Lychnorhiza lucerna*, *Phyllorhiza punctata*, and *Stomolophus meleagris*.

Although the WWW data have limitations and potential biases which could make it difficult to infer distribution patterns and their relationship to oceanographic variables, the present study showed that data generated by citizens on the WWW might contribute to the monitoring of *D. gorgo*, and other large conspicuous medusae, helping to fill knowledge gaps and complementing information obtained from field samplings. With billions of users worldwide, the WWW data represent a low-cost and less time-consuming monitoring strategy than traditional methodologies, providing biodiversity observations challenging to obtain otherwise for rare species (Araujo et al. 2020; Mannocci et al. 2021; Cranswick et al. 2022). Here, we gathered novel and valuable information on the biological and ecological aspects of a little-known jellyfish. Apart from this, we highlighted the high potential of citizen science and social media to provide useful datasets on easily-identifiable and conspicuous species.

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Declarations

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Conflicts of interest

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

Ethical approval

The Human Research Ethics Committee of Federal University of Paraná (CEP/UFPR) manifests itself by the approval of Research Project number 4.751.477 on 02.06.2021, CAAE: 46505721.7.0000.0102. No animal testing was performed during this study.

Informed consent

A Free and Informed Consent Form (FICF) was presented to the collaborators before the interviews, as directed by the CEP/UFPR.

Supplementary material

Online Resource 1. Observations of *Drymonema gorgo* in Brazil, with geographical location, date of observation or posting, number of individuals, size, biological association with other animals, and data source. / = Information not available or not applicable.

Municipality, State	Locality	Date	N	Size	Type of observation	Association	Source
Florianópolis, SC	/	06/01/1857	1	20 cm diam.		/	Müller 1883
Florianópolis, SC	/	11/11/1860	1	50 cm diam.		/	Müller 1883
Florianópolis, SC	/	03/11/1861	1	30 cm diam.		/	Müller 1883
Florianópolis, SC	Ilha do Campeche	14/02/2020	1	/	From the surface	Jellyfish *Aurelia* sp. and *Chrysaora lactea*	https://www.youtube.com/watch?v=XvBkdvQMrKM&t=109s
Florianópolis, SC	Ilha do Campeche	01/01/2022	1	60 cm diam.	From the surface	Fishes	https://g1.globo.com/sc/santa-catarina/noticia/2022/01/02/video-medusa-gigante-rara-e-encontrada-na-ilha-do-campeche-em-florianopolis.ghtml
Ilhabela, SP	Praia do Sino	23/02/1997	1	40 cm diam.		/	Cornelius and Silveira 1997; Morandini et al. 2005
Ilhabela, SP	Praia do Portinho	05/07/1997	1	18 cm diam.		/	Cornelius and Silveira 1997; Morandini et al. 2005
Ilhabela, SP	/	08/02/2013	1	/		/	https://www.instagram.com/p/VfAhljHLBU/
Ilhabela, SP	Ilha de Búzios	04/11/2017	2	1 m diam.	From the surface	Fishes	https://www.facebook.com/matias.ilhabela/videos/1575068122514501
Ilhabela, SP	Praia Grande	09/11/2021	1	70 cm diam.	From the surface	Fishes	canoeing school Vento de Sul Va'a
Ilhabela, SP	Praia Grande	08/03/2022	1	/	Underwater/ Snorkelling	/	https://www.instagram.com/p/Ca3DOcsO-uH/

Rio de Janeiro, RJ	Barrinha	13/04/2015	1	/	Stranded/ Shallow waters	/	https://www.facebook.com/photo/?fbid=826032214137998&set=bc.AbopUbb7V7GCiDf7UtEVSbXEhw6ZUgBikfqXIOEox0Ago3xZAdEa88Lq-BBY6azoQmoiToT2NL6DWtWZT4IT-HksA6GjLaCep5ew2ofnrflrEFACb5jVWhuE7Bbetf6Oy2xP1Da5BRDdf1TBAYQzvzLBACcHGkrJO9aE0C5YxthYeQ&opaqueCursor=AbpkE4p
Rio de Janeiro, RJ	/	19/12/2017	1	/	Stranded	/	https://www.facebook.com/photo/?fbid=1932927146925022&set=p.1932927146925022&opaqueCursor=AbqGaMQp6h0kSnyq437oEwonwAYwewECr_rvi7ftYzRD1zAhZ9iXGVDV10ymIEu3K2mZXUPZiFCVgelZtCRIh1dGhpleaoK8jbHutg0UksoGKaV0gmLf6V1bxjfNsQTYE60ja7Osomxajluu_Y0Nfo7JTk5pfdba_FBtR
Niterói, RJ	Itaipu	09/11/2017	1	/	From the surface	/	https://www.facebook.com/photo/?fbid=2433716323520398&set=p.2433716323520398&opaqueCursor=AboCFW64vb4Wy1cLJvhFMxmN4kt9oFrUmAt6pUz_nLHRnkzysqOr6jV4i88isjwRB8Qa3sDUUNXyXndAWZpJkGgu9Ex8Am4Ddx9UJntlYfVJUYwoyI26NsOPH7MjA8C0vYMVbmaBpsxNdcJUCOEGLeVcO5SZFYJG5zUGicQ5oh2-jdCfj5d2gDdS3xrVx9zIyulujFD2Uncf53tkxnKitPnoqq7bmu2PI6V95uw14gGHgbLQY7_5fg8Kahtrq1nCx0a8-mFnocEkvu_rhG24nI0S0UcvmYVqiSV8Vg4Btkhb89ehOWGFXCjutCoxJqRMGzX1gwPZpb6Q-ZfUcgm5hB7fw-zn3SdiyuxyhWqWwEuBdHFy0KZR6IpMVwzUpit8mmuJpMidJeSkWOXsDTwobpCvE-YOHQ-

							fdHB_M4BKs7RztOO1LJiNIoqd4-Rwjm3H3fjn7UxAN_iHEawLMB7jj4GSr5dDQkFJUZtjVNypseYXag
Maricá, RJ	Gruta da Ponta Negra	02/03/2022	1	/	From the surface	Fishes	https://www.instagram.com/p/CanpDgLO2Lo/
Saquarema, RJ	/	01/03/2022	1	/	Stranded/ Shallow waters	/	https://www.instagram.com/p/CakdTw4OGzL/
Iguaba Grande, RJ	Praia do Forte de Cabo Frio	13/03/2017	1	/	Stranded/ Shallow waters	/	https://www.facebook.com/photo/?fbid=449723998700428&set=bc.Abo31CLIXIUAphG6v-2T5ASxhGpqb-
Arraial do Cabo, RJ	/	14/03/2014	1	/	Stranded/ Shallow waters	/	https://www.youtube.com/watch?v=FYchpYYjz-g
Arraial do Cabo, RJ	/	06/12/2014	1	/	Underwater/ Scuba-diving	Fishes	https://www.youtube.com/watch?v=kEpRKE2oEDc
Arraial do Cabo, RJ	Pontal Leste	08/12/2014	1	/	Underwater/ Scuba-diving	Fishes	https://www.facebook.com/100007038048664/videos/1489165361328051
Arraial do Cabo, RJ	/	24/01/2015	1	/	Underwater/ Snorkelling	Fishes	https://www.youtube.com/watch?v=44UA3FsvT1A&t=2s
Arraial do Cabo, RJ	Praia de Pontal	28/02/2017	1	/	Underwater	/	https://www.facebook.com/photo/?fbid=1212657882180904&set=bc.AbqbjXfB7rCGyhhk3CHIJb1qUU1niQX3_DzoCZkPT1cH3NX2rXtTQTcjktdFVJc2Q4cOrGzdSaU-DcEPqHfsqHcOlFJn0tBYpk9iRDepQxyQSfFEDPKxITC5TOEk5J3snnSbF8Ca0UR7K6J51oP501T0K_G-1NpqR7ivDU_IEs1Npw&opaqueCursor=Abo8GB
Arraial do Cabo, RJ	Praia Grande	17/09/2017	1	/	Stranded	/	https://www.facebook.com/photo/?fbid=844984535665226&set=p.844984535665226&opaque

							Cursor=AbrGlnUMRFtbLEM3OEcmnTlsEjdBuSeE8kxyoTiYjgEv0ASn6F6LzBJtEjYyAdSTIijoCMhb2vzXWpDDrGBnIb07pC7-EXy7eVRr4bhJ2xkbgrGCIPG_Q7dRYzVSja6UqiNIljsr6ovDNUrh463wbOza9WaNWFqZKXRWJRVtnxx7D9To8JAh5MKqSKHF0ymCZowOUw117eZyB-1uxo4zknY_sE1jcmvObBOZPQ_plsYI2YxZ5u7IA7j4yrPRzK2syTT7J4ptHZyHUEvpwaf7OuXgy2FbhUd8qKAVG6akzcL8DKgIPUnPVO1snzmR7CZ93gvq9uTuTCF_m8yiESamhTHqyUxme-HQ5MsLXqL4umUS6yPROe2B05qa6hgRCsN3IXqPVsB6QzP4bBPISrokegaB7nTzCjQdCmAsak4aNIVP7I33O_vvRBMnGI4J28TnPtX6vgakr3YyXjLI6C4n-qd6ZipvLpb8joV9DTfZmLA1fgoLfwa7e5v4bBbOMtJNC2o78ex6LaYqdAGR-Tgklqiu
Arraial do Cabo, RJ	/	27/01/2020	1	/	Underwater/ Scuba-diving	/	https://www.instagram.com/p/B7zub3dhUD1/
Arraial do Cabo, RJ	/	19/02/2021	1	/	Underwater/ Scuba-diving	/	https://www.instagram.com/p/CLerPLbhAbD/
Arraial do Cabo, RJ	Furnas das Mulheres	28/02/2022	2	/	From the surface	Jellyfish agreggation	https://www.youtube.com/watch?v=m503wWW84v8
Arraial do Cabo, RJ	Prainha	09/03/2022	1	/	Underwater/ Scuba-diving	/	https://www.youtube.com/shorts/IONIEDgovww
Arraial do Cabo, RJ	Enseada do Carneiro	12/03/2022	1	/	Underwater/ Scuba-diving	/	https://www.facebook.com/100001644172664/videos/1115197375967137/
Arraial do Cabo, RJ	/	04/04/2022	1	/	Underwater/ Scuba-diving	Green turtle	https://www.instagram.com/p/Cb7Qfx9O7Ri/

Arraial do Cabo, RJ	Ilha dos Porcos	22/04/2022	1	/	Underwater/ Scuba-diving	/	https://www.instagram.com/p/CcqB6j6rYrj/
Cabo Frio, RJ	Praia do Forte	24/03/2014	1	/	From the surface	/	https://twitter.com/turmadacachaa/status/448167746971238400
Cabo Frio, RJ	Canal do Itajuru	07/11/2014	1	50 cm diam.	From the surface	/	https://g1.globo.com/rj/regiao-dos-lagos/noticia/2014/11/agua-viva-gigante-e-rara-e-encontrada-em-ponto-turistico-de-cabo-frio-no-rj.html
Cabo Frio, RJ	Praia do Forte	21/02/2017	1	>10 kg	From the surface	/	https://www.facebook.com/jocelma.abreu.5/videos/1196517107131755
Cabo Frio, RJ	Ilha do Japonês	21/02/2017	1	/	Stranded/ Shallow waters	/	https://www.facebook.com/romulo.alves.142/videos/10206329718640521/
Cabo Frio, RJ	São Bento	03/03/2017	1	/	From the surface	/	https://www.facebook.com/photo/?fbid=1508428155864113&set=bc.AbqzSinTuTc41ymocpEhnASeseTyd9EqQyoyohBjEkUJqcCFWyjiaK4EHFB_Vug2Rk5L0Ls6LNSYS7eTqq3iCmUHsCbtJgyHFVI87SMhnUCT-pQ4zXlvvKD62m6gGuGfbvS8ihGxs9z_IUBEhBOlaDqaDTzriiIxsQ_vPyVWsuFJBA&opaqueCursor=Abq8eV
Cabo Frio, RJ	/	05/03/2017	1	/	From the surface	/	https://www.facebook.com/photo/?fbid=827095190777832&set=bc.AbqF0hX0ef2P-ODQY4wIKScx6Ewgiadby5V4aDrwL06OBpJ-ChkbtBDvIJKaQv79W3LDqY-fvtTmc_vgtDD6Kk5qGNOTUX6BQGeP-RUXb1PyipBflKm_MSM_SrKakjYKQWaU1Pw962ARjYTdSaDNec111JWr7obFKmA2bnrR9qjZkg&opaqueCursor=AbqZN1c
Cabo Frio, RJ	/	08/03/2017	1	/	From the surface	/	https://www.facebook.com/photo/?fbid=1436893016355477&set=p.1436893016355477&opaq

							ueCursor=AbqFjBEpdrHmIiJBDPPUtvCzfuorMbnrY12JjH-SqKTAeIeMbFmeYSGbYreJq6YEGd0eV5NPQ-ovHMSRLbclw_k9qP4FBm5TOx13gHpJvbA6OyxD_xLgEQ-MHmvUdZaNp9rAt-UqEjglqnp_o5WKy3TJjydoxrRpB4Fbre440jW9fx6kih9S2bU9cEvUB4Q0sKan3_Cc9CT20WRVgzLtWojqMuaPZiTugEaO6rlOxuhFHekyt5UZU4jEZEdDBGnALWwi6WDlOQiVwYxJiLwC9voySP3sPCMb-h7YcjLLQnYevUGlqXo270F8bEzrI9dC6JpnIfhFY_uBSMTw8vs7aVMMrCDmiVqjfkv-JJdi91Cy0vJ8ADy_BVbnWTcVKKdlUt_cwxuH5McuwMeeQ6kJyXtwNKtIrPGksqoam5zbKvAJ-xlI9sbFNK1AkTN_2tHidfnSlQ_By27rcRWlqt6Xj3Hk_iELD9y9ZwhE6CQL8bPZ1UVUdMLa3dP15P8sgPiw9oE
Cabo Frio, RJ	/	15/09/2017	1	/	Stranded	/	https://www.facebook.com/photo/?fbid=475806256118625&set=bc.AbpcUI8nW3YNwwsWNcUNlyk_SIVI6tR91F5mIaPZDaT3uoQTEfoa-T9s5SgW7sP01FnXr3iWkILxdB6vARSZnUnxsBC0fSJd1DJqTEXxlZx5h8ljZBEt_eSVR8IecoWdbmPznYC0AfsxYQV-EOYe-xZFduvvOngrDKMAwegDX7EixQ&opaqueCursor=Abrw7Bi
Cabo Frio, RJ	/	19/09/2017	4	/	Stranded	/	https://www.facebook.com/photo/?fbid=2077267769162023&set=p.2077267769162023&opaqueCursor=AboWI82CkOFaMSJFMCskN2hbe6ggYiIYG_rEvAsMBndybRolOFbjaFcBnWN_Ul

							N9R99GI2dsOdn1buG9CejQFToEJ9d_um30A88ZSz5Ov0h9s_e-wcaOGY2MUFWPGRnjpxqkr_uAsA_-AYbB3Tg--VGWDQXzBe_sbIgB6VbhoiflfdJVMdixNRxZbYsrYrgRbI1mPHW2FqTatfcCvYvzgNTvHbLO1rHWXPIKcSEs4cops-vbUQp4A6hsSGHHaxIaeLhDosedV1Hu-JNirCOfX-liwUzLhwb5UX176gfbRRSbpPlxR8PB-6qCgsRL4pN6KfhTaj4yGfFHmJMn4REPGUTclDOncWI9vwq8cVmCX1-vO0YYuvHAMbBeTf8u1Sc7bxVcp0W5g6dbgyeI9J1_CGgIAzpYZOL3FwqyiEGVnBSQvt1ntOSHsITpXm8rM48YsvTZTH6_P9DTiu2e67d7Mh4anSLEpcPFj6-VbM7tfXUvXg
Cabo Frio, RJ	Praia do Forte	22/09/2017	1	1 m diam	Stranded/ Shallow waters	Fishes	https://www.facebook.com/cuscuz.gelado/videos/271150813396072/
Cabo Frio, RJ	/	23/09/2017	1	/	Stranded/ Shallow waters	/	https://www.facebook.com/photo/?fbid=1427634483980332&set=bc.AbrAzzM0UVoh5l7fcnxUsC9PIt-R1cvwpdgPpVgH0jLqn7UNIy5zx6lFiA4TpNWwM6I-L54WEAjGjDt3fVkl-dJZNjaR55ur5ppvInXVDN-xA7XONKBRo4RBTO5Vkax91ZiJdtCspGlacf2v0yP9ZMSiwlCi9PK1s9HB28Gg-fIADA&opaqueCursor=AbrRX9
Cabo Frio, RJ	Praia do Peró	05/03/2021	1	/	Stranded/ Shallow waters	/	https://radio93.com.br/noticias/rj/aguas-vivas-gigantes-e-raras-sao-encontradas-na-praia-do-pero-em-cabo-frio/

Cabo Frio, RJ	Praia das Conchas	05/03/2022	1	/	Stranded/ Sand	/	https://www.facebook.com/watch/?ref=search&v=1108391883277784&external_log_id=49f2f91e-fe49-4bab-8da5-f2c61a041930&q=%C3%A1gua%20viva%20gigante
Cabo Frio, RJ	Canal do Itajuru	07/03/2022	3	3-5 kg	From the surface	/	https://www.instagram.com/p/Ca0uKCXg-xS/?utm_source=ig_embed&]]utm_campaign=embed_video_watch_again
Cabo Frio, RJ	/	08/03/2022	1	/	Stranded	/	https://www.facebook.com/photo?fbid=2124235851063353&set=a.773218599498425
Cabo Frio, RJ	Ilha do Japonês	09/03/2022	1	10 kg	From the surface	/	https://www.tiktok.com/@rlagosnoticias/video/7073133701651057925?is_copy_url=1&is_from_webapp=v1&refer=embed&referer_url=https%3A%2F%2Frlagosnoticias.com.br%2F&referer_video_id=7073133701651057925
Cabo Frio, RJ	/	10/03/2022	1	50 cm diam.	Stranded/ Shallow waters	/	https://www.instagram.com/p/Ca7GUYULLoi/
Cabo Frio, RJ	Ilha do Japonês	12/03/2022	1	10 kg	Stranded/ Shallow waters	/	https://www.instagram.com/p/CbNe8j6Lnwu/
Cabo Frio, RJ	Praia do Peró	15/03/2022	1	10 kg	Stranded/ Shallow waters	/	https://www.facebook.com/photo/?fbid=336002868567475&set=p.336002868567475&opaqueCursor=AbpGGOu_wbYeINI_6HjNTIb4LuGae9
Cabo Frio, RJ	Praia do Peró	20/03/2022	1	50 cm diam.	Stranded	/	https://www.instagram.com/p/CbVzWsolvjn/
Armação dos Búzios, RJ	Praia de João Fernandes	09/03/2017	1	/	Stranded	/	https://www.facebook.com/watch/?ref=search&v=1265280550258138&external_log_id=64118bc5-5ff6-4893-a505-

							db78a5a9a2e0&q=%C3%A1gua%20viva%20gigante
Armação dos Búzios, RJ	Praia dos Ossos	18/03/2017	1	/	From the surface	/	https://www.inaturalist.org/observations/12327386
Armação dos Búzios, RJ	Praia de João Fernandes	17/04/2017	1	/	Underwater/ Scuba-diving	/	https://www.instagram.com/p/BS_ZRcMhKOk/
Armação dos Búzios, RJ	/	06/03/2021	1	/	Underwater/ Snorkelling	/	https://www.instagram.com/p/CMFTRq_nu-P/
Armação dos Búzios, RJ	Praia de João Fernandes	22/03/2021	1	/	Underwater/ Scuba-diving	/	https://www.instagram.com/p/CMvd_fqF30a/
Armação dos Búzios, RJ	/	13/04/2021	1	/	Underwater/ Scuba-diving	/	https://www.instagram.com/p/CNoVPbYhCdG/
Armação dos Búzios, RJ	Praia de João Fernandes	17/04/2021	1	/	Underwater/ Scuba-diving	/	https://www.instagram.com/p/CNxJTKyraue/
Armação dos Búzios, RJ	Praia da Ferradurinha	12/05/2021	1	/	From the surface	/	https://www.instagram.com/p/COx1UlxBJ2F/
Armação dos Búzios, RJ	Praia dos Ossos	06/12/2021	1	/	Shallow waters	/	https://www.instagram.com/p/CXJY-UdLf9S/
Armação dos Búzios, RJ	/	25/02/2022	1	/	From the surface	/	https://www.youtube.com/watch?v=LDfDNdcMcoE
Armação dos Búzios, RJ	Praia do Geribá	02/03/2022	1	/	Stranded/ Shallow waters	/	https://www.instagram.com/p/CanexZbAMmx/?hl=pt-br
Armação dos Búzios, RJ	Praia do Geribá	30/05/2022	1	/	Stranded/ Shallow waters	/	https://www.youtube.com/shorts/NEnOL-edBZs
Armação dos Búzios, RJ	Ilha do Caboclo	04/06/2022	1	/	Underwater/ Scuba-diving	/	https://www.instagram.com/p/CeYrofQL9un/?hl=pt-br

CAPÍTULO IV

Social media in service of marine ecology: new observations of the ghost crab *Ocypode quadrata* (Fabricius, 1787) scavenging on Portuguese man-of-war *Physalia physalis* (Linnaeus, 1758)

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Abstract

Gelatinous animals have been historically viewed as trophic dead-ends. However, there are increasing data showing these organisms being consumed by diverse predators and demonstrating they play an important role in ecosystem functioning. Here we document the *Ocypode quadrata* (Fabricius, 1787) scavenging on stranded *Physalia physalis* (Linnaeus, 1758) at Sergipe and Bahia, tropical Brazil (11° and 14° Lat. S), based on Instagram® posts. These findings highlight the potential of social media to complement the information provided by traditional academic sources. We also suggest that this predatory interaction is probably more common than reported in the literature, perhaps due to methodological constraints of stomach content analyses, which may overlook the consumption of gelatinous animals by ghost crabs.

Keywords Predation, Jellyfish, Ocypodid crab, South Atlantic, Citizen Science, iEcology

Introduction

Jellyfish are a large biomass component of marine ecosystems (Richardson et al. 2009). However, they have been considered uncommon in the diet of most marine predators. These gelatinous animals have been historically viewed as trophic dead-ends (Brodeur et al. 2011; Sommer 2002), regarded as an unlikely primary prey source because of their high water content and low energy density (Doyle et al. 2007). On the other hand, there is growing evidence that many larger animals consume these gelatinous animals (e.g. Houghton et al. 2007; Lamb et al. 2017; Thiebot and McInnes 2020). Cnidarians, ctenophores, fishes, and turtles preying on gelatinous organisms is already well documented, but data is scarcer regarding predation by a wide range of other carnivores such as mollusks, arthropods, reptiles and birds (Arai 2005; Ates 2017; Thiebot and McInnes 2020).

Far from being trophic dead ends, gelatinous organisms play diverse roles in ecosystem functioning (Doyle et al. 2014). For example, jellyfish are preyed on by hundreds of different animals and are important predators in pelagic marine systems (Doyle et al. 2014; Ates 2017). Therefore, recognizing the importance and interaction of jellyfish in food webs contributes to the development and interpretation of trophic models. Here, we document the ghost crab (*Ocypode quadrata*) scavenging on stranded Portuguese man-of-war (*Physalia physalis*) at Sergipe and Bahia, tropical Brazil (11° and 14° Lat. S), based on Instagram® posts.

Methods

During an ongoing investigation that collects and analyzes Instagram® posts containing photos and videos of jellyfish along the Brazilian coast, images showing the ghost crab *Ocypode quadrata* scavenging on the Portuguese man-of-war *Physalia physalis* were found (Figure 1; see Acknowledgments). The search for public posts tagged by users with hashtags of the Portuguese man-of-war common names in the Portuguese language (#caravela and #caravelaportuguesa) were carried out for five months (Oct 2020 – Mar 2021).

Results and discussion

On November 30th 2020, a video was posted online showing the ghost crab *O. quadrata* feeding on stranded Portuguese man-of-war *P. physalis* and dragging it to a burrow at Prainha in Itacaré, Bahia (14°16’40”S, 38°59’49”W) (Figure 1; Online Resource 1). According to the videomaker, this event occurred two days earlier, on 28th November 2020 at 14:30. On December 1st 2020, a photo showing the same behavior and geolocated at Mosqueiro in Aracaju, Sergipe (11°07’0.1”S, 37°09’W) was posted. According to the photographer, the picture was taken at the same day of the posting at 05:30. Both authors said that hundreds of *P. physalis* were stranded in the moment of the recording. On February 28th 2021 at 16:14, another video geolocated at Praia do Forte, Bahia (12°34’35.87”S, 38°0’24.7”W) showing this interaction was posted.

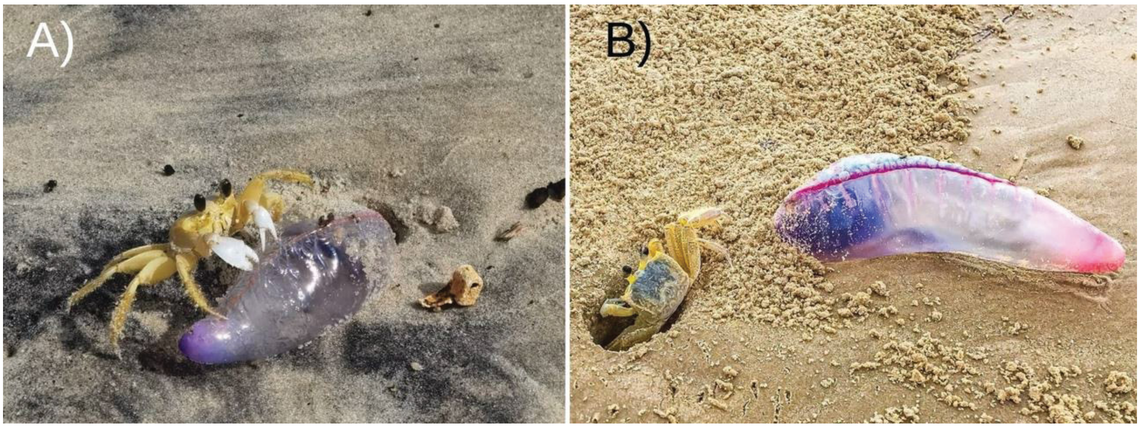

Figure 1. The ghost crab *Ocypode quadrata* (Fabricius, 1787) scavenging on stranded Portuguese man-of-war *Physalia physalis* (Linnaeus, 1758) at A) Prainha in Itacaré, Bahia (14°16’40”S, 38°59’49”W) on 28th November 2020, and B) Mosqueiro in Aracaju, Sergipe (11°07’0.1”S, 37°09’W) on December 1st 2020.

To the best of our knowledge, these Brazilian records are the first of Portuguese man-of-war as a food item for ghost crabs in the South Atlantic, highlighting the potential of social media to complement the information contained in traditional academic sources. After a thorough bibliographic search, we found only three previous records, all in other regions, reporting *Ocypode* spp. scavenging on *P. physalis*: in the Gulf of Mexico (Phillips et al. 1969) and on the east coast of South Africa (McLachlan 1980; Jackson et al. 1991), apart from an induced interaction in a manipulated experiment (Harris et al. 2019).

Ghost crabs are generalists and feed on both live and dead material, being commonly reported to be efficient, frequent, and common scavengers of animal carcasses on sandy beaches and dunes worldwide (Lucrezi and Schlacher 2014). The western Atlantic ghost crab (*Ocypode quadrata*) is known to have a broad feeding spectrum, with insects, crustaceans, and bivalves representing its main food components (Wolcott 1978; Branco et al. 2010), and marine carrion resources contributing only a small percentage to its diet, being commonly interpreted as a supplementary diet (Wolcott 1978; Tewfik et al. 2016). However, in the present study, in just five months (Oct 2020 – Mar 2021) of hashtag-based search on Instagram® posts focusing on gelatinous animals sightings along the Brazilian coast, we observed three records of *O. quadrata* scavenging on *P. physalis*. These records, and the observation that many other ghost crabs were feeding on Portuguese man-of-war at the first date in Prainha, Bahia, indicate that this interaction is common, as suggested in earlier findings (Phillips et al. 1969).

Both animals are globally distributed, inhabiting preferably tropical and subtropical regions (Sakai and Turkay 2013; Mapstone 2017). Portuguese man-of-war blooms are frequent, resulting in massive beach stranding in many localities worldwide (Fenner 1997; Graham 2001), including Brazil (Ferreira-Bastos et al. 2017). The rapid response of *Ocypode* spp. to irregular deposition of carrion emphasizes that carrion is a pivotal component of beach food webs (Schlacher et al. 2013). Thus, stranded *P. physalis* is a potential prey for ghost crabs whenever available, although scarcity of records would suggest otherwise. This discrepancy may be partially associated with methodological constraints.

Studies that evaluate the feeding habits of ghost crabs traditionally analyze their stomach contents after freezing and/or ethanol preservation (e.g. Hughes et al. 1996; Branco et al. 2010; Lim et al. 2016; Gomes et al. 2019). This approach is inadequate to properly evaluate predation on gelatinous organisms (Arai 2005). Due to their fragility, gelatinous tissues break down much faster than other preys such as fish and crustaceans. Therefore, these gelatinous tissues are likely to be partially or totally degraded in the analyzed stomach contents and are hard or impossible to be properly recognized (Thiebot and McInnes 2020). Moreover, the classification of the items found in the stomach of ghost crabs is quite tricky because of the high degree of maceration of the food caused by its strong gastric mill, with a high frequency of non-identified items (Gomes et al. 2019).

Predation on Portuguese man-of-war by ocypodid crabs was only recorded by in situ observations of the species being dragged right up to the burrow entrance by *O. quadrata* (Phillips et al. 1969); of the remains of *P. physalis* which have been found pulled deep into *O. ryderi* burrows (McLachlan 1980); or noted in the claws of *O. madagascariensis* at several occasions (Jackson et al. 1991), also evidencing that stomach content analysis is not the adequate technique to detect jellyfish consumption. Although Portuguese man-of-war may be an efficient food resource for opportunist scavengers such as ghost crabs, representing a way of energy transfer from pelagic carbon to sandy shores, they may be irregularly available to the crabs after stranding events. This may be the reason that standard methods of diet analysis did not detect their consumption.

Besides ghost crabs, other crustaceans have been observed eating stranded Portuguese man-of-war, as the isopods *Scyphax ornatus* Dana, 1853 (Quilter 1987). Since the technique of stomach content analysis has systematically overlooked the consumption of gelatinous animals, stable isotopes analysis (e.g., Cardona et al. 2012), DNA sequencing (e.g., Lamb et al. 2017), and direct observations of prey capture (e.g., Milisenda et al. 2014) are some examples of techniques that have been used to identify jellyvorous specialists and opportunists.

Based on stomach content and stable isotope analyses, the *O. convexa* diet in Australia was typically dominated by brown algae, complemented by seagrass, insects and amphipods, and 4% of unidentified organisms (Rae et al. 2019). However, feeding assays also revealed that this ghost crab had a clear preference for fish and invertebrate carcasses when choices were offered, indicating a proclivity for the more nutritionally valuable animal flesh when available (Rae et al. 2019). The contrast between the results from stomach contents and feeding assays suggests that ghost crab feeding is largely opportunistic and *O. convexa* is likely to respond rapidly to both live animal prey and carrion inputs (Rae et al. 2019).

Invasive approaches to assess animal diets such as stomach contents and stable isotope analyses are better methodologies to quantify diet components and make it possible to compare diet between species or to provide results to build trophic web models (Silveira et al. 2020). On the other hand, noninvasive approaches such as direct observations may report events that may be difficult to capture otherwise, also providing information on animal behaviors during feeding activities, offering a welcome complement of information (Dylewski et al. 2017), but that is biased and not always effective to determine diets, feeding strategies and behaviors (Silveira et al. 2020).

Similar to many other aspects in science, most of our knowledge initially comes from simple observations of the world around us (see early examples of predation on gelatinous organisms ashore observed since 1802 and reported in Ates 1991). iEcology is an emerging research approach focused on collecting, collating, and exploring data generated online by human society, either passively or unintentionally (e.g., Internet search activity, social media interactions, and uploaded data and media) (Jarić et al. 2020), a process also referred to as passive crowdsourcing (Ghermandi and Sinclar 2019) or passive citizen science (Edwards et al. 2021).

Social media have become platforms for many biologists and wildlife enthusiasts to share images and other information. The engagement of sharing biological records in social media seems to be particularly true for conspicuous, high-detectably, large-sized, and popular species (Roberge et al. 2014), such as those analyzed in the present study. Taking advantage of these features, skilled and less-skilled people may meaningfully contribute to scientific research and biological recording (Ghermandi and Sinclar 2019), helping to understand ecological relations in marine environments and contribute to citizen science practices as shown here in this study.

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We want to thank Marion Valadier (Itacaré, Bahia) and André Dantas (Aracaju, Sergipe), media authors of the field observations, for posting the original images online and kindly providing permission to use images and information in a publication to illustrate the findings. We are also grateful to the three anonymous reviewers for their constructive comments on the manuscript.

Declarations

Funding

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Conflicts of interest

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

Ethical approval

The Human Research Ethics Committee of Federal University of Paraná (CEP/UFPR) manifests itself by the approval of Research Project number 4.751.477 on 02.06.2021, CAAE: 46505721.7.0000.0102. No animal testing was performed during this study.

Informed consent

A Free and Informed Consent Form (FICF) was presented to the collaborators before the interviews, as directed by the CEP/UFPR.

Data availability

We compiled data for this study through the inspection of publicly available images on Instagram®: Prainha in Itacaré, Bahia [https://www.instagram.com/p/CINquEhAm8t/], Mosqueiro in Aracaju, Sergipe [https://www.instagram.com/p/CIQAmggh8Re/], and Praia do Forte, Bahia [https://www.instagram.com/p/CL2VGk9F95k/].

Supplementary material

Online Resource 1 Video showing the ghost crab *Ocypode quadrata* (Fabricius, 1787) scavenging on stranded Portuguese man-of-war *Physalia physalis* (Linnaeus, 1758) at Prainha in Itacaré, Bahia, Brazil (14°16’40”S, 38°59’49”W), on 28th November 2022.

CAPÍTULO V

Instagram as alternative data source for the monitoring of #portuguesemanofwar *Physalia physalis* (Linnaeus, 1758)

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Abstract

The beauty and morphological characteristics of Portuguese man-of-war such as translucent colors and floating structure favor the generation of spontaneous posts on popular social media. The usefulness of social media (Instagram) as a source of data for obtaining observations of the Portuguese man-of-war in Brazil by the performance of a method to collect and store these observations combined with multiple data sources has been evaluated. Records (N=1,458) gathered over a 40-year period (1982-2022) were used to assess the distribution and health risks related to Portuguese man-of-war along the Brazilian coast. Social media data contributed to almost 60% of the total data, mainly recorded since 2018. Information about abundance, pneumatophore size; interaction with other animals; human-jellyfish risky interactions, and accidents were obtained. The effectiveness of the method, practical and theoretical advantages, limitations, and challenges of using data originating from social media for research and management purposes are discussed, as well as future directions. This pioneering approach was reliable enough to obtain large-scale, baseline information on Portuguese man-of-war in Brazil, also contributing to real-time monitoring and emerging as a promising and inexpensive alternative in the study of jellyfish and in the development of management priorities, particularly in tourist destinations scarcely investigated.

Keywords Jellyfish, Distribution, Brazil, Social media, Crowdsourcing

Introduction

Jellyfish stings are among the most common envenomation encountered by humans in marine ecosystems (Lee et al. 1998). The stings are caused by specialized organelles present in the jellyfish tentacles called nematocysts (Pantin 1942). Nematocysts consist of a capsule and an eversible, helically-folded tubule immersed in venom (Mariscal 1974), which discharge to penetrate tissue and deliver venom (Pantin 1942; Yanagihara et al. 2002). When tubules are long enough, nematocysts can cause systemic effects, such as cardiovascular, respiratory, neurological, gastrointestinal, renal, and hematological/immunological (Cegolon et al. 2013). This is the case of the colonial jellyfish Portuguese man-of-war (*Physalia physalis* (Linnaeus 1758) Cnidaria: Hydrozoa: Siphonophorae) which has long tubules and powerful toxins (Yanagihara et al. 2002), being responsible for the most common and severe stings worldwide, also occasionally causing deaths (Burnett and Gable 1989; Cunha and Dinis-Oliveira 2022). The venom of the Portuguese man-of-war is as toxic as the snake *Naja* spp. venom; the stings from their nematocysts are powerful enough to penetrate tough surgical gloves and wet suits and can remain active even when air-dried (Pierce 2006; Haddad Júnior et al. 2013).

The Portuguese man-of-war is classified as a dangerous aquatic organism for human health by the World Health Organization in the “Guidelines for safe recreational water environments” (WHO 2003), causing negative impacts on public health, “sun, sea, and sand tourism”, and other human activities in the coastal regions worldwide (Burnett 2001; Ferrer et al. 2015; Mitchell et al. 2021). As growing coastal societies and projected high population densities predict a larger demand for marine ecosystem services in the future, jellyfish may affect the fulfillment of such needs (Lee et al. 2023).

The sting events caused by jellyfish are usually associated with wind conditions, local currents, and the consequent transport of these animals toward the coast (Ferrer and Pastor 2017; Silva 2018; Macías et al. 2021). Pleustonic hydrozoans, such as Portuguese man-of-war, usually occupy the first layers of the water column and experience highly variable and extreme conditions, both daily and seasonally, due to the constant disturbances acting on the sea surface (Zaitsev 1997; Marshall and Burchardt 2005).

There is an urgent need to provide science-based strategies to mitigate the negative impacts of Portuguese man-of-war outbreaks and to manage the potential benefits of ecosystem services (Graham et al. 2014). However, there is a historical lack of knowledge about the ecology of Portuguese man-of-war. Despite the impacts that Portuguese man-of-war colonies cause on the shoreline, it is challenging to study its distribution, due to its wide-ranging distribution and pleustonic habits (Headlam et al. 2020). In fact, for the Atlantic Ocean, for example, it is still necessary to increase the spatiotemporal studies of this species in different zones, with a notable scarcity of data (Torres-Conde et al. 2021). In Brazil, information about the distribution of Portuguese man-of-war was obtained from a few studies conducted locally through systematic regular beach surveys (Cristiano 2011; Luana 2017; Silva 2018; Cavalcante et al. 2020; Francisco 2022), and accidents surveys (Haddad Júnior et al. 2002, 2013; Neves et al. 2007; Ferreira-Bastos et al. 2017; Luana 2017; Calazans et al. 2018; Aquino et al. 2019; Silva 2019).

The Portuguese man-of-war is one of the species responsible for the most severe accidents in Brazil (Haddad Júnior et al. 2007, 2010; Haddad Júnior 2018). But the absence of data on a large spatial and temporal scale makes it difficult to determine the real problem of Portuguese man-of-war stings and to plan preventive actions (Haddad Júnior et al. 2002; Ferreira-Bastos et al. 2017). In fact, the wrong designation of beach bathing by authorities may actually contribute to accident occurrences, such as when a beach is marked as suitable for swimming, but is infested with jellyfish causing several accidents (Cavalcante et al. 2020). In official reports provided by the government, firemen groups, and health units, envenomation accidents caused by Portuguese man-of-war in Brazil are many times included as accidents involving venomous animals or jellyfish in general (Reckziegel et al. 2015; Ministério da Saúde 2023). Moreover, there is underreporting of injuries caused by jellyfish in Brazil, with a mean recorded of only about 80 persons per year (Reckziegel et al. 2015). These knowledge limitations about Portuguese man-of-war in Brazil highlight the need for continuous monitoring in the country.

On the other hand, the easy identification and remarkably conspicuous appearance (vividly colored) make this species well-known to the general public, and its sightings and outbreaks are commonly reported on popular media platforms. The beauty and morphological characteristics of Portuguese man-of-war such as translucent colors and floating “balloon” favor the generation of spontaneous posts on popular social media, for example. Besides its conspicuous appearance, the painful stings of jellyfish such as Portuguese man-of-war may also be an incentive for spontaneous recording and sharing of observations on social media. In fact, the “fear factor” was previously responsible to obtain social media records of another venomous species, the baboon spider (Campbell and Engelbrecht 2017). In a preliminary investigation, we observed that the data from social media can provide spatially-explicit information regarding in-situ observations of Portuguese man-of-war in Brazil.

Social media platforms are intrinsically linked with tourism, being an important tool for travelers willing to share their travel, and favoring nature-based postings in coastal environments (Lin et al. 2023). Moreover, emergencies and urgent natural phenomena have also great potential for providing spatiotemporal data and promoting online engagement, with similar distribution patterns between social media data and the phenomena of interest (Vivacqua and Borges 2012). This is especially true for ecological phenomena with a specific time and location (Hart et al. 2018), as is often the coastal hazard of “jellyfish season” in many parts of the world. In fact, it was already noted that when a beach is invaded by jellyfish, many people share the information on social media, supporting the species monitoring (Laudy et al. 2017, 2020).

Although the investigations are still incipient, previous studies already provided valuable and promising information on jellyfish occurrences and distribution extracted from spontaneous posts on social media platforms (Jovanovic and Vukelic 2015; Chamberlain 2018; Laudy et al. 2020; Martin-Abadal et al. 2020; Rizgalla and Crocetta 2020; Nascimento et al. 2022). Citizen contributions in science are already a paradigm in the study of jellyfish, and these data already helped to obtain valuable information to fill gaps in knowledge about Portuguese man-of-war occurrences and address conservation and management issues (e.g., Pikesley et al. 2014; Canepa et al. 2020; Headlam et al. 2020; Tiralongo et al. 2022). Here, we aim to evaluate the usefulness of spontaneous observations shared on social media as a source of data for obtaining Portuguese man-of-war occurrences in Brazil.

We hypothesized that since social media images involve human observation, this information can be applied as a proxy for the distribution of health risks related to Portuguese man-of-war. To test the study hypothesis and achieve our objective, first, we performed a systematic methodology to collect and store Portuguese man-of-war observations from social media. Second, we examine what other aspects of conservation and management can be informed through social media posts containing Portuguese man-of-war observations. Third, we built a baseline with data available on social media (SM), along with other data extracted from the web: citizen science app (CS) and online news (ON); and data from literature review (LIT), and personal observations and communications (POC). Finally, we analyzed the spatiotemporal distribution of Portuguese man-of-war in order to evaluate periods and regions with health risks for beachgoers along the Brazilian coast. If data spontaneously generated through social media can improve Portuguese man-of-war monitoring in Brazil, it may prove to be a valuable tool for research, conservation, and public safety organizations worldwide.

Materials and methods

Study area

The study area comprises the entire Brazilian coast with about 9.200 km of coastline bordering the South Atlantic Ocean (Figure 1). The South Atlantic atmospheric circulation is dominated by anticyclonic flow around the subtropical gyre, which is strongly influenced by interoceanic connections. Three main current systems influence the Brazilian coast: the Northern Brazil Current (NBC), the Brazil Current (BC), and the Malvinas Current (MC) (Silveira et al. 2000). The NBC and BC originate by the bifurcation of the westward trans-Atlantic South Equatorial Current, at about 10°S. The NBC transports warm subtropical waters northward along the Brazilian coast, across the Equatorial region, and into the Northern Hemisphere. The BC carries salty and warmer waters southward along the Brazilian coast and down to about 38°S, where it converges with the Malvinas

Current. The MC originates from the Circumpolar Current and carries cold waters northward through the continental shelf of Argentina and Uruguay.

The Brazilian coastline has some peculiarities such as metropolitan areas with high population density, and others with low density, artisanal fishermen, and indigenous communities (Ministério do Meio Ambiente 2008). More than 60% of the Brazilian population lives in coastal areas, with more than 38 million people living in the coastal capitals. The country has a great coastal and marine economy; and generated US$ 286 billion (19%) in the Gross Domestic Product (GDP; i.e. measures the monetary value of final goods and services) in 2015 (Carvalho and Moraes 2021). The economy of the Brazilian coast is dominated by the service sector, mainly tourism (Carvalho and Moraes 2021).

The vast coast of Brazil guarantees a high diversity of landscape, which starts from the equatorial zones extending through semi-arid, tropical, and subtropical segments. In general, there is increasing energy of incident waves from north to south, and a reverse trend occurring in tides along the Brazilian coast. In the present study, we followed the biophysical and socioeconomic macroscale compartmentalization of the Brazilian coast proposed in the Coastal Zone Macrodiagnostic (Silveira 1964; Diegues and Rosman 1998; Muehe and Nicolodi 2006).

The North Coast goes from the state of Amapá to the Golfão Maranhense (3°49’N–2°46’S), with three macro-compartments: Amapá (AP), Golfão Maranhense (AP/PA), and Pará-Maranhão (PA/MA) (Silveira 1964; Diegues and Rosman 1998). This region is marked by sedimentary deposits, flat islands, finger-like reentrances, and a succession of small estuaries and mangroves (Silveira 1964; Diegues and Rosman 1998). The great tide amplitude (>4 m) generates strong currents of ebb and flow, which puts a lot of material in suspension, giving the water an appearance of great turbidity. Moreover, the massive water and sediment discharge from the large rivers Rio Amazonas and Tocantins interacts with the high annual precipitation, wave action, and especially the tides in the region (Pereira et al. 2014). Extensive and persistent easterly trade winds are the leading source of most of the northern Brazilian wave energy (Rodríguez et al. 2016), generating southeast and northeast waves that are generally less than 1.5 m (Innocentini et al. 2000). In addition, westerly seabreezes, a local wind system that flows from sea to land, are also important in the region (Rodríguez et al. 2016).

The Northeast Coast goes from the proximities of Baía de São Marcos to the Baía de Todos os Santos (2°46'S–13°S), characterized by two distinct portions: the Semi-Árida and Tabuleiros, with five macro-compartments: Costa Norte Semi-Árida (MA/PI/CE), Costa Sul Semi-Árida (CE/RN), Costa Norte de Tabuleiros (RN/PB/PE/AL), Costa Central de Tabuleiros (AL), and Costa Sul de Tabuleiros (SE/BA). The Semi-Árida portion is dominated by the sedimentary deposits of the Grupo Barreiras formation, with fields of dunes and beach sandstone formations (Diegues and Rosman 1998; Muehe and Nicolodi 2006). In the Tabuleiros portion, there is an alteration of the coastline (from W-E to NNE-SSW) and the dunes are less pronounced, as a reflection of greater precipitation, and the increasing of estuaries and associated mangroves from Paraíba (Diegues and Rosman 1998; Muehe and Nicolodi 2006). It also features decks that reach the ocean on cliffs of the Grupo Barreiras and sand ridges outcropping on the beaches (Diegues and Rosman 1998; Muehe and Nicolodi 2006).

The East Coast goes from Salvador to Cabo Frio (13–23°S) and presents many geomorphological characteristics similar to the Northeast Coast, with significative river input and four macro-compartments: Costa de Estuários (BA), Royal Charlotte, and Abrolhos (BA/ES), Embaiamento de Tubarão (ES), and Bacia de Campos (RJ) (Silveira 1964; Diegues and Rosman 1998). The main features of this coastal region are the Barreiras formation, crystalline outcrops, and beach ridges (Diegues and Rosman 1998; Muehe and Nicolodi 2006). The wave climate is maintained by the trade winds generated by the Tropical South Atlantic Anticyclone (TSAA), with waves arriving from east, northeast, and southeast, with heights of 1–2 m (Tessler and Goya 2005).

The Southeast Coast goes from Cabo Frio in the state of Rio de Janeiro to Cabo de Santa Marta in Santa Catarina (23–28°36'S), with five macro-compartments: Cordões Litorâneos (RJ), Costa Norte das Escarpas Cristalinas (RJ/SP), Litoral das Planícies Costeiras e Estuários (SP/PR/SC), Costa Sul das Escarpas Cristalinas (SC), and Planícies Costeiras de Santa Catarina (SC) (Diegues and Rosman 1998). The unconsolidated sediments of the Barreiras formation progressively disappear to give way to outcrops of Precambrian rocks, in which its main feature is its proximity to the Serra do Mar slope, reaching the ocean in many regions (Silveira 1964; Muehe and Nicolodi 2006). The physiognomy of this region is marked by coastal ridges, lagoons, pocket and long arcs beaches, spurs, islands, crystalline outcrops, and important estuaries (Diegues and Rosman 1998; Muehe and Nicolodi 2006). On the coast between Cabo Frio (23°S) and Chuí (33°S), the Southeast and South Coasts receives easterly and southerly waves generated by high latitudes storms in the South Atlantic (Pianca et al. 2010), with an average height of 1–4 m (Tessler and Goya 2005), but northeast trade winds are influential during much of the year (Rodríguez et al. 2016). Tides are about 1 m in the north decreasing to 0.5 m in the south (Tessler and Goya 2005).

The South Coast (28°36’S –33°44’S) goes from Santa Marta to Chuí, with a broadening of the continental shelf to the southern end of the Brazilian coast and two macro-compartments: Costa Retificada do Norte (SC/RS) and Sistemas Laguna-Barreira (RS) (Bisbal 1995; Diegues and Rosman 1998). This coast is characterized by straight coastlines, beach arcs, coastal ridges, extensive fields of dunes, salt marshes, and numerous lagoons (Diegues and Rosman 1998). The outcrops, formed by volcanic rocks from the east edge of the Paraná Basin are the only rocky promontory on the entire coast (Diegues and Rosman 1998; Muehe and Nicolodi 2006). The estuary of the Rio de La Plata and Patos Lagoon is an example of the main sources of freshwater and sediments to the continental shelf (Moreira et al. 2013). Inserted in a micro-tidal environment, coastal hydrodynamics is dominated by wave action (Diegues and Rosman 1998).

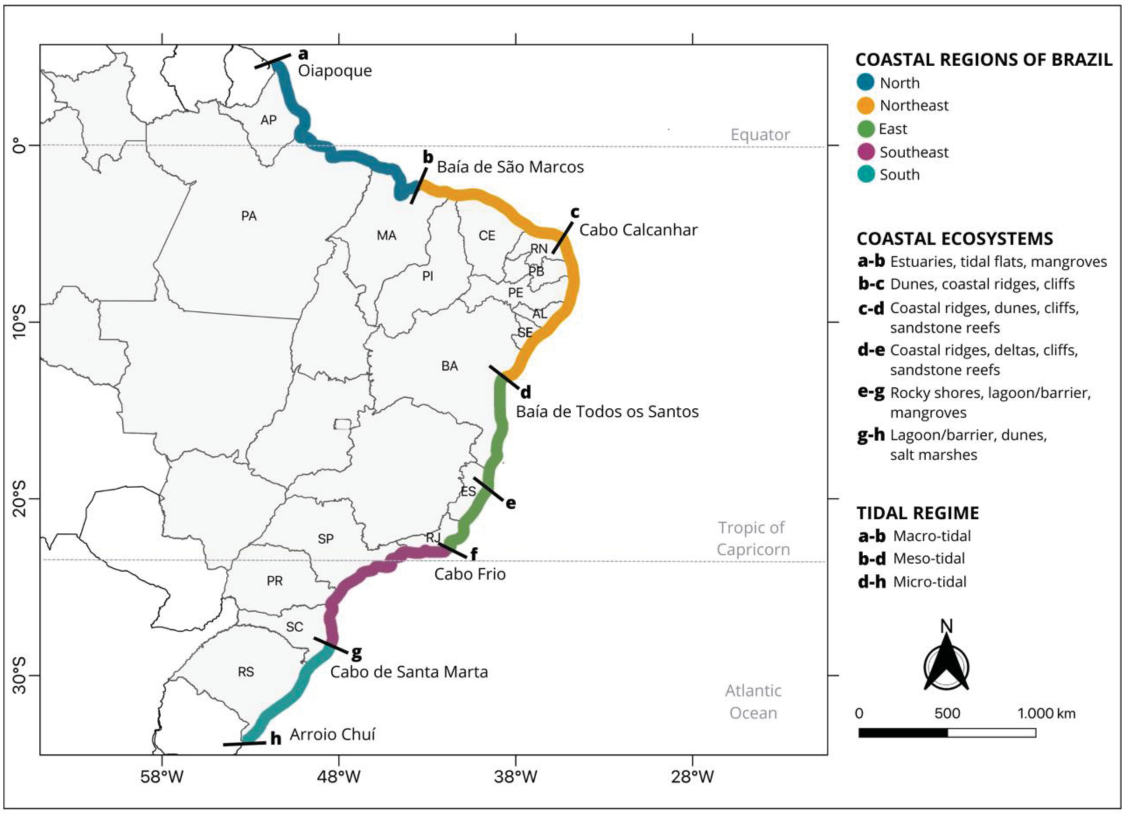


Figure 1. Brazilian map showing the coastal states (AP = Amapá; PA = Pará; MA = Maranhão; PI = Piauí; CE = Ceará; RN = Rio Grande do Norte; PB = Paraíba; PE = Pernambuco; AL = Alagoas; SE = Sergipe; BA = Bahia; ES = Espírito Santo; RJ = Rio de Janeiro; SP = São Paulo; PR = Paraná; SC = Santa Catarina; RS = Rio Grande do Sul), along with the coastal regions, ecosystems and tidal regime classification proposed in the Coastal Zone Macrodiagnostic. Modified from Silveira (1964) and Souza et al. (2005).

Ethical issues

Data shared online, especially on social media platforms, sometimes include explicit personal information, while implicit information could also be used to identify individuals or extract sensitive information. Then, the privacy of individuals and their identifiers was maintained in both data repositories and outputs, adhering to the highest ethical standards (Di Minin et al. 2021; Ghermandi et al. 2023). In line with social media terms and conditions as well as user privacy, we only gather publicly available data.

Data collection

We only included in the baseline Portuguese man-of-war observation records containing at least geolocation information and timestamp. From each data source, the following variables were identified or estimated and extracted: latitude, longitude, Federated Unit/State, beach name and the municipality of exposure, and date of sighting and posting. Besides this, always as possible, we extracted information about jellyfish abundance; pneumatophore size; interaction with other animals; human-jellyfish risk interactions, and accidents. All searches were performed until December 31, 2022.

Social media (SM)

Here, we used Instagram to extract and filter Portuguese man-of-war observations. The data quality of the information from the Instagram database was first assured by exploratory searches. We found Portuguese man-of-war sightings on other social media platforms, such as Youtube, Facebook, Twitter, Flickr, and Tiktok, but in the present study, we will focus our investigations on Instagram, because it is an image-based mobile platform that allows its users to capture time-and-space-specific characteristics through photographs or videos (Leaver et al. 2020). Then, the mobile, social, and visual aspects are fundamental to this popular platform, providing a large volume of georeferenced data. Moreover, Instagram posts specifically demonstrably outnumber and outperform other types of social media platforms as a reliable, modern proxy for tourist visitation, which allows the sharing of observations in marine environments (Lin et al. 2023). In fact, previous studies already showed the potential of Instagram to provide marine species observations (Sullivan et al. 2019; Leitão et al. 2022).

Instagram was launched in 2010. In 2022, there are more than 2 billion users in Instagram (Business of Apps 2023). Brazilians are among the people who use most social networks in the world, being the third country in the ranking of Instagram users, with about 110 million users in January 2022 (Statista 2023c). From this social media, we extracted presence-only records of the Portuguese man-of-war, which typically report the observation but not the non-observation of the jellyfish (or ‘true absence’) (Kingsford et al. 2018).

Specific hashtags (#) provided by users facilitate post categorization, contributing to searches in Instagram's public content. In our exploratory searches, we found that there are different hashtags with the scientific and common names of Portuguese man-of-war in the Portuguese and English languages which contain sightings of this species along the Brazilian coast on Instagram (Table 1). But, in the present study, we accessed posts with the hashtags 'jellyfish' and 'Portuguese man-of-war' in the Portuguese language. Due to the smaller number of posts, we were able to evaluate all posts tagged with hashtags #caravelaportuguesa and #caravelasportuguesas, but for the other hashtags explored, we set a search start date due to a large number of posts which generates limitations in the processing of the results and hamper loading all available posts through manual searches (Table 2).

All posts were manually filtered by binary classification (if it was a Portuguese man-of-war observation with spatiotemporal information or not), saved in the private tab on a personal profile and spreadsheet in Excel. We also used the Instaloader Python API (Application Programming Interface) to download posts with the explored hashtags. Instaloader is a Python package written by Alexander Graf (aandergr) to download desired URLs of posts or images with various attributes. From the posts downloaded, we obtained the following attributes: images and videos, image URLs, date and time of upload, captions, and coordinates.

The occurrence information (species observation, location, and date) was extracted from images, geotags, and captions of posts. In addition to the observation of Portuguese man-of-war (photo and/or video) and spatial and temporal information, whenever possible, we extract information on abundance, pneumatophore size, ecological relations, risky interactions with humans, and accidents.

It is important to define data quality criteria for filtering the social media data to reduce the impact of Type I error (i.e. reject the null hypothesis when it is true), guarantee reliability, reduce variability, and eliminate outliers (Barve 2014; Becken et al. 2019). Then, we standardized the collection and sampling effort. The minimum requirements to classify a post as an occurrence record includes at least taxonomic identification and geographical coordinates as geotag or location of observation (Pace et al. 2019). A general view of the methodology applied here for collecting, filtering, and storage of observation records of Portuguese man-of-war in Brazil from hashtags on Instagram is presented in Figure 2. To ensure data quality, the accuracy of the storage data was checked by more than two researchers to verify and validate the data.

The first filtering criterion was the image of the post clearly showing a Portuguese man-of-war. Only the photographs and video footages in which the diagnostic features of the species were clearly visible were selected. In most cases, species identification was usually an easy and straightforward process. Reposts, double entries, different fragments of the same footage, and different pictures of the same sighting were used only once in the final analysis, to ensure that each jellyfish encounter was represented exclusively by a unique video or set of photographs. Then, we searched by information about the date of observation provided by the user in the caption or comments. If no, we searched by clues in the text of the post that could indicate that it was not made in real-time, such as memory hashtags (e.g., #tbt which means ‘Throwback Thursday’ and is used to tag posts that refer to past events, in a way of remembering). Only the date of posting was used in the further analysis for those posts with Portuguese man-of-war observations in which the user did not provide the date of observation and also did not write words or tags of remembering in the caption or comments because Instagram posts are generally performed on personal mobile devices as a quick reaction to an ephemeral moment, then, it was assumed that the date of posting was closely related to the initial observations. In the sequence, we searched by geotag, which are geographic coordinates associated with place IDs that the user explicitly specifies when posts. If no, location information provided by the user was extracted from the text of the post (captions or comments). Such data are informative rather than absolute (e.g., #praiadofrances #alagoas), and general areas were used to address the lack of coordinates for these observations. These general areas were converted into approximate GPS coordinates using Google Earth. We did not include in our baseline posts without geographical information (in geotag or text) or without detailed location information, such as only the name of the state (e.g., #santacatarina) or only the generic name of the beach (e.g., #praiadoforte). We also did not include observations with geolocation in the interior of the country which could indicate an error in post classification.

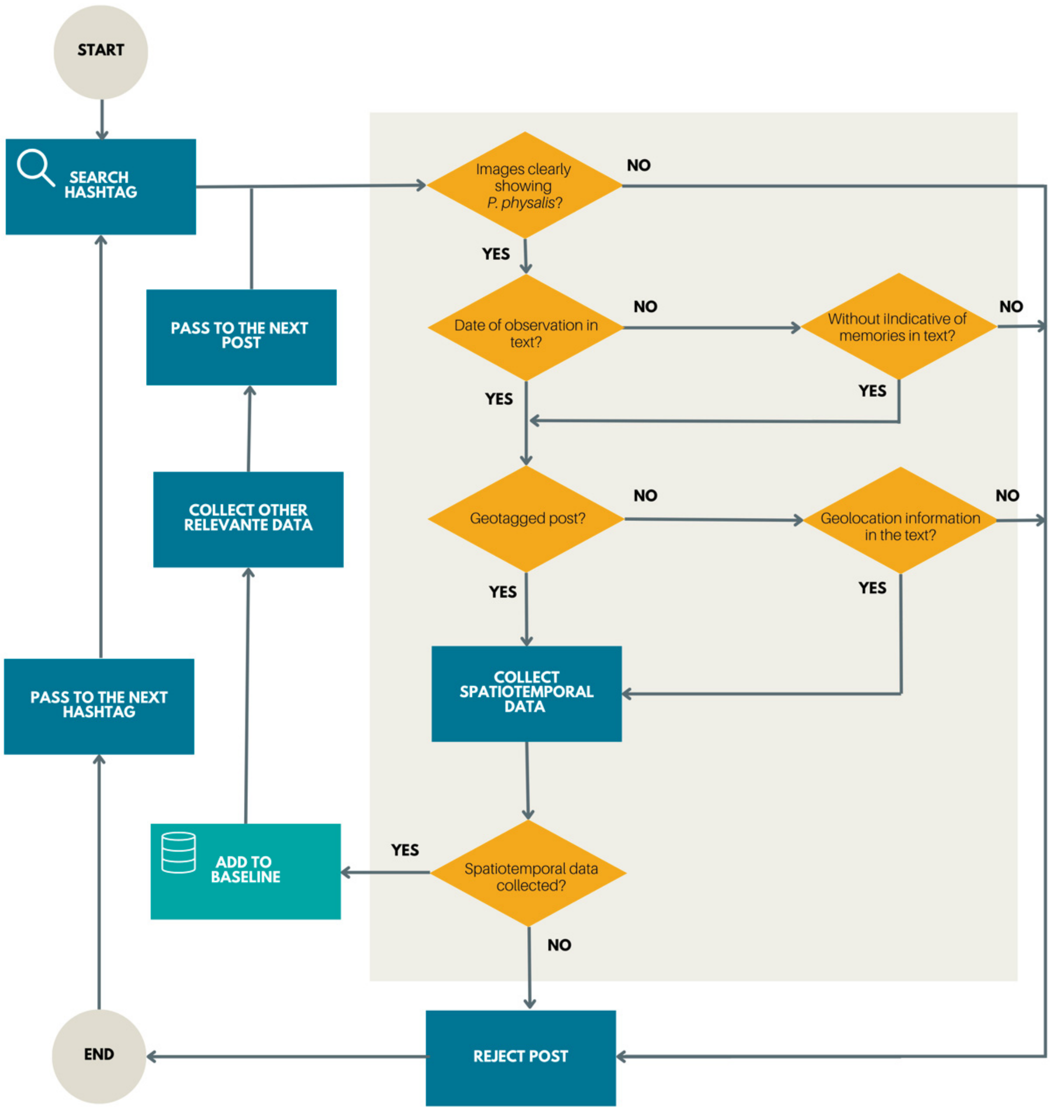


Figure 2. Schematic methodology for collecting, filtering, and storing Portuguese-man-of-war observations from Instagram data in each post and hashtag.

Table 1. Examples of hashtags on Instagram containing Portuguese man-of-war observations along the Brazilian coast and the approximate number of posts for each one. In bold, are the hashtags used in the present study. Updated on 31 December 2022.

Hashtag	*No. posts*	*Hashtag*	*No. posts*
águaviva	18,100	siphonophores	370
aguaviva	158,350	siphonophore	3,400
águasvivas	1,000	cnidaria	19,200
aguasvivas	10,560	cnidário	40
mãedágua	2,520	cnidario	910
maedagua	15,670	cnidários	480
mãedagua	1,220	cnidarios	3,400
caravelaportuguesa	3,483	hydrozoa	2,750
caravelasportuguesas	320	hydrozoan	1,300
caravela	51,740	hydrozoans	270
caravelas	67,890	physaliaphysalis	2,660
caravel	18,040	physalia	1,710
caravels	1,660	portuguesecaravel	210
portuguesemanofwar	9,720	jellyfish	3,299,520
portuguesemanowar	7,620	jellyfishes	54,720
bluebottle	369,950	medusa	2,486,020
bluebottles	35,000	medusas	92,310

Table 2. Period of searches for each Instagram hashtag used in the present study.

Hashtag	*From*	*To*
caravelaportuguesa	19 June 2014	31 December 2022
caravelasportuguesas	02 February 2016	31 December 2022
aguasvivas	31 July 2020	31 December 2022
águasvivas	31 July 2020	31 December 2022
águaviva	31 July 2020	31 December 2022
aguaviva	31 October 2021	31 December 2022
caravelas	31 October 2021	31 December 2022
caravela	31 October 2021	31 December 2022

Online news (ON)

Data from ON were extracted by systematic searches in Google News Search. We used the keywords "*caravela portuguesa*" (Portuguese man-of-war) and "*caravela*" (man-of-war) + "*Brasil*" and the name of coastal states along the Brazilian coast. These data were manually filtered.

Citizen science (CS)

The citizen science database of the iNaturalist platform (https://www.inaturalist.org/) was accessed to obtain Portuguese man-of-war observations along the Brazilian coast. Operating since 2008, iNaturalist is a platform that aims to map biodiversity across the globe by sharing observations (e.g., photographs). The platform was designed with the primary intention of engaging people with the natural world, with the potential secondary use of the observations for scientific purposes. It is one of the most popular citizen science platforms, with over 1.3 million users contributing millions of observations globally each month (Seltzer 2019). We only extracted ‘research level’ observations, which have media, location, date, and community consensus on accurate identification.

Personal observations and communications (POC)

Data from POC provided both scientific field samplings and opportunistic observations of Portuguese man-of-war. Data from scientific samplings were obtained through weekly beach surveys at Pontal do Sul beach (25.5781°S, 48.3625°W) between May 2018 to May 2019. Data from opportunistic observations were mainly obtained from personal observations made by the authors or shared by citizens and fellow researchers.

Literature review (LIT)

Data from LIT also provided both scientific field samplings observations and opportunistic observations. A systematic and focused on the target species literature review was performed using the Scopus database, Science Direct, Web of Science, and Google Scholar, from the combination of the following search terms: “Portuguese man-of-war”, “man-of-war”, “*Physalia physalis*”, “*Physalia*”, “Physaliidae”, “Cnidaria”, and “Brazil” in Portuguese and English languages. The references cited in the studies found were also investigated. We included in the database every paper, thesis, dissertation, monograph, and conference publication available online with Portuguese man-of-war occurrence information on the Brazilian coast.

Data analysis and visualization

All data collected were visually summarized in the format of image boards, tables, charts, and maps using Microsoft Excel (Microsoft Corporation 2018), Canva (https://canva.com/), Flourish (https://flourish.studio/), and QGIS (QGIS Development Team 2022). The analysis of temporal and spatial trends was based on the number of records, here named 'Baseline', and in the number of Portuguese man-of-war colonies, in the results section 'Strandings and health risks'.

We developed a macro-diagnostic of the level of risk of Portuguese man-of-war stings in Brazil adapted from Tiralongo et al. (2022). We grouped the total number of colonies recorded in each coastal region of Brazil (North, Northeast, East, Southeast, and South Coast) according to the number of visitors over the year (Table 3). The level of risk was represented by the color gradient (red = high-risk; yellow = medium-risk; and blue = low-risk). As a proxy of the level of risk, we used data on international and national arrivals in the coastal states of each region extracted from the Tourism Statistical Yearbook 2020 (IBGE 2023). To define the level of risk for each month in each coastal region, we calculated the monthly percentage of the number of visitors in relation to the total annual. If >9% of total, the month was classified as high-risk level, when 9-7% it was medium-risk, and when <7% the month was classified as low-risk level.

Table 3. Classification of months with high (red), medium (yellow), and low (blue)-risk for each coastal region in Brazil.

Risk-level	*N*	*NE*	*E*	*SE*	*S*
🔴	Dec, Jan, Jul	Dec, Jan, Jul	Dec, Jan, Jul	Dec, Jan, Jul	Dec, Jan, Oct, Nov
🟡	Jun, Aug, Sep, Oct, Nov	Feb, Mar, Aug, Sep, Oct	Feb, Mar, Oct, Nov	Feb, Mar, Oct, Nov	Feb, Jul, Aug, Sep
🔵	Feb, Mar, Apr, May	Apr, May, Jun	Apr, May, Jun, Aug, Sep	Apr, May, Jun, Aug, Sep	Mar, Apr, May, Jun

Results

Baseline

The first result of this investigation was the creation of a long-term and large scale baseline containing the information on occurrences of Portuguese man-of-war along the Brazilian coast extracted from different data sources. A total of 1,457 Portuguese man-of-war occurrence records were obtained in the present study (Figure 3; Online resource 1). The oldest record was made on 15 September 1982 and the most recent was made on 30 December 2022. Social media (SM) had the highest contribution to the database, corresponding to 59.2% of the total occurrence records (Table 5). Citizen science (CS) contributed to 18.9% of occurrences on the baseline; followed by literature (LIT; 8.37%), online news (ON; 6.93%), and personal observations and communications (POC; 6.58%). The records of SM were mainly from photos (91.43%), and 8.56% were extracted exclusively from videos.

There is a marked increase in the volume of data over the years, of which 1,247 occurrences were recorded in the last five years, with a maximum of 426 occurrence records in 2021 (Figure 4). This year, we obtained 281 records from SM, 67 records from CS, 38 from POC, 37 from ON, and 3 from LIT. There is also a seasonal distribution in the number of records, being higher during end-of-year vacations, with a tendency to increase from November to January since 2016. The highest value was recorded in January 2022 with a total of 108 occurrences, with 59 records from SM, 30 from CS, 13 from POC, 6 from ON, and none from LIT. Since July 2017, only in June 2018 and July 2021, was no record Portuguese man-of-war on the Brazilian coast.

Portuguese man-of-war was recorded all over the Brazilian coast, except in latitudes lower than 0°S (Figure 5). From SM and CS database, it was possible to extend the Portuguese man-of-war occurrences further north on the coast of Brazil, at 0°35’S, in Salinópolis, Pará. In general, SM data had greater spatial coverage than the other data sources.

Considering that the higher volume of data was recorded since 2018, we compared the temporal trends in the number of records between data sources for each region from 2018 to 2022 (Figure 6). The coastal regions with more records were the Northeast (41.7% of the total) and Southeast (37.9%), followed by the East (9.5%), North (6.2%), and South (4.6%). In general, the temporal distribution of records was similar between data sources, especially in the Southeast and South coasts, with a marked seasonality in the occurrences.

Figure 3. Examples of photography and video footage showing one colony of Portuguese man-of-war stranded (A, B, G, H, I, J, K), and in abundance (C, E, F); one colony in the water (D); associated stranding of the predator *Glaucus atlanticus* (G); scavenging by *Ocypode quadrata* (H), and insects (I); human-jellyfish risk interactions of touching (J) and biting the Portuguese man-of-war (K); and wounds of linear plaques in the Portuguese man-of-war victim's leg (L). Sources: Instagram (A, C, D, E, F, I, K, and L); news portals (B and G); and iNaturalist (H and J).

Table 4. Descriptive features of the datasets explored in this study.

Data source	*Platforms, apps or applications*	*Type of observation*	*Provider*	*Period*	*N records*	*% total*
SM	Instagram	Opportunistic	Citizens	2010-2022	863	59.2
CS	iNaturalist	Voluntary and opportunistic	Citizens	2007-2022	276	18.9
LIT	Scopus database, Science Direct, Web of Science, and Google Scholar	Field sampling and opportunistic	Researchers	1982-2021	122	8.37
ON	Google Search	Opportunistic	Citizens	2017-2022	101	6.93
POC	Whatsapp, Facebook and Instagram	Field sampling, voluntary, and opportunistic	Citizens and researchers	2018-2022	96	6.58
TOTAL				**1982-2022**	**1,457**	**100**

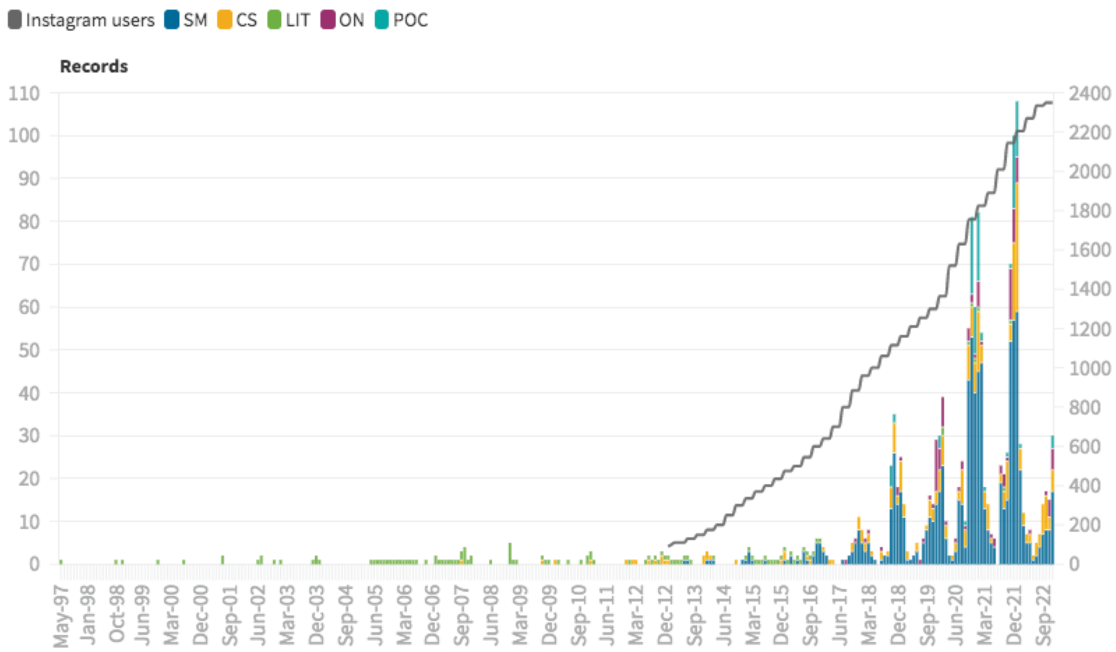


Figure 4. In the bars, monthly distribution of the number of records of Portuguese man-of-war along the Brazilian coast from May 1997 to December 2022 obtained from each data source. SM = social media; CS = citizen science; LIT = literature; ON = online news; and POC = personal observations and communications. Note that records from the literature prior to May 1997 are not shown, these are: Barra do Itarari, Bahia, on 15/09/82; Cabo Branco, Paraíba, on 10/10/82 and 05/11/83; and Guarujá, São Paulo, in Jan/94 and in 28/02/94. In the line, quarterly distribution of the number of Instagram users worldwide from the first quarter of 2013 to the last quarter of 2022 (in millions) (Source: Business of Apps 2023).

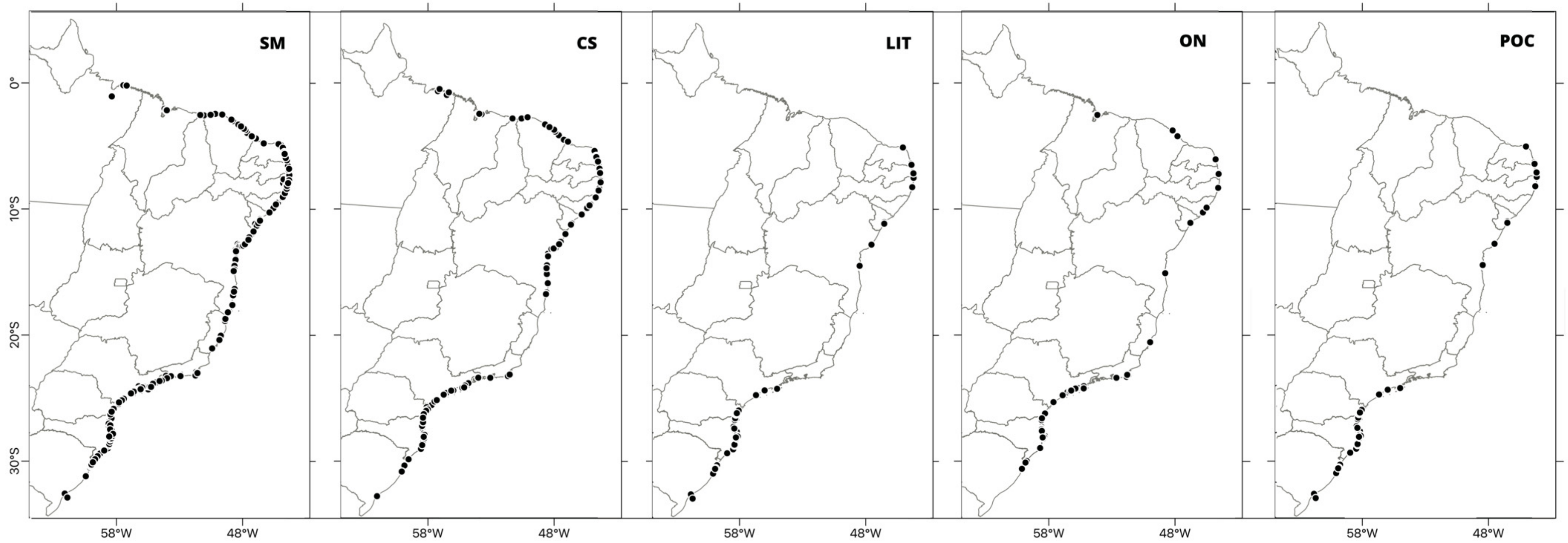
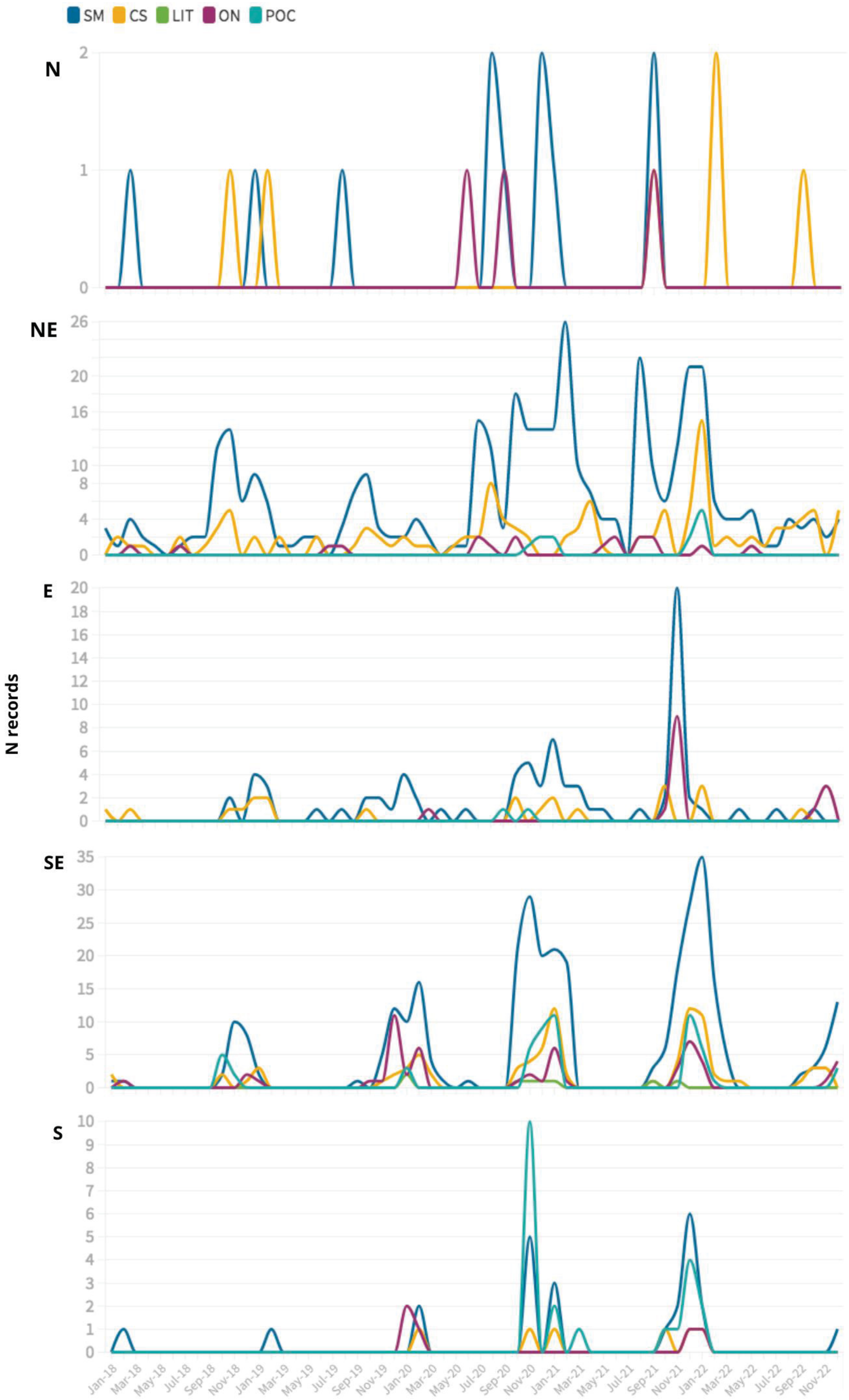


Figure 5. Spatial distribution of Portuguese man-of-war records along the Brazilian coast from 1982 to 2022, obtained from each database. SM = social media; CS = citizen science; LIT = literature; ON = online news; and POC = personal observations and communications.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Jan-21
Mar-21
May-21
Jul-21
Sep-21
Nov-21
Jan-22
Mar-22
May-22
Jul-22
Sep-22
Nov-22

Figure 6. Monthly distribution of the Portuguese man-of-war records in the coastals regions of Brazil (North, Northeast, East, Southeast, and South Coast) from each database since 2018 to 2022. SM = social media; CS = citizen science; LIT = literature; ON = online news; and POC = personal observations and communications. Note the differences in y-axis values for each region.

Abundance

The abundance of Portuguese man-of-war was present in 105 records qualitatively (e.g., many, bloom, all over the beach), and in 348 records quantitively. A total of 10,074 colonies were recorded in the present study. Qualitative abundance information was mainly extracted from SM (74%); and quantitative abundance from SM (31%), LIT (29%), and POC (29%) datasets (Figure 7a; b).

Size

The majority of colonies recorded in the present study had between 2 and 5 cm of pneumatophore length (43.8% of total), with a total of 1,914 measures of pneumatophores extracted from 826 records (Table 5; Figure 7c). LIT database mainly contributed to obtaining information on the size of jellyfish (54%), being especially recorded on the North Coast (95.9%).

Table 5. Size classes of pneumatophores length from Portuguese man-of-war colonies on the Brazilian coast.

Size (cm)	*N records*	*% total*	*% N*	*% NE*	*% E*	*% SE*	*% S*
< or 2	374	19.5	19	0.3	0.1	0	0
>2-5	840	43.8	43.1	0.6	0.1	0	0
>5-10	502	26.2	24.7	0.4	0.5	0.6	0.2
>10-15	162	8.4	7.5	0.3	0	0.5	0
>15-20	36	1.8	1.6	0.1	0	0.3	0
TOTAL	**1,914**	**100**	**95.9**	**1.7**	**0.6**	**1.4**	**0.2**

Ecological relations

We recorded 23 occurrences of associated strandings of Portuguese man-of-war colonies along with other pleustonic animals: the hydrozoans *Velella velella* and *Porpita porpita*, and the mollusks predators of the Portuguese man-of-war, *Janthina janthina* and *Glaucus atlanticus* (Table 6). Besides this, records of scavenging of stranded specimens of Portuguese man-of-war by insects (7 records), in which six of them were associated with flies and one with the ants *Camponotus sericeiventris*. Moreover, we recorded scavenging of stranded colonies by the ghost crab *Ocypode quadrata* (4). Alive in the water, we also recorded fishes swimming around this jellyfish (4 records), in which one colony was associated with the *Nomeus* cf. *gronovii*. SM (32%) and POC (26%) contributed mostly to obtaining information on ecological relations (Figure 7d).

Table 6. Ecological relations with Portuguese man-of-war in the Brazilian coast.

Ecological relation	*Description*	*N records*	*% total*
Associated strandings	Strandings of Portuguese man-of-war along with other pleustonic species	23	60.5
Scavenging	Scavenging of stranded Portuguese man-of-war	11	28.9
Fish association	Association of school of fishes with lived Portuguese man-of-war	4	10.5
TOTAL		**38**	**100**

Human-jellyfish risky interactions

The recorded risky interactions were touching/holding the jellyfish (23 records), transporting the jellyfish (8 records), and biting the jellyfish (1 record) (Table 7). Records on risky interactions were mainly obtained from the SM dataset (69%) (Figure 7e), occurring 57% with males and 43% with females.

No risky interactions were recorded for the North Coast (Figure 8). On the other hand, risky interactions were recorded on the Northeast coast in almost all months of the year, totaling 14 interactions. A total of 8 risky interactions were recorded on the East Coast, with the highest value in October. In the Southeast, a total of 9 risky interactions were obtained, only recorded in January, November, and December. Only 1 record of risky interaction was obtained on the South Coast, in January.

Table 7. Human-jellyfish risky interactions with Portuguese man-of-war observed in the Brazilian coast.

Interaction type	*Description*	*Risk type*	*N records*	*% total*
Touching	When the person hangs in direct contact with the Portuguese man-of-war	Intermediate	23	72
Transporting	When the person transport the Portuguese man-of-war with direct contact (e.g., returning the jellyfish to the sea)	Intermediate	8	25
Biting	When the person put the Portuguese man-of-war in the mouth	Major	1	3
TOTAL			**32**	**100**

Accidents

A total of 928 accidents were recorded in the present study, extracted from 91 records (Figure 7f). Accident records were mainly obtained from the SM (51%), ON (22%), and LIT (20%). From the accidents recorded, 62% of the victims were male, and 38% were female. About 85% of the accidents occurred with people under 20 years old; 45% affected people from 0 to 10, and 40% from 11 to 20 years old. Legs (39%) and hands (24%) were mainly reported as common sites of wounds.

A total of 61 accidents were obtained for the North Coast (Figure 8). On the North Coast, accidents were reported throughout the year, except in June. The highest number of accidents in this region was recorded in November and January, with 19 and 12 records, respectively. In the Northeast, the highest number of accidents was recorded in August, with a total of 58 records, but we also obtained records throughout the year on this coast. A total of 7 accidents were recorded on the East Coast, being recorded only in November and January. In the Southeast, a total of 628 accidents were recorded. It is possible to observe a seasonality in accidents on the Southeast Coast, occurring from November to February, but the highest values were recorded in December and January. Only 1 accident was recorded on the South Coast, in January.

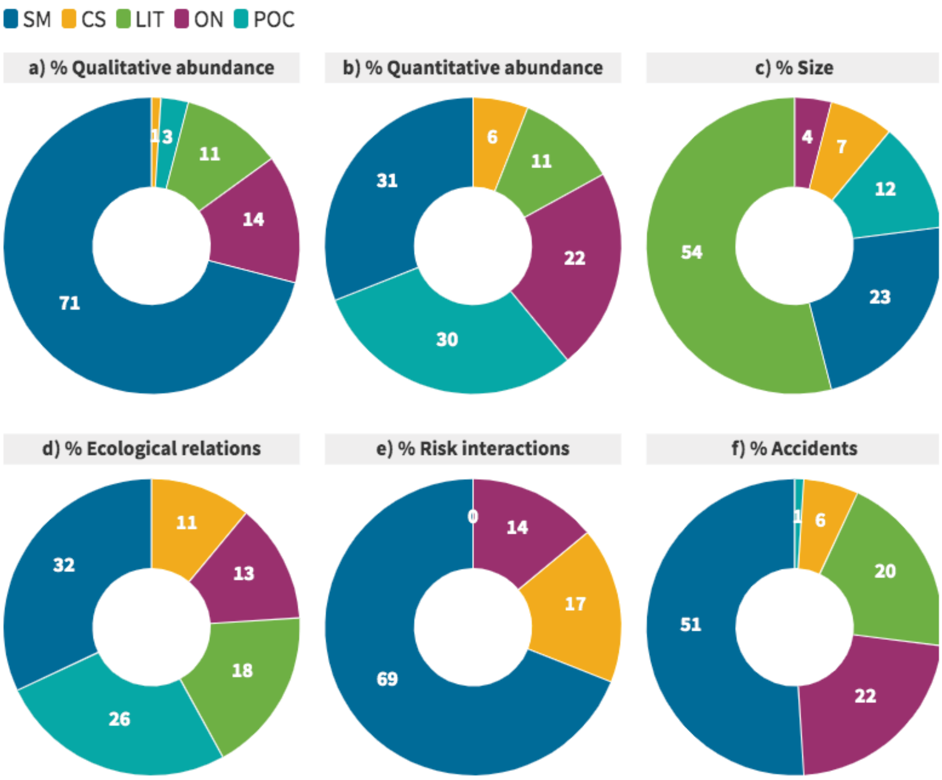

Figure 7. Percentage of the contribution of each database on Portuguese man-of-war occurrence records for data about abundance qualitatively (a; n = 105), and quantitatively (b; n = 348); size classes of pneumatophores length from recorded Portuguese man-of-war colonies on the Brazilian coast (c; n= 826); ecological relations (d; n = 38); human-jellyfish risk interactions with Portuguese man-of-war (e; n = 32); and accidents (f; n = 91).

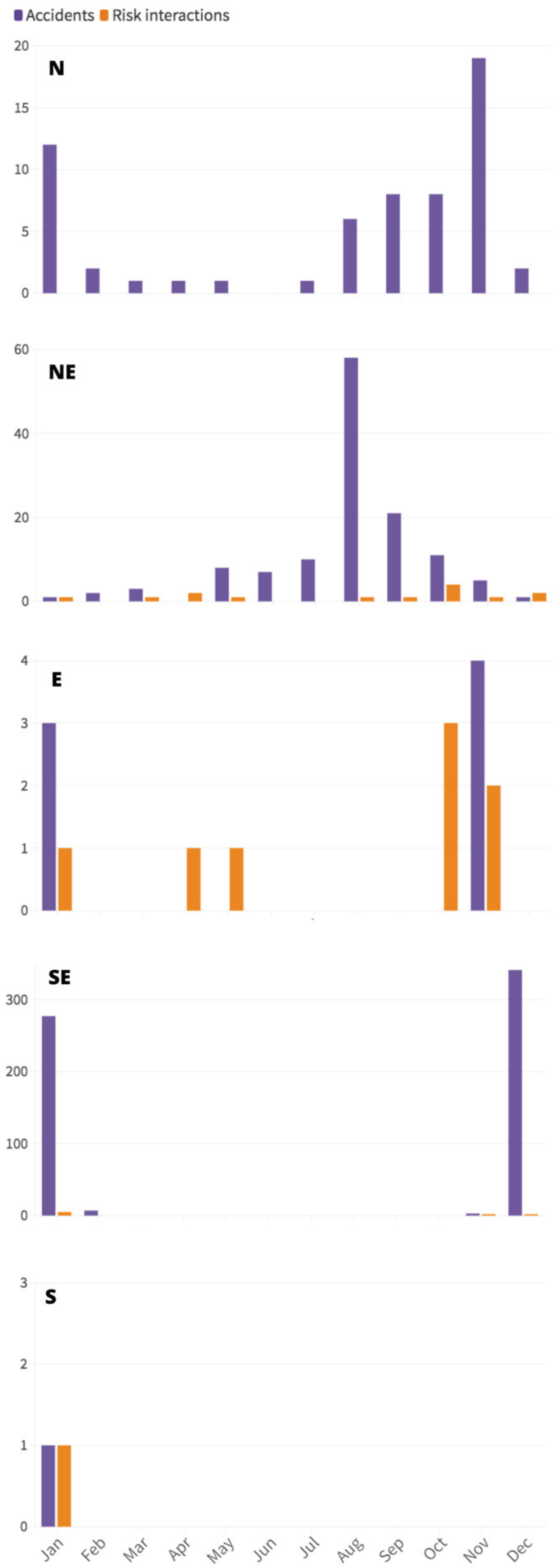

Figure 8. Monthly distribution of the total number of accidents and risk interactions with Portuguese man-of-war for each coastal region in Brazil (North, Northeast, East, Southeast, and South Coast) from January 2016 to December 2022. Note the differences in y-axis values for each region.

Strandigns and health risks

The North Coast had the highest number of colonies (total of 4,384), being mainly recorded in the period of medium-risk for beachgoers (3,019 colonies) and in the winter (2,306 colonies) (Figure 9). Winter was also the season with the highest colonies concentration on the Northeast Coast, with 1,642 colonies. The highest number of colonies in the Northeast was recorded during the high-risk level (1,458). A total of 2,459 colonies were recorded in the Northeast. The lowest number of colonies was recorded on the East Coast, with a total of 214 colonies, mainly reported in the medium-risk period (106), and in the spring (168). The Southeast Coast had the number of colonies mainly recorded in the high- (1,553) and medium-risk periods (1,096), with only 16 colonies recorded in the low-risk. The highest concentration on the Southeast Coast was in the summer (1,616 colonies). On the South coast, 352 colonies were recorded during the high level of risk, 43 in the medium, and only 5 in the low-risk period; also with the highest number of colonies in the summer, totaling 255. The year with the highest number of Portuguese man-of-war colonies was 2020, with a total of 3,848 colonies recorded, followed by 2016 with 1,298, and 2021 with 1,278 colonies (Figure 10).

Portuguese man-of-war strandings commonly occur throughout the year on the North Coast, with blooms especially occurring in the second half-year, from winter to early summer (Ferreira-Bastos et al. 2017; Luana 2017; Silva 2018; Aquino et al. 2019). In Salinópolis (0°35’S), where 71.7% of bathers, health professionals, and lifeguards identified Portuguese man-of-war as the cause of envenoming, accidents with jellyfish were more frequent during the vacation months (July and December) (Aquino et al. 2019). But in a fishing village in São Caetano de Odivelas, Pará (0°44’S), this species is known to cause accidents in artisanal fishermen during the dry season, from June to November (Silva 2019), during the period of medium-risk and higher number of colonies here observed. Moreover, from recent records extracted from online news, 56 accidents with Portuguese man-of-war were mentioned in São Luís, Maranhão (2°31'39.8"S; 44°17'54.6"W) between the end of 2019 to June 2020 (Globoplay 2021). These results highlight the presence of Portuguese man-of-war on the North Coast throughout the year and the seasonality of the type of victims (bathers and fishermen) according to human behavior. This jellyfish is historically known to occur in high abundances and frequencies in Amazonian urban beaches at São Luís in the State of Maranhão (2°29’17.70” S, 44°17’04.53” W and 2°28’58.65” S, 44°15’15.61” W) (Ferreira-Bastos et al. 2017; Luana 2017; Silva 2018; Cavalcante et al. 2020). From observations extracted here from SM, we recorded the highest bloom in this location, with more than 1,000 colonies stranded on 24 August 2020 (Figure 11). The observer mentioned that these colonies were “baby” jellyfish. In fact, in these beaches, the predominance of small colonies (0-2.5 cm) may indicate the occurrence of continuous reproduction throughout the year, but they especially occur in the dry period, in the second half of the year (Silva 2018).

Records of Portuguese man-of-war from the literature on the Northeast Coast were only obtained by punctual observations or surveys about accidents, without data on regular and systematic beach surveys focused on its distribution (Alves and Rosa 2006, 2007; Bardi and Marques 2007; Neves et al. 2007; Risk et al. 2012; Lima 2016; Serra et al. 2018; Brito et al. 2019; Santos and Almeida 2015, 2019; Calazans et al. 2018). But this species is also known to especially occur throughout the year on this coast, especially in the second half of the year. In the present study, the highest value in the Northeast was recorded at Praia da Piedade, in Pernambuco (8°09'32.2"S; 34°54'37.7"W), with more than 1,000 colonies in July 2020 during the high level of risk for beachgoers extracted from SM (Figure 11). In a previous investigation in Recife and Jaboatão dos Guararapes, Pernambuco (~8°S), 35 accidents with cnidarians were recorded in a period of one year, in which 34 of them were caused by the Portuguese man-of-war and occurred by July to December (Neves et al. 2007).

On the East Coast, we extracted from the POC database the highest number of colonies in this region, a total of 50 colonies in the Praia de Jeribucaçu, Bahia (14°21'08.5"S; 39°00'47.2"W), on 24 September 2020, during the low-risk period (Figure 11). In addition, frequent strandings were extracted from SM and ON between 20°S to 22°S, in Rio de Janeiro and Espiríto Santo, when “several” jellyfish were seen from 11 to 24 November 2021 (Figure 12). In fact, November was the month when the observers reported qualitative abundance of Portuguese man-of-war on the East Coast (Figure 13). On this coast, little information is available in the literature about the occurrence of Portuguese man-of-war. Only punctual records were available, from Arraial do Cabo, Rio de Janeiro (22°57′58″S, 42°1′44″W) on 16 October 1998, with 18 colonies observed (Bardi and Marques 2007), and one colony for Península de Maraú, Bahia (13°55'46"S, 38°55'49.5"W) on 11 January 2012 (Farias and Silva 2021). But through empirical knowledge, it is already known that the higher concentrations of abundance and accidents on the East Coast occur in the second half of the year, during the low and medium-risk periods, as observed in recent observations herein.

The Portuguese man-of-war is historically recognized for causing poisoning in bathers mainly on the Northern and Northeastern coasts of Brazil, and it was mentioned as rare in the South and Southeast in the literature, with sporadic and more localized occurrences (Haddad et al. 2013; Resgalla Júnior et al. 2019). But from recent sightings obtained in the present study, this species was recorded in numerous beaches and throughout the year on the South and Southeast Coast. With a marked seasonality, this jellyfish mainly occurred from October to February from 2018 to 2022, during the high and medium levels of risk (Figure 12). This seasonal pattern was already observed in previous studies, with blooms of Portuguese man-of-war and outbreaks of envenoming occurring during the summer (Haddad Júnior et al. 2002, 2007, 2010, 2013; Resgalla Júnior et al. 2005, 2019; Cristiano 2011; Francisco 2022). At the beginning of summer in 2008, coinciding with school vacation, a local newspaper reported thousands of envenoming events associated with Portuguese man-of-war at a distance of approximately 100km on the coast at Praia Grande, São Paulo (Haddad Júnior et al. 2013). From recent observations, the beaches with higher abundances and frequencies in the São Paulo state were also in Praia de Guaraú and Praia Grande, at ~24°S. On the Southeast Coast, the highest number of colonies was recorded in the summer of 2020/2021, especially at beaches in Florianópolis, such as Praia do Campeche, Santa Catarina (27°40'38.3"S; 48°30'24.2"W), with information mainly extracted from SM. These results were also in accordance with the information available in the literature obtained by fortnightly beach surveys between December 2019 to November 2021 (Francisco 2022). Furthermore, the 'true' absences obtained for this coast through field samplings were also in accordance with the absence of opportunistic observations from SM, ON, and POC.

On the South Coast, the occurrences were mainly concentrated near Praia de Tramandaí (~30°S) and Praia do Cassino (32°20’S, 51°53’W), in Rio Grande do Sul (Figure 11). As well as in the Southeast, it is possible to observe a marked seasonality in the South Coast, with colonies especially occurring from November to February, during the high-risk level in this region (Figure 12). For example, on 04 November 2020 Portuguese-man-of-war were reported “all over the beach” at Capão da Canoa (29°45’S, 50°01’W) through SM (Figure 13). Besides SM, the POC database had also an important contribution to data obtained on the South Coast. For example, dozens of colonies with >10 cm in pneumatophores were seen in the Praia do Cassino on 16 November 2020 (Nagata RM in personal communication). Outbreaks in warmer months were previously recorded at Imbé and Praia do Cassino, Rio Grande do Sul (Cristiano 2015; Pinotti et al. 2019).

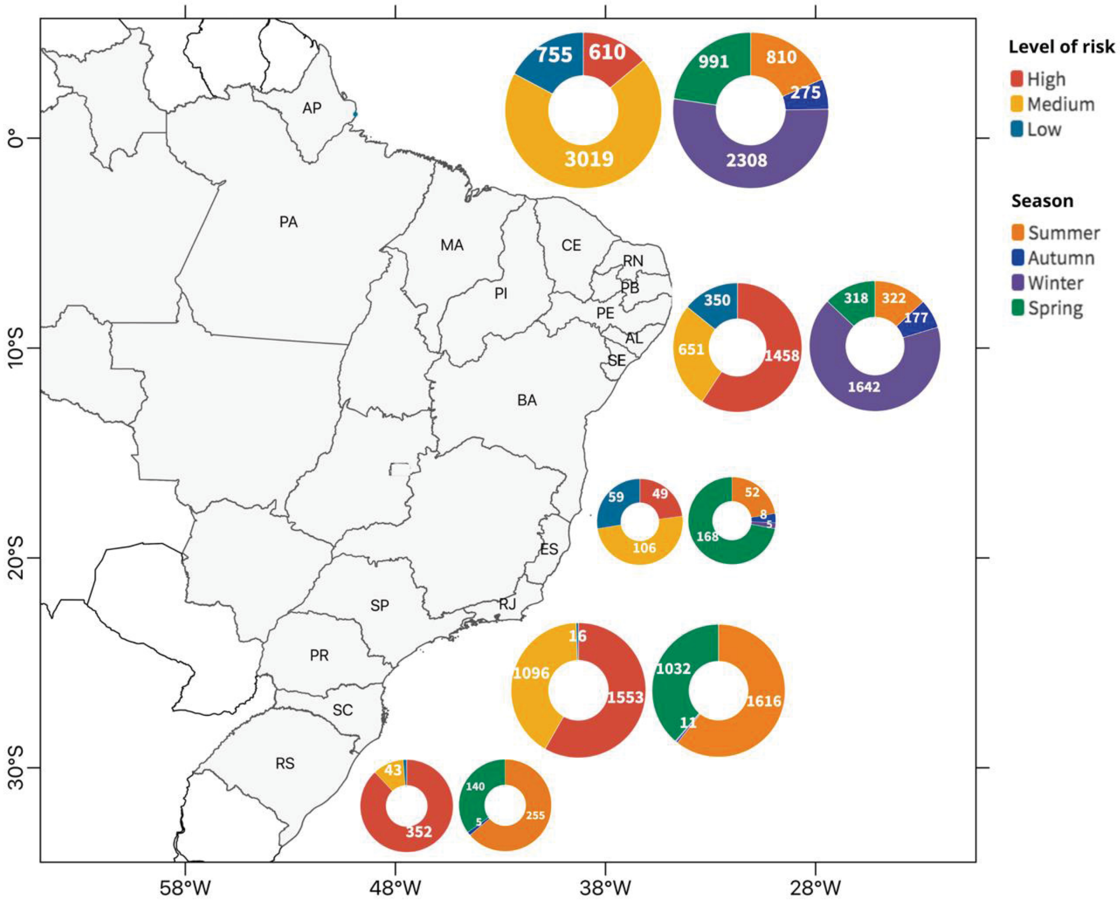

Figure 9. Schematic clustering of the total number of colonies of Portuguese man-of-war aggregated according to the coastal regions of Brazil (North, Northeast, East, Southeast, and South Coast), the level of risk of accidents (high, medium, and low) are presented in the pie chart in the left, and seasons (summer, autumn, winter, and spring) in the pie chart in the right.

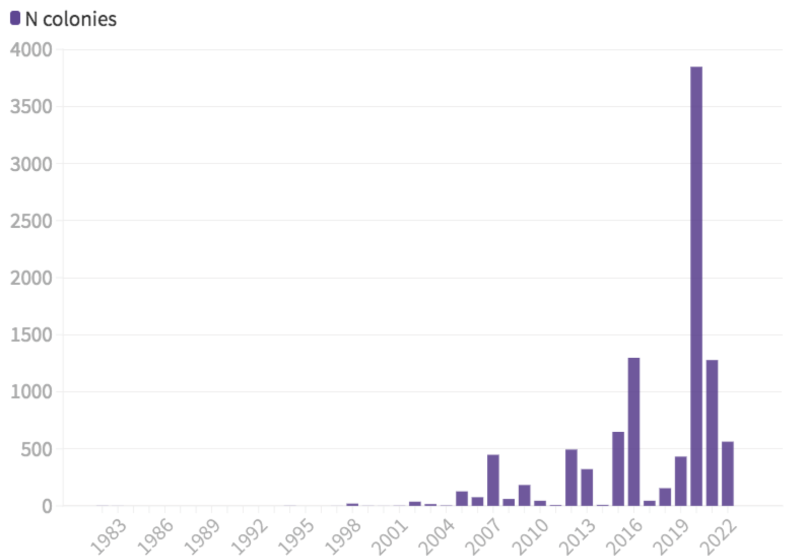

Figure 10. Annual distribution of Portuguese man-of-war colonies reported along the Brazilian coast from 1982 to 2022.

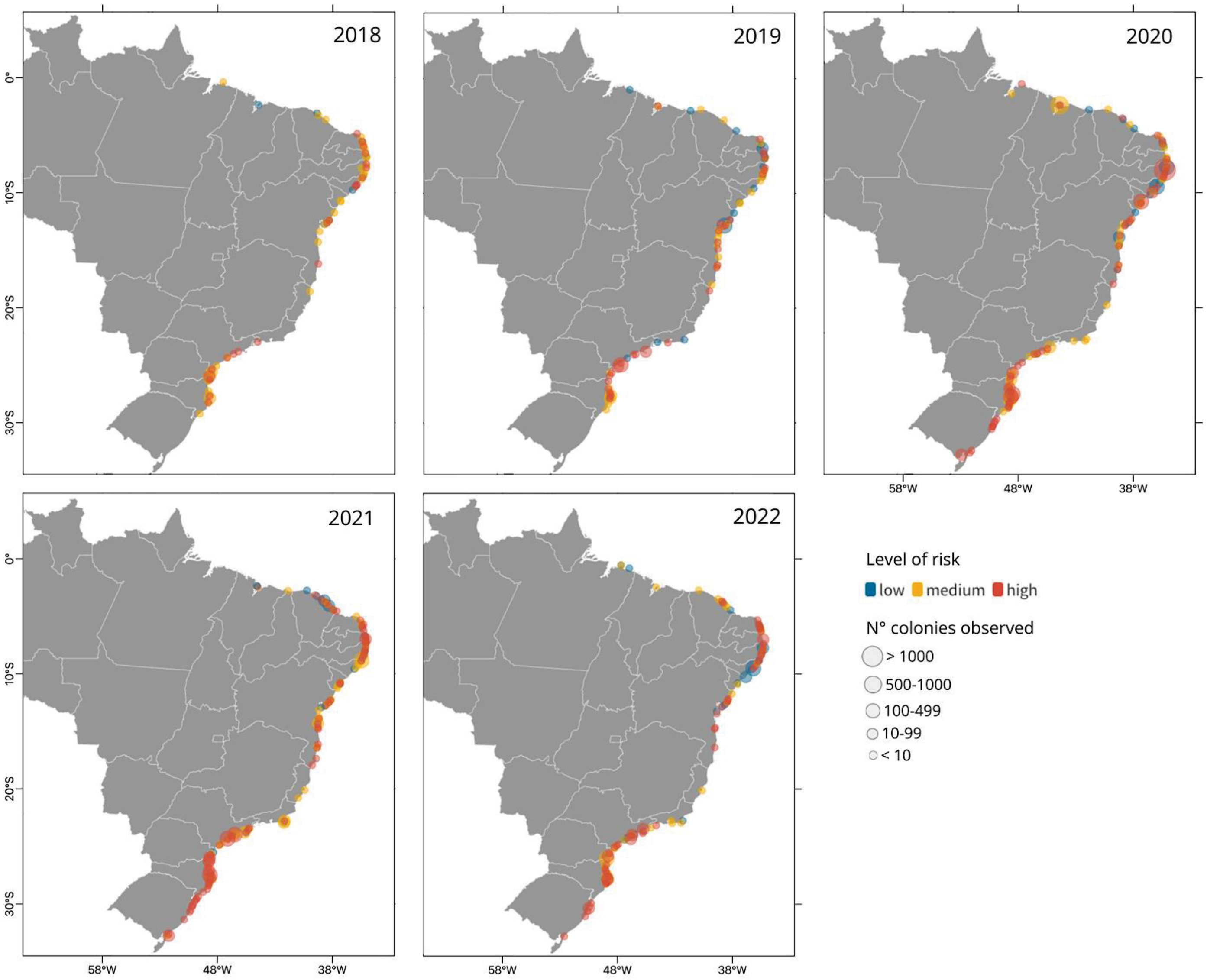
2018
2019
2020
2021
2022
0°
10°S
20°S
30°S
58°W
48°W
38°W
Level of risk
low
medium
high
N° colonies observed
> 1000
500-1000
100-499
10-99
< 10

Figure 11. Distribution of Portuguese man-of-war colonies along the Brazilian coast from 2018 to 2022, according to the period of level of risk for beachgoers (high, medium, and low) at each coastal region.

Lat 0 2
N
Lat
Lat 2 12
NE
Lat 13 22
E
Lat 22 28
SE
Lat 28 32
S
> 1000
> 100
> 10
< 10
'true' absence
01/01/2018
01/04/2018
01/07/2018
01/10/2018
01/01/2019
01/04/2019
01/07/2019
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01/04/2021
01/07/2021
01/10/2021
01/01/2022
01/04/2022
01/07/2022
01/10/2022

Figure 12. Daily distribution of Portuguese man-of-war colonies along the Brazilian coast from January 2018 to December 2022 for each coastal region in Brazil (North, Northeast, East, Southeast, and South Coast), according to the latitude. The light gray circle (•) in the Southeast Coast indicates the non-observation ('true' absence) of colonies obtained from weekly regular beach surveys at 25.5781°S, 48.3625°W (samplings made by LSN), and fortnightly at 27.5961°S, 48.4587°W (Francisco 2022).

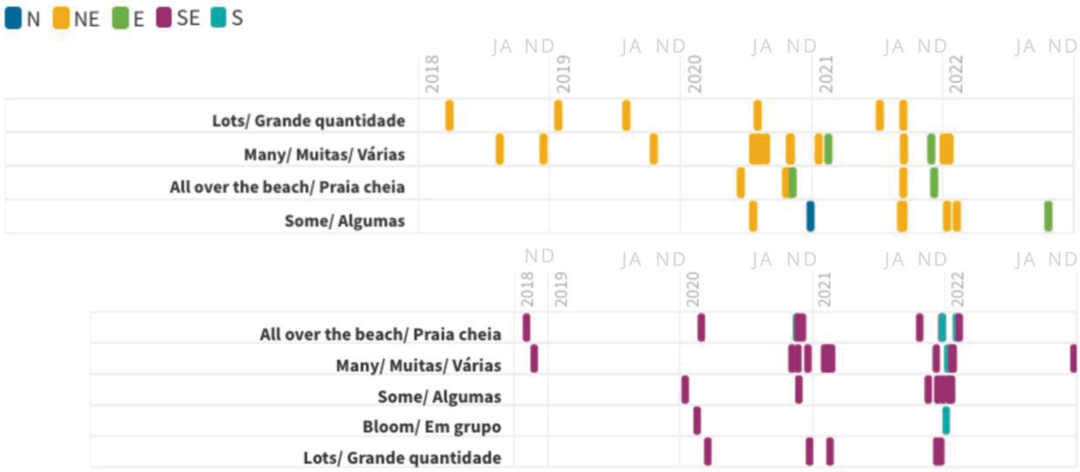

Figure 13. Monthly distribution of the qualitative abundance of Portuguese man-of-war colonies from 2018 to 2022 for each coastal region in Brazil (North, Northeast, East, Southeast, and South Coast), according to common terms utilized by observers.

Discussion

Our evaluation of the utility of social media found that Instagram, as an example of social media, was a valuable tool in Portuguese man-of-war research and monitoring. The quality of the images allied to spatiotemporal information was sufficient to allow scientists to positively identify the species occurrence and add it to the database. The images combined with the geotags, hashtags, captions, and comments provided by users on Instagram to describe the content, their feelings, and moments, enhanced significantly the location and temporal information, the labeling and categorization of posts, and the compilation with other relevant content from the other data sources. Supporting our hypothesis, from these occurrences generated by citizens through social media, it was possible to assess the distribution of health risks related to Portuguese man-of-war occurrences along the Brazilian coast.

We were impressed by the volume of data obtained herein via social media, corresponding to about 60% of the total data, with greater spatial coverage than the other data sources, also providing detailed temporal information of recent records (2018-2022). Social media provided biological records of Portuguese man-of-war at a large spatio-temporal coverage combined with the fine precision of the data, especially in the Northeast and Southeast coasts. Previous studies that compared the contribution of social media with other data sources to obtain observations of other marine species also recorded the predominance of social media data (Jovanovic and Vukelic 2015; Mannocci et al. 2021). For example, during the investigation of cetaceans in southern Portugal, Morais et al. (2021) obtained 1,403 records from Instagram and Facebook and only 82 from voluntary citizen science.

For jellyfish investigations, the integration between citizen science and field surveys is of great importance to study pelagic hydrozoans and analyze their role in ecosystems and impacts on human activities (Edelist et al. 2022; Tiralongo et al. 2022). A key point in using species records generated by citizens is the search and the development of a method to standardize the data to decrease the biases from surveys without sampling design and different efforts (Gutiérrez-Estrada et al. 2020). Considering the similarity in the temporal and spatial trends among the data sources herein, the standardization and the criteria used for collecting, filtering, and storing social media data proved to be efficient to extract occurrences of the Portuguese man-of-war in Brazil. It was common to obtain different sightings of Portuguese man-of-war temporally and spatially close, especially in massive and frequent strandings, reinforcing that these observations were made in real-time and helping to validate the social media data. In fact, an important aspect of social media data was the ability to monitor sightings in real-time, which would help to give researchers and managers more frequent and timely information about health risks. Since the stranding of Portuguese man-of-war is a real public health issue across the Brazilian coast and the widespread of social media represents a mass of users who may provide a sufficient volume of occurrences, this data source can be a cost-effective approach in which everyone is able to help in the challenge of monitoring its populations.

Although we still do not know the origin of the colonies or more detailed information about the reproduction and population dynamics of Portuguese man-of-war in Brazil, we showed that the temporal distribution of this species along the Brazilian coast begins in the north during the winter and goes south in warmer months, with outbreaks mainly during the summer in the southern regions. From the occurrences and abundances compiled in the present study, the highest number of colonies were recorded during winter in the North and Northeast coasts, during spring in the East, and during summer in the Southeast and South. However, the number of colonies concentrated during the high-risk level only in the Northeast, Southeast, and South coasts. Further, from the temporal trends observed herein, apparently, there is an interannual cyclicity in Portuguese man-of-war occurrence on the Brazilian coast, with higher abundances every 3-5 years. But there is still not enough long-term data to verify this hypothesis. The interannual variability in abundance is common for Portuguese man-of-war in other parts of the world (Prieto et al. 2015; Canepa et al. 2020) and the same is true along the Brazilian coast.

Large-scale phenomena are known to influence the interannual variability of the Portuguese man-of-war, mainly associated with changes in the wind regime. For example, in the Mediterranean, the North Atlantic Oscillation index and the Arctic Oscillation index explained the occurrence of the Portuguese man-of-war in the summer of 2010 (Pietro et al. 2015). In the present study, the year 2020 presented the highest number of colonies. In 2020, a La Niña event started in September, reaching the moderate event category in a few months of 2021, which may have contributed to the results obtained herein. We raised this hypothesis, based on the observations obtained by Ferreira-Bastos et al. (2017) which also suggested that the increase in the number of accidents in São Luís during 2007/2008 would have related to the La Niña phenomenon, but further investigations of Portuguese man-of-war distribution in relation to environmental variables are also still necessary to test this hypothesis.

Despite having remarkable morphological characteristics, such as size, format, and colors, this study is a pioneer in proposing a methodology to obtain spatiotemporal information about Portuguese man-of-war from data generated spontaneously in social media. As far as we know, only one previous study investigated mentions of *Physalia physalis* in Facebook groups about marine fauna, obtaining five posts with images of this species, of which three presented geospatial information (Chamberlain 2014, 2018; https://www.purpleoctopus.org/groupsourcing/). This project used the 'groupsourcing' technique to obtain observation data about diverse marine species, in other words, it extracted information from mentions of species made by users of social media in specific groups, with 93% of success in identifying the image in relation to the mentioned species.

During a jellyfish occurrence investigation using Twitter and voluntary citizen science, previous researchers reported that the social media content often did not provide information on abundance (Laudy et al. 2020). But, in the present study, social media was far more likely to provide information about Portuguese man-of-war abundance than any other data source. Although the volume of data from social media was almost 8 times greater than the volume of data from literature and personal observations and communications, the contribution from social media about the quantitative abundance of Portuguese man-of-war was similar to that provided by personal communications and observations and higher than literature. Moreover, social media contributed mostly to obtaining information about qualitative abundance, which may also be used to understand the spatiotemporal distribution of Portuguese man-of-war as shown in the present study and in previous investigations of jellyfish occurrences using citizen science (Gutiérrez-Estrada et al. 2021; Bourg et al. 2022).

The most immediate and obvious value of the observations on social media was in determining the spatiotemporal distribution of Portuguese man-of-war. But social media also provided valuable information about accidents and risky interactions between humans and jellyfish, contributing to about 50% and 70% of total records in the present study, respectively. Most people can easily identify this species as the cause of accidents (Freitas et al. 1995; Aquino et al. 2019), as we observed here in social media posts. In general, the victims report Portuguese man-of-war injuries over several regions of the body, however, the most common sites affected are the legs, arms, and hands (Haddad Júnior et al. 2002, 2013; Cristiano 2011; Ferreira-Bastos et al. 2017; Aquino et al. 2019; Silva 2019; present study).

Although it is dangerous, it is also possible to observe viral videos on social media of people holding, bursting, licking, and biting the Portuguese man-of-war in Brazil and abroad (e.g., TikTok 2023). Image-based social media provides the benefit of recording human-animal interactions regardless of the awareness level of the users (Sullivan et al. 2019). The instances of risky behaviors associated with social media usage noted in the present study, give us a better understanding of this issue that is underestimated by traditional means.

In addition to information about the spatiotemporal distribution of Portuguese man-of-war and interactions of this species with humans, we also obtained ecological relations of this species with others, including rare records in the literature. For example, we showed the first record of the ghost crab (*Ocypode quadrata*) scavenging on the stranded Portuguese man-of-war (*Physalia physalis*) in Brazil (Nascimento et al 2022). Another example of rare ecological relation is the scavenging of Portuguese man-of-war by the ants *Camponotus sericeiventris*. To the best of our knowledge, there is no information about insects predating gelatinous organisms in the literature. But the isopod *Scyphax ornatus*, also a terrestrial arthropod, is known to consume pleustonic hydrozoans, such as *Physalia physalis* and *Velella velella* (Quilter 1987; Ates 2017). Crabs and ants are well-known scavengers, but most food webs underappreciate scavenging (Wilson and Wolkovich 2011). A mass of jellyfish strandings on the beach can increase the input of carbon to beach environments, given that these are poorly productive environments (Pitt et al. 2014). Then, getting these sightings are important to better understand interactions and energy flows associated with marine carrion.

Challenges and limitations

Despite the promising results here obtained for Portuguese man-of-war occurrences, it is important to mention the limitations and challenges we face in the investigation of social media. Social media data are not generated systematically or conducted by specific campaigns developed by researchers, with associated biases (Ghermandi and Sinclar 2019). This data source usually presents more observations in urbanized beaches and more accessible coastal regions and during the period with appropriate conditions to go to the beach, in the warmer months (Estima and Painho 2013; Papafitsoros et al. 2023; present study), which proved to be useful to analyze the spatiotemporal distribution of health risks associated with Portuguese man-of-war in the present study but may devaluate this data source for the analysis of species distribution. For example, in the North Coast, the number of records extracted from social media was limited, especially when compared to the Northeast, which may be related to a lower rate of urbanization and not necessarily to the lesser occurrence of the Portuguese man-of-war. In addition, the lower number of records on the North and East coasts may be related to the higher number of colonies during the medium and low-risk periods, with fewer people on the beaches and consequently few observations shared on the web. Nevertheless, biases associated with sampling efforts are expected in citizens-derived data, whether it is intentionally generated or not (Pace et al. 2019; Tang et al. 2021).

The number of records was lower in 2022 than the previous years, despite the number of Instagram users increasing in Brazil. It might mean that the occurrences of Portuguese man-of-war along the Brazilian were lower in 2022 since the records from the other data sources also decreased in this year. But this result may also be influenced by the changes in the way of using the Instagram platform. Since 2022, algorithms prioritize videos and not valued photos as much as before, discouraging users to post photos, which may significate a decrease in the number of records from social media, since the photos represented more than 90% of the records obtained here from this data source. However, further investigations are still necessary to analyze the influence of this change in the next years. Further, the highest number of Portuguese man-of-war records was obtained in 2020, but the volume of data on the web increased this year due to the pandemic restrictions (Statista 2022b), which may also be influenced the data obtained herein from social media.

The combination of social media along with research data is also relevant to confirm the inferences in the species distribution obtained from this non-traditional methodology. For example, to compare if citizen observations shared on social media are similar to experts' records obtained from systematic surveys (Pace et al. 2019). In the present study, ground truth data were only obtained from field samplings about Portuguese man-of-war distribution in Brazil extracted from literature (e.g., Cristiano 2011; Silva 2018; Francisco 2022) along with field samplings conducted by LSN. But the volume of ground truth data provided by researchers is still small, especially if compared with social media and other citizens' data sources. Although the distribution patterns of Portuguese man-of-war obtained from social media were similar to those previously recorded on research surveys, the scarcity of controlled and structured data difficult to properly validate the higher volume of data obtained here through opportunistic observations. Regardless of this, we observed similarities between records extracted from social media with other opportunistic observations from citizen science platform, online news, and personal observations and communications. The same was true for the investigation in Malta; the authors also found corresponding trends between jellyfish occurrences extracted from online sources (Twitter, Google+, blogs, and online news) and citizen science, especially at the peak period (Jovanovic and Vukelic 2015). Then, we can infer that if there are a lot of people talking about some event it is highly likely that it is real, which ends up validating the data obtained from social media.

In the present investigation, the Portuguese man-of-war images from social media were many times not accompanied by geographic information and were not included in our baseline. In addition, although it was common to achieve observations close in time and space in social media, the user did not provide the exact date of observation for most posts extracted here (78%), which can be a source of error for some observations. For example, it is possible that users may post a picture from years ago and not say so. The posts could also be intentionally misleading by users about when or where an image was taken. It is still possible for users to tag a post with the wrong location. In this regard, social media data is considered to be supplemental to traditional data, but the volume of data presents a valuable resource, providing adequate quality controls are used.

Future research

The next step of the present research is to analyze the spatiotemporal distribution of Portuguese man-of-war in Brazil according to environmental variables, especially the wind, which is known as the main responsible for strandings. Moreover, we intend to access the biases associated with social media data in order to improve the analysis of species distribution by investigating the uneven sampling effort and exploring the potential existence of preferential locations (Powney and Isaac 2015; Tang et al. 2021). We also intend to expand the methodology here applied to the Portuguese man-of-war through social media for other jellyfish that occur on the Brazilian coast. Furthermore, multi-platform studies could also be beneficial as each social media platform offers an additional group of users and different demographics that could provide different data or benefit from specific posts.

The jellyfish observations extracted and filtered from social media may also contribute to the creation of drift models based on oceanographic variables and machine-learning techniques (Laudy et al. 2020). In the drift models, early jellyfish warnings report on the Portuguese man-of-war and their spatial and temporal distribution and predict potential stranding locations before they reach public beaches, installations, and tourist zones along the coast in order for local authorities and industries in affected areas to respond appropriately (Ferrer and Pastor 2017; Headlam et al. 2020). The possibility to monitor and forecast Portuguese man-of-war strandings is of global interest in human health, and the ability to achieve human observations at a massive scale and to cross-reference such data across a variety of sources and modalities (e.g. data entry, texts, and images) presents a unique opportunity to obtain information regarding the stranding events (in space and time).

Besides Brazil, the spontaneous data generated by citizens through social media may act as an inexpensive solution to supplement traditional knowledge about the ecology of the Portuguese man-of-war and to gather extensive spatiotemporal data for real-time monitoring and for the development of management priorities worldwide. The growing presence of humans in aquatic environments has increased the probability of contact with jellyfish and risks of envenomation, but also the sharing of occurrences and accidents on social media. With the increasing need for studying jellyfish ecology and distribution, passive citizen science through social media can be widely explored to manage the under-monitored jellyfish distribution, promoting its monitoring allied to the ubiquitous and efficient digital technologies, and helping to inform future surveillance and mitigation measures for blooms in the Anthropocene coasts.

There is historical evidence that jellyfish have been more numerous over the past years in certain areas (Mills 2001; Brotz et al. 2012; Bosch-Belmar et al. 2020). However, there are still critical knowledge gaps associated with the abundance of jellyfish and the impacts of localized increases, and social media can help to complement data and contribute to the investigation of “a more gelatinous future” (Richardson et al. 2009). For example, pelagic hydrozoans such as Portuguese man-of-war are bioindicators of hydrographic conditions

(Graham et al. 2001; Edwards 2012) and information about its stranding dynamics is relevant to understand the effects of major disturbances such as global climate change (Canepa et al. 2020).

Other examples of ecological insights about marine species which can also be extracted from social media are the extension (Deidun et al. 2017) and delimitation (Kovačić et al. 2023) of species distribution ranges, and information about ecological relations (Pace et al. 2019). For example, invasions of Portuguese man-of-war have become increasingly common (e.g., Fathalli et al. 2020; Boughamou and Ladoul 2022), and social media data containing observations of these animals can help to detect and monitor these invasions. Moreover, as shown in the present study, it is possible to obtain rare observations of ecological relations with jellyfish from social media data, also contributing to citizen science practices.

The interest generated by social media posts about these organisms presents an opportunity for researchers and managers to provide animal-specific information or suggest best practices to an audience that is likely to be receptive. Indeed, visitors and residents seem to prefer social media dissemination to acquire information about jellyfish coastal hazards (Riley 2018; Crowley-Cyr et al. 2022). There are many misconceptions about jellyfish, so the scientific community should help vet the information presented on social media and the web in general (Licuanan et al. 2021). In addition, social media data may also contribute to obtaining information about stings on beachgoers, such as sting sites and complications (Licuanan et al. 2021; present study).

Understanding public perceptions is critical for addressing human-wildlife conflicts (Dickman et al. 2010). Social media can also provide information about the motivations and perceptions of beachgoers about jellyfish since we observed many posts containing positive and negative perceptions in relation to Portuguese man-of-war. For example, it was common to observe posts containing Portuguese man-of-war observations evoking an emotional response and an alert (e.g., “Caution! Beautiful and danger! Today I saw several #portuguesemanofwar on the beach!”). Previous studies already obtained valuable information about public perceptions and preferences towards wildlife extracted from social media (Sbragaglia et al. 2022; Leitão et al. 2022), and the same must be done for jellyfish through sentiment analysis and by the analysis of “likes”, for example.

The Portuguese man-of-war has marked morphological characteristics such as its pneumatophore and vivid colors in pinkish and bluish tones which facilitates its identification and consequently the image classification by machine learning (Correia et al. 2020). Recently, within the scope of the present study, an investigation conducted on the automating classification of Portuguese man-of-war images extracted from Instagram using a Convolutional Neural Network (CNN) obtained satisfactory results, with 94% of accuracy and 95% precision (Carneiro et al. 2022), highlighting the potential to improve real-time monitoring of health risks associated with Portuguese man-of-war through machine learning applied for the social media database here obtained. Another proposal that still is in development is the automation of the other filtering steps of social media data developed here, such as extracting from geotags and captions the geographical location of posts with Portuguese man-of-war images (Reips and Hara 2022; Rocha and Hara 2022; Camargo et al. 2023). The management of image-ID and other tools may facilitate the integration of data from collective knowledge shared on social media with other data sources, being a cost-effective strategy to monitor Portuguese man-of-war.

Conclusions

The present study is a pioneering initiative to assess the large-scale and long-term spatiotemporal distribution and health risks of Portuguese man-of-war in Brazil. The recent observations mainly extracted from social media allowed the real-time monitoring of Portuguese man-of-war, with the highest number of colonies occurring during the winter northwards and during summer in the southwards, with occurrences during the high-risk level especially in the Northeast, Southeast, and South coasts. As it can be a source of information efficient in terms of cost and time, social media is becoming a rich source of data on species occurrence and, therefore, is a new and promising alternative to monitor jellyfish distribution, seasonality, and other ecological information, particularly in tourist destinations scarcely investigated.

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Declarations

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Conflicts of interest

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

Ethical approval

The Human Research Ethics Committee of Federal University of Paraná (CEP/UFPR) manifests itself by the approval of Research Project number 4.751.477 on 02.06.2021, CAAE: 46505721.7.0000.0102. No animal testing was performed during this study.

Informed consent

A Free and Informed Consent Form (FICF) was presented to the collaborators before the contact focused on animal observation, as directed by the CEP/UFPR.

Data availability

We compiled data for this study through the inspection of publicly available images on the web.

Supplementary material

Online resource 1. Data about Portuguese man-of-war observations compiled for the Brazilian coast according to each data source.

CONCLUSÕES

A partir deste esforço pioneiro de obtenção de registros de águas-vivas por meio de observações espontâneas compartilhadas nas redes sociais, descobrimos que estas plataformas são úteis para monitorar as águas-vivas ao longo da costa brasileira. Confirmando nossa hipótese de estudo, as redes sociais permitiram a coleta de observações de águas-vivas, ajudando a preencher lacunas de conhecimento, complementando a informação existente e potencialmente contribuindo para a gestão dos seus impactos negativos e serviços ecossistêmicos. Ao comparar e combinar várias fontes de dados, foi possível entender melhor a distribuição de algumas espécies de águas-vivas no Brasil e construir uma ferramenta útil para monitorar a sua ecologia e os seus perigos a partir das redes sociais.

Aqui, apresentamos uma revisão das oportunidades e desafios desta abordagem de pesquisa para estudar espécies marinhas em todo o mundo; dois estudos detalhados com metodologias específicas desenvolvidas para detectar e examinar registros de espécies conspícuas de águas-vivas derivados sistematicamente de fotos e vídeos em redes sociais, com insights ecológicos relevantes; e mais dois estudos de caso de primeiros registros baseados em observações oportunistas de águas-vivas extraídas das redes sociais. Sendo assim, criamos recursos de dados em larga escala temporal e espacial sobre a distribuição de *Drymonema gorgo* e *Physalia physalis* no Brasil. Além disso, também obtivemos registros raros na literatura mundial, como a ocorrência de *Stygiomedusa gigantea* em baixas latitudes e a relação de predação de *Ocypode* sp. e *Camponotus sericeiventris* sobre a *Physalia physalis*.

Os aspectos logísticos e financeiros podem representar barreiras para investigações marinhas com notáveis lacunas de conhecimento nas distribuições das espécies. Isto é especialmente verdade para as águas-vivas, que geralmente são difíceis de detectar e coletar, sofrendo com a falta de dados primários de biodiversidade e sendo historicamente negligenciadas nas pesquisas. Entretanto, analisando imagens, textos, geotags e hashtags nas redes sociais, foi possível mapear a distribuição de águas-vivas no Brasil, o que comem, o que as come e suas interações com os humanos. Sendo assim, o uso do conhecimento coletivo compartilhado nas redes sociais aqui investigado provou ser uma fonte de dados econômica e poderosa para monitorar as suas ocorrências.

Apesar do potencial de aplicação da ciência cidadã passiva para estudos ecológicos no Brasil devido ao grande número de usuários de redes sociais, esta investigação não foi realizada anteriormente para águas-vivas no país. Além disso, a exploração da rede social como fonte de dados também é incipiente para águas-vivas em todo o mundo, com apenas alguns estudos anteriores desenvolvidos no Mediterrâneo (Jovanovic e Vukelic 2015; Kienberger e Pietro 2017; Laudy et al. 2020; Rizgalla e Crocetta 2020), enfatizando a importância dos resultados aqui obtidos.

Os dados das redes sociais parecem ser especialmente relevantes para as grandes espécies marinhas, como as grandes águas-vivas, provavelmente porque os grandes tamanhos favorecem a sua detecção pelos humanos e os pequenos animais não parecem ter o mesmo impacto no ambiente humano. Essas criaturas majestosas invocam uma ampla gama de emoções nos seres humanos, do medo ao espanto, ao carinho e à inspiração, o que desperta o interesse do público pelo oceano. Além disso, as águas-vivas grandes também tendem a ser mais robustas do que as espécies menores e, portanto, geralmente possuem algumas características que podem ser usadas para identificá-las (até certo ponto) a partir de imagens extraídas da web.

Os benefícios do uso das redes sociais são moderados pelos muitos desafios e limitações de dados, como por exemplo os viéses de observação em localidades muito visitadas e em períodos mais quentes do ano. Entretanto, esta pesquisa mostra o enorme potencial das redes sociais em fornecer observações de espécies marinhas. É muito provável que as redes sociais representem oportunidades cada vez mais valiosas e o presente estudo pode ser uma base para recomendações de conversas e propostas para iniciativas de pesquisa e educação no Brasil e no mundo.

CONCLUSIONS

From this pioneering effort to obtain jellyfish records using spontaneous observations shared on social media, we found that these platforms are useful for monitoring jellyfish along the Brazilian coast. Confirming our study hypothesis, social media allowed the collection of jellyfish observations, helping to fill knowledge gaps, complement existing information, and potentially contributing to the management of its negative impacts and ecosystem services. By comparing and combining multiple data sources, it was possible to better understand the distribution of some jellyfish in Brazil and build a useful tool for monitoring its ecology and hazards through social media.

Here, we presented a review of the opportunities and challenges of this research approach to study marine species; two detailed studies with specific methodologies developed to detect and examine records of conspicuous jellyfish systematically derived from photos and videos on social media, with relevant ecological insights; and more two case studies of first records based on opportunistic observations of jellyfish extracted from social media. Then, we created large-scale data resources about the distribution of *Drymonema gorgo* and *Physalia physalis* in Brazil. Further, we also obtained rare records such as the occurrence of *Stygiomedusa gigantea* at low latitudes and the predation of *Ocypode* sp. and *Camponotus sericeiventris* on *Physalia physalis*.

The logistical and financial aspects may represent barriers to marine investigations with notable knowledge gaps in the species distributions. This is especially true for jellyfish which are usually difficult to detect and collect, suffering from a lack of primary biodiversity data and being historically overlooked in research. But, by analyzing the images, texts, geotags, and hashtags on social media it was possible to map the distribution of jellyfish species in Brazil, what they eat, what eats them, and their interactions with humans. Then, the use of collective knowledge shared on social media here investigated proved to be a cost-effective and powerful data source to monitor jellyfish occurrences.

Despite the potential to apply passive citizen science for ecological studies in Brazil due to the high number of social media users, this investigation was not previously performed for jellyfish in the country. Further, the exploration of social media as a data source is also incipient for jellyfish worldwide, with only a few previous studies developed in the Mediterranean Sea (Jovanovic and Vukelic 2015; Kienberger and Pietro 2017; Laudy et al. 2020; Rizgalla and Crocetta 2020), emphasizing the importance of the results obtained here.

Social media data seem to be especially relevant for large marine species, such as macro jellyfishes, probably because large sizes favor its detection by humans and small animals do not seem to have the same impact on the human environment. These majestic creatures invoke a wide range of emotions in humans from fear to astonishment, to caring, to inspiration, which ignites the public's interest in the ocean. In addition, large jellyfish also tend to be more robust than smaller species and so should have some features that can be used to identify them (to some level) from images extracted from the web.

The benefits of using social media are moderated by the many challenges and limitations of data, such as observation biases in highly visited locations and in warmer periods of the year. However, this research shows the enormous potential of social networks in providing observations of marine species. It is very likely that social networks represent increasingly valuable opportunities and the present study can be a basis for recommendations for conversations and proposals for research and education initiatives in Brazil and worldwide.

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