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COMPORTAMENTO ALIMENTAR DO PETREL-GIGANTE-DO-SUL NA ANTÁRTICA:

seleção de habitat, variação individual e efeitos da personalidade

São Leopoldo
2023

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Tese apresentada como requisito parcial para obtenção do título de Doutora em Biologia, pelo Programa de Pós-Graduação em Biologia da Universidade do Vale do Rio dos Sinos (UNISINOS).

Orientadora: Prof.ª Dra. Maria Virginia Petry
Coorientador: Dr. Lucas Krüger Garcia

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“The quality I look for most is optimism: especially optimism in the face of reverses and apparent defeat. Optimism is true moral courage.” (Ernest H. Shackleton)

RESUMO

A variabilidade intraespecífica no comportamento de forrageio de aves marinhas é um fato conhecido. Além de variações associadas ao sexo, classes morfológicas ou idade é comum que indivíduos se especializem sua alimentação em graus variados, alguns sendo altamente fiéis a áreas específicas e consistentes em suas estratégias de forrageio. A variação individual pode ter importantes implicações para a espécie. Estudos recentes indicam que personalidade – a variação individual consistente em traços comportamentais, por ex. ousadia ou agressão – pode levar os indivíduos a diferirem em seu comportamento de forrageio. O objetivo geral dessa tese foi investigar diferenças sexuais e individuais na seleção de habitat e no comportamento de forrageio de petréis-gigantes-do-sul (*Macronectes giganteus*) e os efeitos da personalidade sobre esses padrões. A população de petréis-gigantes aqui estudada reproduz na Ilha Nelson, na Antártica Marítima. Foram utilizados dispositivos GPS de rastreamento para investigar a distribuição reprodutiva e o comportamento de forrageio em fina escala de 67 indivíduos nas estações reprodutivas de 2019/2020 e 2021/2022. Também foi aplicado o teste comportamental "resposta a um objeto novo" para definir a personalidade dos indivíduos rastreados, através do seu nível de ousadia. S*tep-selection functions* foram utilizadas para investigar quais variáveis ambientais determinam a seleção de habitat alimentar, análises de repetibilidade e índices de afinidade de Bhattacharyya foram utilizados para investigar a consistência nas métricas e nas áreas de forrageio ao longo da reprodução, respectivamente. A população também foi monitorada constantemente para identificar potenciais comportamentos alimentares oportunísticos. Os petréis-gigantes apresentaram uma ampla distribuição espacial ao longo da reprodução. Fêmeas forragearam ao longo de toda a Península Antártica oeste enquanto machos se concentraram na costa da porção noroeste. A proximidade a colônias de pinguim influenciou fortemente a seleção de habitat de forrageio de machos, enquanto para fêmeas a profundidade da coluna d'água foi mais importante. Ambos os sexos sobrepuseram sua distribuição com áreas utilizadas pela pesca na Antártica e fêmeas, em particular, utilizaram áreas com atividade pesqueira na plataforma continental da Patagônia Argentina. A população apresentou consistência média nas áreas de forrageio entre viagens, assim como na distância máxima e duração das viagens de alimentação. Apesar da existência de variação interindividual de personalidade, ela não influenciou na consistência das áreas de forrageio, nem nas métricas das viagens. A principal fonte de variação se deu em termos de estágio reprodutivo e sexo. O canibalismo intergeracional e a coprofagia de fezes de foca-de-Weddell foram registrados pela primeira vez para a espécie. O primeiro comportamento, expresso apenas por machos, foi possivelmente resultado de especialização individual nesse recurso. O segundo, expresso por fêmeas e machos, ocorreu principalmente após longos turnos de incubação, provavelmente para recuperar-se rapidamente do jejum antes de uma viagem longa de alimentação. Devido à sua ampla distribuição na Península Antártica, de uma seleção de habitat associada a zonas marinhas variadas e a colônias de pinguins, áreas de descanso de foca e de atividade pesqueira, a espécie se configura como uma importante plataforma para monitorar populações isoladas e atividades de pesca ilegal dentro e fora da Antártica.

Palavras-chave: Distribuição reprodutiva. Seleção de habitat. Consistência individual. Canibalismo. Coprofagia.

ABSTRACT

The intraspecific variability in the foraging behavior of seabirds is a known fact. In addition to variations associated with sex, morphological classes or age, it is common for individuals to specialize their feeding behavior to varying degrees, some being highly faithful to specific areas and consistent in their foraging strategies. Individual variation in foraging can have important implications for the species. Recent studies indicate that animal personality – consistent individual variation in behavioral traits, e.g. boldness or aggression – can lead individuals to differ in their foraging behavior. The overall goal of this thesis was to investigate sexual and individual differences in habitat selection and foraging behavior of southern giant petrels (*Macronectes giganteus*) and the effects of personality on these patterns. The giant petrel population studied here breeds on Nelson Island, in the maritime Antarctic. GPS tracking devices were used to investigate the breeding distribution and fine-scale foraging behavior of 67 individuals throughout the 2019/2020 and 2021/2022 breeding seasons. The behavioral test "response to a novel object" was also applied to define the personality of tracked individuals, based on their level of boldness. Step-selection functions were used to investigate which environmental variables determine foraging habitat selection, analysis of repeatability and Bhattacharyya affinity indexes were used to investigate consistency in metrics and foraging areas throughout breeding, respectively. The population was also constantly monitored to identify potential opportunistic feeding behaviors. Giant petrels showed a wide spatial distribution during reproduction. Females foraged along the entire western Antarctic Peninsula while males were concentrated along the northwest coast. Proximity to penguin colonies strongly influenced foraging habitat selection for males, while for females, water column depth was more important. Both sexes overlapped their distribution with fishing areas in Antarctica and females, in particular, used areas with fishing effort on the continental shelf of Patagonia Argentina. The population showed average consistency in foraging areas between trips, as well as in the maximum distance and duration of foraging trips. Despite the existence of inter-individual personality variation, it did not influence the consistency of foraging areas, nor the metrics of trips. The main source of variation was in terms of breeding stage and sex. Intergenerational cannibalism and coprophagy of Weddell seal feces were recorded for the first time for the species. The first behavior, expressed only by males, was possibly the result of individual specialization in this resource. The second, expressed by both females and males, occurred mainly after long incubation shifts, probably to quickly recover from fasting before a long feeding trip. Due to its wide distribution in the Antarctic Peninsula, a selection of habitat associated with varied marine zones, penguin colonies, seal resting areas and fishing activities, the species is configured as an important platform to monitor isolated populations and activities. illegal fishing in and out of Antarctica.

Key-words: Breeding distribution. Habitat selection. Individual consistency. Cannibalism. Coprophagy.

SUMÁRIO

APRESENTAÇÃO

A presente tese, intitulada "Comportamento alimentar do petrel-gigante-do-sul na Antártica: seleção de habitat, variação individual e efeitos da personalidade", está estruturada na seguinte forma: possui uma introdução geral, onde consta o referencial teórico, objetivos e hipóteses, seguida de quatro capítulos onde são apresentados os resultados na forma de artigos científicos e considerações finais. Ao final, estão incluídos um apêndice e anexos. No apêndice A constam as licenças de coleta, no anexo A as folhas de rosto dos três artigos da tese já publicados e o comprovante de submissão do capítulo 2. No segundo anexo, constam as folhas de rosto de outros quatro artigos científicos publicados no período do doutorado (B), e nos seguintes (C – G) outras produções bibliográficas (por exemplo, resumos de congresso) e de divulgação científica que comprovam as diferentes dimensões que compuseram este processo de doutoramento.

O primeiro capítulo, intitulado "*Habitat selection of southern giant petrels: potential environmental monitors of the Antarctic Peninsula*", investiga a seleção de habitat e a distribuição espacial reprodutiva de petréis-gigantes-do-sul com enfoque na utilização de sua ampla distribuição como plataforma para monitorar ambientes remotos e populações da Península Antártica. Este capítulo foi publicado no periódico *Antarctic Science* (https://doi.org/10.1017/S0954102023000147), e está, portanto, de acordo com as normas desse.

O segundo capítulo, intitulado "*Personality does not predict short-term consistency in the foraging behavior of a highly dimorphic Antarctic seabird*" investiga a existência de influência da personalidade sobre a consistência individual nas áreas e estratégias de forrageio de petréis-gigantes-do-sul ao longo da reprodução. O artigo está formatado de acordo com as normas do periódico *Animal Behaviour*, ao qual foi submetido.

O terceiro capítulo, intitulado "*Cannibalism in southern giant petrels (Macronectes giganteus) at Nelson Island, Maritime Antarctic Peninsula*" descreve um comportamento alimentar inédito para a espécie, o canibalismo intergeracional e explora hipóteses para explicar a ocorrência deste raro comportamento. Este capítulo foi publicado no periódico *Polar Biology* (https://doi.org/10.1007/s00300-021-02859-8) e está, portanto, de acordo com as normas desse.

O quarto capítulo, intitulado "*Coprophagic behaviour of southern giant petrels (Macronectes giganteus) during breeding period*", foi desenvolvido em coautoria e além de descrever outro comportamento alimentar inédito para a espécie, a coprofagia associada a focas, investiga a frequência e padrões de atendimento a áreas de descanso de focas por petréis-gigantes, e salienta a relevância dessa fonte de alimento como quebra-jejum durante o período de incubação. Este capítulo foi publicado no periódico *Polar Biology* (https://doi.org/10.1007/s00300-020-02757-5) e está, portanto, de acordo com as normas desse.

1 INTRODUÇÃO GERAL

1.1 A seleção de habitat em aves marinhas

A distribuição espacial das aves marinhas é definida pelas suas características ecológicas, morfológicas e comportamentais, bem como pelos aspectos abióticos e bióticos do meio marinho (FURNESS e MONAGHAN, 1987; NEWTON, 2010). A disponibilidade de alimento (ABRAMS, 1985), proximidade da colônia (ORIANS e PEARSON, 1987), ventos, salinidade, temperatura da superfície (ABRAMS, 1985), frentes marinhas (ABRAMS, 1985; ACHA *et al.*, 2004; BOST *et al.*, 2009), a batimetria e profundidade da coluna d'água (RIBIC *et al.*, 2008), a produtividade primária, e concentração de clorofila (ABRAMS, 1985) e presença de barcos de pesca (GARTHE e HUPPOP, 1994; GONZÁLEZ-ZEVALLOS e YORIO, 2006; COPELLO *et al.*, 2009) são os principais fatores que atuam sobre a distribuição (AINLEY, 1980; GARTHE, 1997; WEICHLER *et al.*, 2004; KRÜGER e PETRY, 2011).

Durante o período reprodutivo, aves marinhas da região subantártica e antártica geralmente estão associadas a temperaturas de superfície mais frias (QUILLFELDT *et al.*, 2015; THIERS *et al.*, 2014), frentes marinhas e redemoinhos (BOST *et al.*, 2009), e a outros locais de alta concentração de produtividade que se configuram como *hotspots* de biodiversidade (SANTORA *et al.*, 2017). O uso dessas regiões de produtividade tem a finalidade de otimizar suas viagens de forrageio e adquirir recursos mais próximos à área de reprodução (PHILLIPS *et al.*, 2004; AWKERMAN *et al.*, 2005). Durante o período de inverno os indivíduos não mais limitados pela necessidade de incubar o ovo e alimentar a prole, podem se deslocar para áreas mais distantes e se distribuir associadas à locais com maiores concentrações de fauna marinha (*e.g.*, NAVARRO et al., 2015; RIBIC et al., 2008; THIERS et al., 2014)

As populações de aves marinhas têm sofrido declínios globais nas últimas décadas devido a pressões variadas sobre os ecossistemas que habitam, como a predação e distúrbio por espécies invasoras, a captura incidental na pesca, a sobrepesca, a poluição e as mudanças climáticas (CROXALL et al., 2012; DIAS et al., 2019). Nas regiões subantárticas e antárticas especificamente, mudanças climáticas têm provocado ao longo das últimas três décadas alterações físicas no ecossistema marinho, dentre as quais, as mais evidentes são o aumento da temperatura da superfície do mar (CLARKE *et al.*, 2007), a redução e a variação na extensão da camada de gelo marinho (SCHOFIELD *et al.*, 2018; VORRATH *et al.*, 2020), aumento das áreas terrestres livres de gelo (LEE *et al.*, 2017) e o deslocamento das frentes oceânicas em direção ao sul (BÖNING *et al.*, 2008). Atividades econômicas como a pesca, através da captura incidental e dos descartes, o turismo e a pesquisa científica também podem influenciar as dinâmicas das comunidades antárticas (AINLEY; PAULY, 2014; BARBRAUD *et al.*, 2012; TRIVELPIECE *et al.*, 2011). Essas pressões em grande escala sobre o ecossistema provocam respostas da biota, como por exemplo alterações fenotípicas (*e.g.*, mudanças na distribuição e na dieta) (PÉRON *et al.*, 2010) e mudanças demográficas das populações (CONSTABLE *et al.*, 2014; JENOUVRIE *et al.*, 2018; ROLLAND; WEIMERSKIRCH; BARBRAUD, 2010; SALMERÓN *et al.*, 2023). Essas respostas são mais visíveis nas populações de predadores de topo, pois eles integram ou amplificam os efeitos das mudanças climáticas e impactos antrópicos devido à sua alta posição trófica (CROXALL; TRATHAN; MURPHY, 2002). Apesar de muitas populações de aves marinhas serem afetadas negativamente, algumas espécies oportunistas podem apresentar tendências populacionais positivas ao utilizar como recurso adicional o descarte da pesca. Este consumo parece favorecer o aumento da taxa de sobrevivência da população, especialmente quando as condições ambientais estão desfavoráveis e a disponibilidade de recursos naturais é baixa. (KRÜGER *et al.*, 2017; QUINTANA *et al.*, 2006).

A variação natural nas condições ambientais e na disponibilidade de recursos por si só, são fatores que atuam no surgimento de novos fenótipos entre e dentre as populações de aves (GRANT; GRANT, 2002). Nesse cenário, indivíduos de espécies com ampla distribuição espacial e, portanto, submetidos a diferentes condições ambientais, podem desenvolver traços fenotípicos particulares, a fim de explorar os recursos disponíveis em cada local (JAKUBAS; JAKUBAS; JENSEN, 2014; KRÜGER *et al.*, 2018a). Essa variação intraespecífica no uso de recursos provoca mudanças nas interações consumidor-presa, promovendo o aumento da diversidade ecológica e, portanto, da estabilidade populacional (BOLNICK *et al.*, 2011). Por outro lado, submete indivíduos de uma mesma população a diferentes pressões seletivas (VAN VALEN, 1965; BOLNICK *et al.*, 2003). Portanto, o avanço da compreensão sobre a ecologia dos predadores de topo, considerando as variações intraespecíficas, é essencial para que possamos inferir a suscetibilidade ou resiliência das espécies às mudanças climáticas, impactos antrópicos e alterações no ambiente (NUSSEY; WILSON; BROMMER, 2007).

1.2 Personalidade e o comportamento de forrageio

A personalidade animal (às vezes também chamada de temperamento) refere-se a diferenças individuais em traços comportamentais fundamentais, que são consistentes ao longo do tempo e em diferentes contextos (RÉALE *et al.*, 2007). Ela é uma das variações fenotípicas que pode moldar a forma como os indivíduos respondem às condições ambientais, e alguns traços de personalidade podem ser, por exemplo, prejudicados e ter sua eficiência de forrageio reduzida em cenários de mudança climática (KRÜGER *et al.*, 2019).

Normalmente, esses traços comportamentais são organizadas em cinco eixos principais: (1) timidez-ousadia, como um animal responde ao risco; (2) agressividade, a tendência de um animal a reações agonísticas contra membros da mesma espécie; (3) atividade, o nível de comportamento ativo que um animal mostra em um ambiente familiar e sem riscos; (4) exploração, a reação de um animal a um novo cenário; (5) sociabilidade, a resposta (não agressiva) de um animal à presença de membros da mesma espécie; indivíduos sociais buscam a presença de conspecíficos, enquanto os não-sociais evitam (RÉALE *et al.*, 2007). Frequentemente, esses eixos de personalidade estão correlacionados em um conjunto de traços comportamentais, ou “síndromes comportamentais” (SIH *et al.*, 2004); como por exemplo, o caso das aranhas de teia de funil *Agelenopsis aperta* que exibem respostas mais ousadas a um teste de emergência (são mais rápidas para reemergir de seu funil após uma tentativa de predação simulada) também são mais agressivas em relação aos conspecíficos (RIECHERT *et al.*, 1993).

A pesquisa sobre a personalidade animal tem crescido nas últimas duas décadas, e revela um fenômeno taxonomicamente onipresente de que a variação individual dessas características é surpreendentemente baixa (GOSLING, 2001; RÉALE *et al.*, 2007; BELL; HANKISON; LASKOWSKI, 2009), e de que a variação de personalidade tem grandes implicações para os processos evolutivos e ecológicos (RÉALE *et al.*, 2007; SIH *et al.*, 2004, 2012). É provável que as diferenças de personalidade entre os indivíduos influenciem os comportamentos de forrageio e, particularmente, os movimentos de forrageio, por diversos motivos (TOSCANO *et al.*, 2016; SPIEGEL *et al.*, 2017).

Os métodos utilizados pelos pesquisadores para avaliar os traços de personalidade geralmente medem diretamente as tendências de movimento dos animais (por exemplo, atividade, exploração). O eixo ousado-tímido (*bold-shy*), que capta como um animal responde ao risco, é frequentemente medido como a propensão do indivíduo entrar ou sair de uma situação de risco (por exemplo, latência para emergir em um novo ambiente, SCHIRMER *et al.* 2019; resposta a um objeto novo, KRÜGER *et al.*, 2019; HARRIS *et al.*, 2020). Em um contexto ecológico mais amplo, tal característica pode explicar por que alguns indivíduos têm tendência a forragear em habitat aberto versus protegido (por exemplo no caso de cervos, CIUTI *et al.*

2012). Grande parte da variação individual observada nos movimentos de forrageio de animais pode, portanto, estar relacionada diretamente a variação na personalidade animal (NILSSON *et al.*, 2014).

Por exemplo, em anos de condições ambientais desfavoráveis e consequentemente de baixa disponibilidade de alimento, indivíduos “tímidos” da espécie *Calonectris diomedea* (Aves: Procellariidae) foram forçados a forragear em áreas pelágicas distantes da colônia, uma vez os indivíduos mais “ousados” dominaram os recursos nas proximidades por competição exclusiva (*e.g.*, KRÜGER *et al.*, 2019; PATRICK; WEIMERSKIRCH, 2014). Essa exclusão poderia tornar os indivíduos tímidos mais propensos a utilizar áreas pelágicas onde ocorrem os descartes da pesca, o que pode ser vantajoso em períodos de escassez de presas naturais (FURNESS, 2003). Por outro lado, uma parte significante dos descartes é composta por peixes demersais que tendem a ter um menor conteúdo lipídico em comparação a peixes pelágicos, que são presas naturais das aves (ARCOS; ORO, 2002). Por essa razão, para algumas espécies, os descartes podem ser considerados “*junk food*”, ou seja, alimentos sub-ótimos, já que os parâmetros de história de vida são reduzidos quando algumas espécies de aves marinhas se alimentam de presas de baixa caloria (GRÉMILLET *et al.*, 2008). Se apenas uma personalidade em particular é afetada, tanto pelo consumo de descartes, quanto pelas mudanças climáticas, podem ocorrer fortes consequências para a dinâmica da população (BARBRAUD *et al.*, 2013). Sendo assim, compreender quais fenótipos são mais afetados por esses impactos é importante para prever mudanças futuras a nível populacional e específico.

As escolhas que um indivíduo faz de onde forragear são afetadas por muitas variáveis, incluindo a qualidade e a distribuição das manchas de alimento no ambiente e o custo de deslocamento entre elas (CHARNOV, 1976; MEHLHORN *et al.*, 2015). Para espécies que se alimentam em ambientes onde os recursos estão distribuídos irregularmente em diferentes níveis de previsibilidade, como as aves marinhas, a competição por recursos cria um trade-off entre obter informações sobre onde se alimentar (exploração) e alimentar-se (exploração) (O *trade-off* exploração- exploração) (COHEN; MCCLURE; YU, 2007; ELIASSEN *et al.*, 2007; KRAMER; WEARY, 1991; MEHLHORN *et al.*, 2015). Estudos recentes mostram que a escolha de uma estratégia de forrageio de um indivíduo, ou seja, onde ele se encontra no *trade-off* exploração-exploração, está altamente correlacionado com sua posição no eixo ousado-tímido (PATRICK; PINAUD; WEIMERSKIRCH, 2017). Aves ousadas tendem a mostrar níveis mais altos de comportamento agressivo em resposta a novos objetos em comparação com aves mais tímidas (PATRICK; CHARMANTIER; WEIMERSKIRCH, 2013).

Em um ambiente relativamente imprevisível onde a comida é distribuída de forma irregular, personalidades mais ousadas tendem a mover-se rapidamente pelo ambiente e a explorar uma maior variedade de áreas, mesmo aquelas que não oferecem grande qualidade (ou seja, não têm grandes quantidades de alimento). Indivíduos com personalidades mais tímidas gastam mais tempo procurando uma mancha de alimento e, portanto, visitam menos manchas com alta qualidade e exploram totalmente cada área que visitam (JEFFRIES; PATRICK; POTTS, 2021; PATRICK; PINAUD; WEIMERSKIRCH, 2017)

Nesse contexto, se uma personalidade em particular é mais negativamente afetada por suas escolhas nas estratégias de forrageio, devido ao consumo de descartes ou às mudanças climáticas, podem ocorrer fortes consequências para a dinâmica da população (BARBRAUD *et al.*, 2013). Sendo assim, compreender quais fenótipos são mais afetados por esses impactos é importante para prever mudanças futuras a nível populacional e específico. No atual contexto de mudanças climáticas e de exploração de recursos naturais em águas antárticas, definir o uso do habitat e a vulnerabilidade da população frente a esses impactos é de suma importância para entender o quão flexíveis essas espécies podem ser às mudanças ambientais futuras.

1.3 Espécie modelo: o petrel-gigante-do-sul

O petrel-gigante-do-sul (*Macronectes giganteus;* daqui em diante “petrel-gigante”) (Gmelin, 1789) é um Procellariiforme de grande porte (3 – 5.5 kg; envergadura de 150–210 cm), sexualmente dimórfico, com hábitos reprodutivos coloniais de superfície e com distribuição na região patagônica, antártica e subantártica (CARBONERAS; JUTGLAR; KIRWAN, 2020) (Figura 1). A espécie apresenta o maior dimorfismo sexual dentre todas as aves marinhas, e machos são 30% mais pesados e 15% maiores que as fêmeas (COPELLO; QUINTANA; SOMOZA, 2006). A espécie não está ameaçada de extinção (status de ameaça Pouco Preocupante; BIRDLIFE 2023) e a última análise populacional global realizada estimou uma população de 30.575 pares reprodutivos no início dos anos 2000 (PATTERSON *et al.*, 2008). Globalmente, a espécie apresenta tendência populacional crescente, mas apresenta variações em diferentes regiões. Na Antártica, onde a população foi estimada em 5700 pares reprodutivos (PATTERSON *et al.*, 2008), tem apresentado declínios em algumas localidades das Ilhas Shetland do Sul (*e.g.*, Ilha Nelson: KRÜGER, 2019; Ilha Pinguim: HARRIS *et al.*, 2015 e Ilha Rei George: SANDER *et al.*, 2006) e aumentos em outras (*e.g.*, Ilha Elefante: PETRY *et al.*, 2018). Os aumentos na Antártica têm sido associados com o consumo de descartes da pesca e a proibição de acessos a áreas reprodutivas para turismo (KRÜGER *et al.*, 2017; SILVA *et al.*, 1998) e em outras regiões, como na Patagônia, a aumentos das populações de presas (COPELLO; QUINTANA, 2009; COPELLO, SOFÍA; QUINTANA, 2003; KRÜGER *et al.*, 2017; QUINTANA *et al.*, 2006).

Figura 1 - Ilustração de um casal de petrel-gigante-do-sul (*Macronectes giganteus*); à esquerda uma fêmea e à direita um macho.

Fonte: Elaborado pela autora

Na Antártica, os petréis-gigantes iniciam seu ciclo reprodutivo em meados de outubro e novembro com a cópula e postura de um ovo, seguida da incubação até o início de janeiro. Nesse período, os adultos alternam o atendimento ao ninho, que consiste em longos períodos de incubação em que um membro do par permanece em jejum, enquanto o outro se alimenta no mar. Quando o filhote eclode, nas primeiras semanas de janeiro, inicia-se o período de guarda intensiva do ninhego, que precisa da presença do adulto a todo o momento para a manutenção da sua temperatura corporal. Nesse estágio, os adultos fazem turnos de guarda mais curtos, devido à necessidade de alimentar constantemente o filhote. Cerca de três semanas depois, os filhotes começam a ser deixados sozinhos no ninho por algumas horas e conforme a estação avança, os adultos chegam a ficar dias longe do ninho, até a sua saída definitiva da colônia em abril (GONZÁLEZ-SOLÍS; CROXALL; WOOD, 2000; OTOVIC *et al.*, 2018; WARHAM, 1962; Observações pessoais).

Com hábitos alimentares generalistas, o petrel-gigante possui uma dieta composta por carcaças, placentas de mamíferos e indivíduos vivos de aves e mamíferos marinhos, e por lulas, crustáceos, peixes, descartes da pesca e, eventualmente, resíduos de cozinha de embarcações (COPELLO; QUINTANA; PÉREZ, 2008; HUNTER, 1983; observação pessoal). Assim, a espécie é considerada uma espécie necrófaga oportunista e predadora de topo nos ecossistemas subantárticos e antárticos (HUNTER, 1985). Os petréis-gigantes apresentam uma ampla gama de estratégias de predação, como a captura de superfície, o mergulho de perseguição, o afogamento, espancamento e o agarramento das presas com o bico (WARHAM 1996). Devido à essa plasticidade, a cada ano novos comportamentos alimentares ou novos tipos de presas integram o repertório alimentar da espécie (*e.g.*, consumo de carcaças no ninho: JONES; RISI; COOPER, 2019; predação de filhotes de lobo-marinho: NAGEL *et al.*, 2022; predação de albatrozes adultos: RISI *et al.*, 2021; predação de carne de cachalotes: TOWERS; GASCO, 2020)

Durante o período da reprodução, a espécie utiliza ambientes pelágicos, costeiros e terrestres como zonas de forrageio (GRANROTH-WILDING; PHILLIPS, 2019). No período não reprodutivo, já livres da necessidade de atender o ninho, utilizam uma amplitude maior de áreas, incluindo a zona oceânica e, no caso das populações da Ilha Elefante, a plataforma continental da América do Sul no Atlântico e Pacífico (KRÜGER *et al.*, 2018). Os sexos comumente apresentam áreas de forrageio espacialmente segregadas para reduzir a competição intersexual, especialmente durante a estação reprodutiva (GONZÁLEZ-SOLÍS; CROXALL; AFANASYEV, 2007; GRANROTH-WILDING; PHILLIPS, 2019). Fêmeas utilizam predominantemente áreas pelágicas e sua dieta é composta sobretudo de lulas e crustáceos, enquanto os machos apresentam distribuição mais costeira e terrestre, se concentrando em áreas reprodutivas ou de descanso de aves e mamíferos, se alimentando primariamente das carcaças desses animais (COPELLO *et al.*, 2011; FORERO *et al.*, 2005a; GONZÁLEZ-SOLÍS; CROXALL; AFANASYEV, 2007; HUNTER, 1983; RAYA REY *et al.*, 2012).

Assim como para muitas espécies de aves marinhas, as áreas de forrageio de petréis-gigantes estão sobrepostas a áreas de atividade pesqueira, e a espécie frequentemente interage com embarcações de espinhel e traineiras em busca dos descartes de vísceras (COPELLO; QUINTANA, 2009; KRÜGER *et al.*, 2017; THIERS *et al.*, 2014), de aves feridas e mortas por petrechos das embarcações (GONZÁLEZ-ZEVALLOS; YORIO, 2006) ou mesmo de cetáceos que depredam o pescado (TOWERS; GASCO, 2020). As taxas de interações fatais da espécie com petrechos pesqueiros, como por exemplo a captura incidental em anzóis de espinhel ou a colisão e afogamento por contato com de redes de arrasto, são baixas se comparadas às de albatrozes dos gêneros *Thalassarche* sp. e *Diomedea* sp., e de pardelas *Procellaria* sp. (TUCK *et al.*, 2011). Justamente por conta disso, o crescimento populacional do petrel-gigante em algumas localidades foi atribuído ao consumo dos descartes durante a estação não reprodutiva (Patagônia: COPELLO; QUINTANA, 2009; COPELLO, SOFÍA; QUINTANA, 2003; QUINTANA *et al.*, 2006; Ilha Elefante, Antártica: KRÜGER *et al.*, 2017). No entanto, as taxas de mortalidade ainda são altas para algumas modalidades de pesca e regiões, como por exemplo, a pesca de arrasto nas Ilhas Malvinas/Falklands onde, entre 2016/2017, ao menos 75 petréis-gigantes foram mortos. Porém, a mortalidade é possivelmente muito maior devido a eventos de colisão com as redes que não resultaram em morte imediata (KUEPFER, 2017). Existem evidências de que o impacto da pesca sobre a espécie seja enviesado para classes de idade e sexo, especialmente devido a diferenças na distribuição espacial, e, portanto, na frequência de exposição a embarcações (BUGONI; GRIFFITHS; FURNESS, 2011; GIANUCA *et al.*, 2019; KRÜGER *et al.*, 2017; THIERS *et al.*, 2014). Fêmeas de petrel-gigante apresentam maior probabilidade de se alimentar de descartes ou de serem capturadas incidentalmente na pesca de espinhel nas águas das Ilhas Malvinas/Falklands (NEL; RYAN; WATKLNS, 2002) e Ilhas Príncipe Eduardo, no sul do Oceano Índico (OTLEY *et al.*, 2007). A sobrevivência de fêmeas da espécie congênere, *Macronectes halli,* também foi negativamente afetada pelo esforço de pesca de espinhel pelágico em populações das Ilhas Geórgia do Sul (GIANUCA *et al.*, 2019).

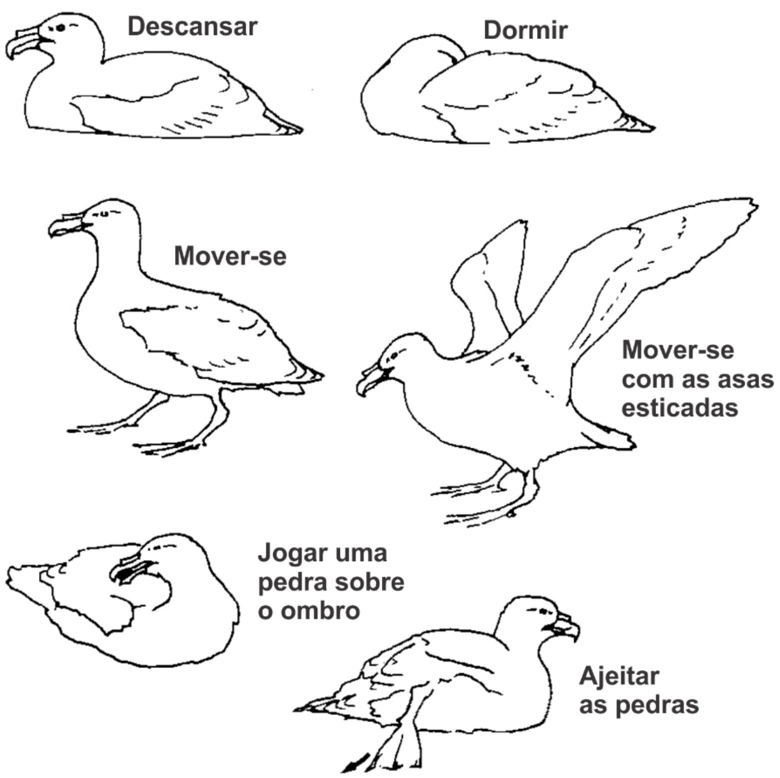
Enquanto a ecologia espacial de populações de petréis-gigantes reproduzindo em áreas subantárticas é bem conhecida (GONZÁLEZ-SOLÍS; CROXALL; AFANASYEV, 2007; GRANROTH-WILDING; PHILLIPS, 2019; THIERS *et al.*, 2014; TREBILCO *et al.*, 2008), poucas informações existem sobre a distribuição espacial das populações reproduzindo acima de 60°S (zona antártica), com exceção de uma população que reproduz na Ilha Elefante (KRÜGER *et al.*, 2017, 2018; PETRY *et al.*, 2018). As fêmeas, devido aos seus hábitos oceânicos de forrageio, buscam alimento, em média, a distâncias maiores da colônia que machos e fazem viagem mais longas, tanto em termos de distância percorrida quanto em duração. Em uma população do Oceano Índico, por exemplo, fêmeas chegam a forragear em áreas a mais de 1.466 km de distância da colônia durante a reprodução e podem percorrer cerca de 5.000 km em viagens de até 15 dias (THIERS *et al*., 2014). Por outro lado, machos da mesma população percorrem em média 2.645 ± 1.608 km em suas viagens, que duram, em média, 10 dias (THIERS *et al.*, 2014).

Os dados de distribuição publicados para a região Antártica, no entanto, são apenas do período não reprodutivo e de baixa resolução espacial (o método utilizado, de rastreio por geolocalização, apenas permite dois pontos diários com um erro médio de ~150 km), dificultando análises precisas sobre a interação com atividades de pesca, uso e seleção de habitat e comportamento alimentar de alta resolução. Atualmente, interações com a pesca durante a estação reprodutiva para a região não estão descritas na literatura científica. No entanto, com o aumento do esforço de pesca de krill (*Euphausia superba*) e de peixes demersais do gênero *Dissostichus* sp. nos meses de verão (SANTA CRUZ; KRÜGER; CÁRDENAS, 2022), espera-se que as populações de petrel-gigante-do-sul tirem vantagem desses recursos, assim como as populações subantárticas o fazem (COPELLO; QUINTANA, 2009). Devido à ampla distribuição de forrageio das fêmeas, é possível que elas interajam com embarcações pesqueiras fora dos limites da Antártica mesmo durante o período reprodutivo e, portanto, fora da proteção das áreas reguladas pela Comissão para a Conservação de Recursos Vivos Marinhos da Antártica (CCAMLR, na sigla em inglês).

1.4 O comportamento social do petrel-gigante-do-sul

Ao contrário de muitas espécies pertencentes à família Procellariidae que reproduzem em cavidades ou penhascos, petréis-gigantes são diurnos e utilizam superfícies amplas e com topografia relativamente plana para construir suas colônias. A alta densidade e o contato frequente entre indivíduos da mesma colônia, facilitado pela topografia, levou ao surgimento de um complexo comportamento social na espécie, o mais elaborado dentre os membros da sua família (BRETAGNOLLE, 1988; WARHAM, 1962). Os comportamentos sociais são aqueles relacionados, por exemplo, a aspectos funcionais da territorialidade sobre recursos alimentares ou o ninho, hierarquia social e evitamento de predadores, enquanto o comportamento sexual está relacionado a formação de pares, cópula e relações entre pares (BRETAGNOLLE, 1988). Ademais, petréis-gigantes, assim como outras aves, possuem comportamentos chamados “elementares”. Comportamentos como bocejar, descansar, dormir, ajeitar as penas, caminhar e ajeitar as pedras do ninho (Figura 2) são distinguidos do comportamento social, uma vez que não funcionam como sinalizações a outras aves (BRETAGNOLLE, 1988).

Figura 2 - Atos elementares do petrel-gigante-do-sul, relacionados ao descanso, movimentação ou manutenção do ninho



Fonte: adaptado de Bretagnolle (1988)

Dentre os comportamentos sociais descritos na literatura (BRETAGNOLLE, 1988; WARHAM, 1962) estão: os *displays* de alarme (Fig. 3a e 3b), nos quais a ave estica levemente o bico para a frente, permanece quieta e pode ou não eriçar as penas da nuca. Através desse display agonístico, a ave comunica para aves ou observadores que estão distantes que está atenta a sua presença; a postura apaziguadora, na qual a ave fica em posição similar ao *display* de alarme, mas o bico é esticado para cima (Figura 3c). Essa postura tem o papel de apaziguar e demonstrar submissão ao outro indivíduo; a postura "*sealmaster*", na qual o indivíduo fica de pé com o corpo inclinado para frente com as asas quase esticadas ou semiencolhidas sobre a lateral do corpo, as penas do dorso e costas eriçadas ou não, e a cauda espanada ou não (Figura 3d e 3e). Essa postura é geralmente utilizada para se aproximar de um recurso alimentar e defendê-lo de outras aves. Outros comportamentos são: a postura de ameaça ereta na qual a ave permanece de pé com as asas semiabertas com um aspecto "quebrado", balança a cabeça lateralmente e vocaliza "relinchos" e rosnados (Figura 3f); a postura de ameaça direcionada para frente, na qual a ave mantém as asas esticadas e a cauda espanada e já não está apenas sinalizando, mas sim se movendo em direção ao seu oponente; a atitude de baixa intensidade (ABI; Figura 3h) e de baixa intensidade de pé (ABI de pé; Figura 3i), na qual a ave está deitada e “varre” a cabeça bilateralmente avançando no máximo 120° em relação ao seu eixo central (3h) ou de pé movendo a cabeça até 200° (3f). Em ambos os comportamentos a ave vocaliza “relinchos” e rosnados que tem o objetivo de sinalizar comportamento agonístico a aves em geral. A ABI “de pé” é mais utilizada para sinalizar a aves que estão próximas. Por fim, existem os *displays* de ameaça, no quais a ave está deitada no ninho e permanece com a cabeça esticada, vocalizando rosnados e investindo para frente, podendo chegar a cuspir óleo estomacal (Figura 3j) ou “varrendo” a cabeça como na atitude de baixa intensidade (Figura 3k). Esses dois comportamentos são realizados quando a ave está incubando ou guardando o filhote no ninho e alguma outra ave exibe um comportamento agonístico próximo a ela. Cuspir óleo estomacal é um comportamento de agressividade extremo e é muito comum para afastar potenciais predadores de filhotes (*e.g*., skuas) e humanos que se aproximam. A postura de defesa (Figura 4l) pode ser exibida também durante alguma interferência humana e geralmente quando o observador se aproxima da ave observando-a de cima (BRETAGNOLLE, 1988; WARHAM, 1962).

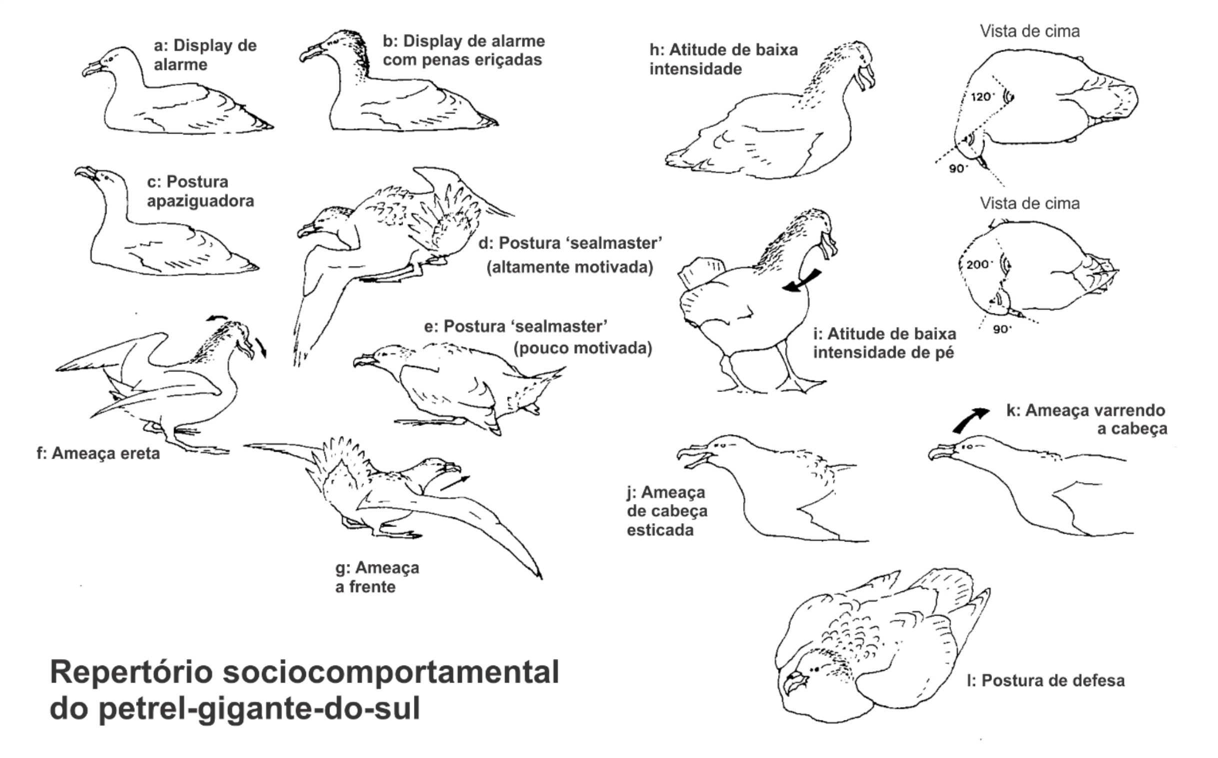
A frequência dos comportamentos exibidos difere marcadamente entre os sexos, com fêmeas realizando *displays* em frequência mais baixa que machos. Alguns *displays*, como a postura apaziguadora e a evasão da área, são mais comuns em fêmeas, enquanto *displays* agonísticos são mais comuns para machos (BRETAGNOLLE, 1989). No entanto, observações de campo indicam que indivíduos reagem consistentemente de forma distinta a presença de humanos nas colônias, alguns apresentando reações mais tímidas e submissas e outros mais agonísticas, mesmo dentre o mesmo sexo (observação pessoal). Ou seja, há variabilidade interindividual e personalidades diferentes. No entanto, apesar do amplo repertório sociocomportamental da espécie, o papel da personalidade sobre o comportamento de forrageio nunca foi explorado para o petrel-gigante-do-sul.

1.5 Características da área de estudo

A população de petrel-gigante-do-sul investigada nesta tese reproduz na Ponta Harmonia (62°18’S; 59° 14’W), uma porção de terra localizada no sudeste da Ilha Nelson, que é parte do Arquipélago das Ilhas Shetland do Sul, na Antártica marítima (Figura 4). Boa parte da área se torna livre de gelo durante o verão, possibilitando a reprodução de cerca de 480 pares reprodutivos de petrel-gigante (KRÜGER, 2019) e de grandes populações de pinguim-antártico

(*Pygoscelis antarcticus*), de pinguim-papua (*P. papua*) e de outras nove espécies de aves marinhas (SILVA *et al.*, 1998).

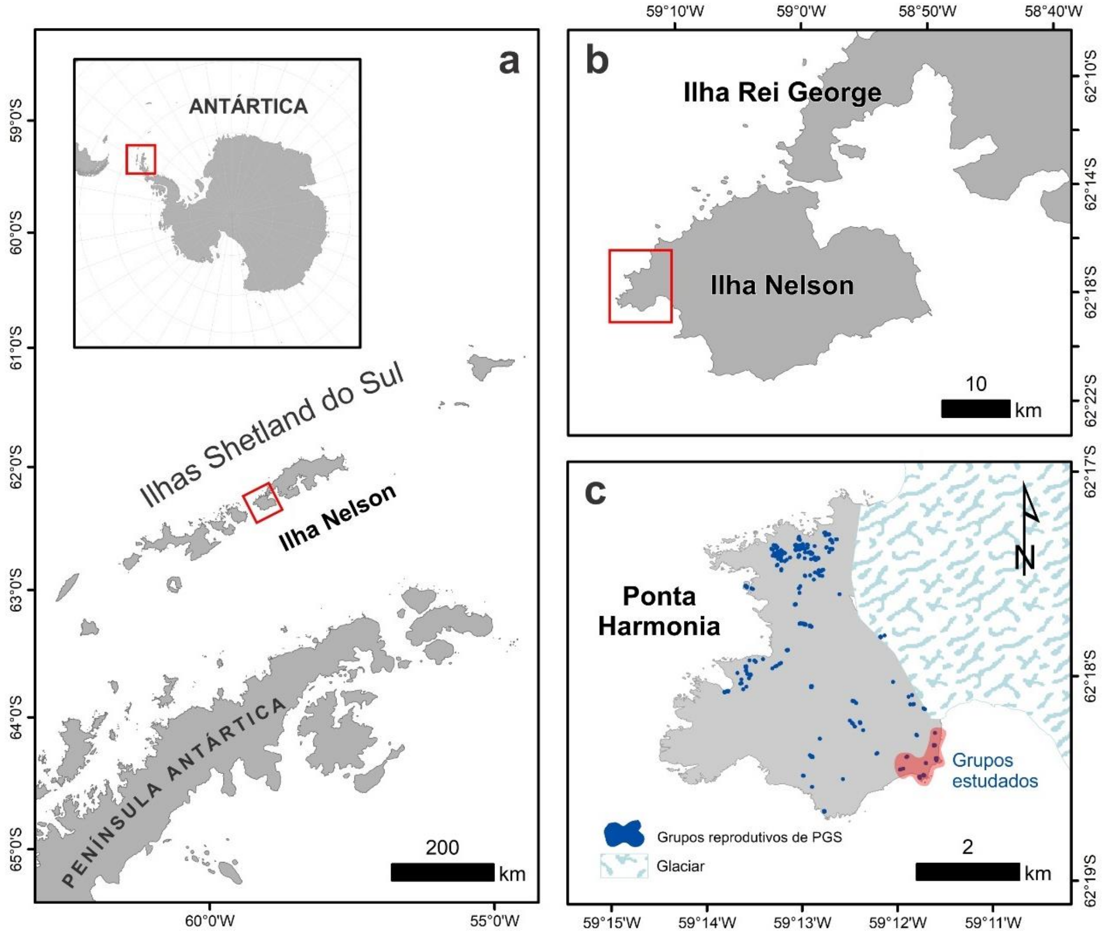
Figura 3 - Comportamentos sociais do petrel-gigante-do-sul, relacionados a comunicação com conspecíficos ou a respostas à ameaças



Fonte: adaptado de Bretagnolle (1988)

A Ilha Nelson está localizada a noroeste da Península Antártica, a região da Antártica que tem experienciado as mudanças ambientais e climáticas mais rápidas (CONVEY; PECK, 2019) e o maior impacto antrópico local (TIN; LIGGETT; LAMERS, 2014). A perda de gelo marinho e a redução na duração da temporada de gelo marinho (SCHOFIELD *et al.*, 2018; VORRATH *et al.*, 2020), a contração rápida das geleiras (Silva *et al.* 2020), expansão de áreas livres de gelo (LEE *et al.*, 2017), as mudanças nas comunidades de plâncton (KIM; KIM, 2021; SCHOFIELD *et al.*, 2018; SCHULTZ *et al.*, 2021), a provável redução de biomassa e a contração na distribuição de krill para o sul (ATKINSON *et al.*, 2019; TRATHAN *et al.*, 2021) são algumas das mudanças ambientais observadas na região.

Figura 4 – Localização da Ilha Nelson, a noroeste da Península Antártica (a) e da Ponta Harmonia (b), onde está localizada a população de petrel-gigante-do-sul investigada na presente tese



Fonte: elaborado pela autora

A região logo ao norte das Ilhas Shetland do Sul e, sobretudo, o Estreito de Bransfield são as principais áreas de atividade da pesca de krill-antártico (*Euphausia superba*) na região antártica, e esta tem se intensificado desde 2010 (SANTA CRUZ; KRÜGER; CÁRDENAS, 2022). Além dos riscos das interações de petrechos pesqueiros com a fauna, há evidências de que a pesca contribui para flutuações nas populações de pinguins-antárticos, uma das espécies-presa do petrel-gigante, devido ao seu impacto sinergético com as mudanças climáticas (KRÜGER *et al.*, 2021a). Ademais, Nelson está situada logo à esquerda da Ilha Rei George (Figura 2), o principal centro logístico da Antártica marítima, onde uma alta densidade de embarcações de vários operadores logísticos nacionais atua, especialmente durante o verão austral (BENDER; CROSBIE; LYNCH, 2016; FINGER *et al.*, 2021). Desde 1998, a Ponta Harmonia foi classificada como uma Área Antártica Especialmente Protegida de n° 133 devido a suas comunidades representativas de aves marinhas e de ecossistemas terrestres (ATCM, 2012). Apesar de estar livre do impacto de atividades de turismo, a área é frequentada durante os verões austrais por pequenos grupos de pesquisadores. Há evidências de poluição por detritos antropogênicos de origem remota que chegam via correntes marítimas, poluição oriunda de embarcações e de estações de pesquisa do entorno e até mesmo de edificações locais (FINGER *et al.*, 2021). Ainda que não tenham sido registrados impactos diretos, detritos antropogênicos (i.e., vidro) já foram encontrados em ninhos de petrel-gigante na área (FINGER *et al.*, 2021). De modo geral, toda a região das Shetland do Sul tem sido afetada pela contaminação não só de detritos sintéticos, mas de efluentes de água residual de estações de tratamento, queima de combustíveis fósseis, incineração de detritos e derramamentos acidentais de combustíveis (BARGAGLI, 2008). Ainda que o monitoramento contínuo dessas mudanças ambientais seja primordial, a escala do continente e os custos associados tornam bastante desafiador que pesquisadores e órgãos reguladores consigam realizar a cobertura de tantas áreas vulneráveis.

1.6 Predadores de topo como sentinelas dos ecossistemas marinhos

Os grandes predadores marinhos têm sido considerados como ferramentas para monitorar mudanças nos ecossistemas devido à sua distribuição em larga escala e por amplificarem informações tróficas em múltiplas escalas espaço-temporais (HAZEN *et al.*, 2019; SERGIO *et al.*, 2008). As aves marinhas, devido às suas associações de habitat (KRÜGER 2022; TAM *et al.*, 2017; VELARDE; ANDERSON; EZCURRA, 2019) e acesso mais fácil em comparação com outros grupos de predadores marinhos de topo, foram propostas como sentinelas oceânicas ideais (KRÜGER 2022; LASCELLES *et al.*, 2012).

Por exemplo, as fortes associações do pinguim-imperador (*Aptenodytes forsteri*) com o gelo marinho os tornam sentinelas das mudanças climáticas na Antártica (JENOUVRIER *et al.*, 2021), enquanto os pinguins *Pygoscelis* spp., que são especialistas em krill, podem indicar o estado das populações do crustáceo (LYNNES; REID; CROXALL, 2004). Por outro lado, as espécies de aves marinhas generalistas a nível populacional estão geralmente associadas a uma vasta gama de condições ambientais e/ou habitats e podem atuar como monitores de impactos humanos em grandes escalas espaciais. Os albatrozes, por exemplo, têm sido sugeridos como sentinelas da pesca ilegal, não declarada e não regulamentada (IUU, na sigla em inglês) nas latitudes médias do Oceano Antártico, devido à sua ampla distribuição oceânica e propensão a interagir com embarcações de pesca (WEIMERSKIRCH *et al.*, 2020). Os albatrozes modificam seu comportamento de busca de alimento quando estão interagindo com embarcações e, por exemplo, as características de sinuosidade da sua trajetória e tempo de permanência em uma área restrita de busca de alimento (ARS, na sigla em inglês) são indicativos dessa interação (CORBEAU *et al.*, 2019).

As associações com embarcações pesqueiras, os variados habitats utilizados por petréis-gigantes ao longo do ano, sua posição como predador/necrófago na teia trófica antártica e seu grande tamanho corporal, tornam a espécie uma potencial plataforma de monitoramento do estado das populações e dos ambientes antárticos. Por exemplo, petréis-gigantes-do-sul já foram utilizados como monitores de níveis de poluição antrópica por poluentes orgânicos persistentes (COLABUONO *et al.*, 2016) e elementos-traço (GONZÁLEZ-SOLÍS; SANPERA; RUIZ, 2002; TREVIZANI *et al.*, 2022) no Oceano Austral e das tendências de liberação de lixo por embarcações pesqueiras (PEROLD; SCHOOMBIE; RYAN, 2020; PHILLIPS; WALUDA, 2020). Devido ao papel que a espécie possui na regulação de populações nos ecossistemas subantárticos e antárticos (HUNTER, 1985) e da sua ampla área de forrageio, o petrel-gigante se configura como uma espécie ideal a ser estudada para a identificação de áreas marinhas importantes para a conservação, especialmente na região antártica onde é uma das principais espécies predadoras de topo. A definição das variações individuais também é importante devido às possíveis implicações para a conservação da própria espécie. (BOLNICK *et al.*, 2003; BEARHOP *et al.*, 2004).

1.7 Objetivo

1.7.1 Objetivo Geral

O objetivo geral dessa tese é investigar diferenças sexuais e individuais na seleção de habitat e no comportamento de forrageio de petréis-gigantes-do-sul (*Macronectes giganteus*) e os efeitos da personalidade sobre esses padrões.

1.7.2 Objetivos específicos

- Investigar a distribuição reprodutiva e a seleção de habitat de petréis-gigantes-do-sul, enfatizando diferenças intersexuais e variações ao longo da reprodução, com o intuito de propor o uso da espécie como plataforma monitoradora de ambientes remotos na Antártica;

- Investigar a sobreposição da distribuição reprodutiva de petréis-gigantes-do-sul com atividades pesqueiras no Oceano Austral;
- Investigar a ocorrência de consistência individual em áreas de forrageio ao longo do período reprodutivo e nas características de viagens de forrageio;
- Investigar diferenças na personalidade de indivíduos;
- Testar se a personalidade dos indivíduos prediz a ocorrência de diferenças no grau de consistência individual;
- Descrever os hábitos alimentares oportunísticos da espécie.

1.8 Hipóteses

a) Considerando a segregação espacial e alimentar conhecida para a espécie, espera-se que os machos façam viagens mais curtas e forrageiem em áreas mais próximas da colônia e estejam associados a colônias de pinguins e locais de descanso de focas, e que fêmeas façam viagens mais longas e mais duradouras e forrageiem em locais produtivos, zonas pelágicas e, em maior medida do que os machos, que utilizar zonas com atividades de pesca.
b) Uma vez que os recursos no ambiente terrestre são mais previsíveis, espera-se que machos mais ousados forrageiem e dominem os recursos mais próximos da colônia e sejam mais consistentes, enquanto machos mais tímidos busquem recursos em áreas mais distantes onde a competição é reduzida e sejam menos consistentes.
c) Uma vez que fêmeas se alimentam no ambiente pelágico que é menos previsível, espera-se que as fêmeas mais ousadas demonstrem um comportamento mais exploratório, forrageando por mais áreas e com viagens mais curtas que fêmeas mais tímidas, que devem preferir explorar menos e se deslocar mais até áreas com maior qualidade de recursos.

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Capítulo 1

Habitat selection of southern giant petrels: potential environmental monitors of the Antarctic Peninsula

CAPÍTULO 1

Habitat selection of southern giant petrels: potential environmental monitors of the Antarctic peninsula

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Abstract

The southern giant petrel (*Macronectes giganteus*) is a widely distributed top predator of the Southern Ocean. To define the fine-scale foraging areas and habitat use of Antarctic breeding populations, 47 southern giant petrels from Nelson Island were GPS-tracked during the summers of 2019–2020 and 2021–2022. Step-selection analysis was applied to test the effects of environmental variables on habitat selection. Visual overlap with seal haul-out sites and fishing areas was also analysed. Birds primarily used waters to the south of the colony in the Weddell and Bellingshausen seas. Females showed a broader distribution, reaching up to -70°S to the west of Nelson Island, while males were mainly concentrated in waters off the northern Antarctic Peninsula. Habitat selection of both sexes was associated with water depth and proximity to penguin colonies. Both overlapped their foraging areas with fishing sites and females in particular overlapped with toothfish fishery blocks in Antarctica and with fishing areas in the Patagonian Shelf. Due to their habitat associations and overlap with fisheries, when harnessed with tracking devices and animal-borne cameras, giant petrels can act as platforms for monitoring the condition and occurrence of penguin colonies, haul-out sites and unregulated fisheries on various temporal and spatial scales in Antarctica.

Key words: spatial distribution; spatial ecology; monitor species; maritime Antarctica; tracking

1. Introduction

The Antarctic Peninsula is the region of the Antarctic experiencing the fastest environmental changes (Convey & Peck 2019) and greatest local human impact (Tin *et al.* 2014). Loss of sea ice and the reduction in the length of the sea-ice season (Schofield *et al.* 2018, Vorrath *et al.* 2020), rapid glacier contraction (Silva *et al.* 2020), increased ice-free land (Lee *et al.* 2017), shifts in plankton communities (Schofield *et al.* 2018, Kim & Kim 2021, Schultz *et al.* 2021), probable biomass reduction and contraction in the southward distribution of krill (Atkinson *et al.* 2019, Trathan *et al.* 2022) are some of the observed environmental changes caused by warming. Increased fishing concentration (Nicol *et al.* 2012, Trathan *et al.* 2022, Santa Cruz *et al.* 2022) and increased human presence due to the intensification of tourism and scientific activities (Chown *et al.* 2012, Bender *et al.* 2016) have led to the contamination of several areas through the release of synthetic debris (Tirelli *et al.* 2020, Finger *et al.* 2021) and wastewater effluents, burning of fossil fuels, waste incineration and accidental spillage (Bargagli 2008). While it is important to continuously track these changes, it is challenging for researchers to simultaneously cover a substantial number of vulnerable areas.

Marine top predators have been considered as tools for monitoring ecosystem changes due to their large-scale distribution and because they amplify trophic information across multiple spatiotemporal scales (Sergio *et al.* 2008, Hazen *et al.* 2019). Seabirds, given their habitat associations (Tam *et al.* 2017, Velarde *et al.* 2019, Krüger 2022) and easier access in comparison to other groups of marine top predators, have been proposed as optimal ocean sentinels (Lascelles *et al.* 2012, Krüger 2022).

For instance, the strong associations of emperor penguins (*Aptenodytes forsteri*) with sea ice make them sentinels of climate change in Antarctica (Jenouvrier *et al.* 2021), while krill-specialist *Pygoscelis* spp. penguins can indicate the state of krill populations (Lynnes *et al.*

2004). On the other hand, population-level generalist seabird species are usually associated with a wide range of environmental conditions and/or habitats and can act as monitors of human impacts across large spatial scales. Albatrosses, for example, have been suggested as useful sentinels of illegal, unreported and unregulated (IUU) fishing in the mid-latitudes of the Southern Ocean due to their wide oceanic distribution and propensity to interact with fishing vessels (Weimerskirch *et al.* 2020).

Southern giant petrels (SGPs; *Macronectes giganteus*) are large (3.0–5.5 kg), avian generalist top predators and the main scavenger species of the Southern Ocean (Hunter 1985). In the Antarctic, they breed mainly on offshore islands of the Antarctic Peninsula, with an estimated population of 5409 breeding pairs on the South Shetland Islands (Patterson *et al.* 2008). During the breeding season, the species uses pelagic, coastal and terrestrial environments of the Antarctic as foraging zones (Granroth-Wilding & Phillips 2019, Corá *et al.* 2020). During the non-breeding season, they use a much wider range of areas as their foraging grounds, including the high seas and the continental shelf of the south-west Atlantic and south-east Pacific (Krüger *et al.* 2018). In terrestrial zones, giant petrels usually concentrate in areas with penguin colonies (Copello *et al.* 2011) and breeding and haul-out sites of seals, where they feed on carrion or faeces (Corá *et al.* 2020). Sexes commonly have spatially segregated foraging areas to decrease intersexual competition, especially during the breeding season (González-Solís *et al.* 2008, Granroth-Wilding & Phillips 2019). Females are mainly pelagic and feed primarily on marine prey, such as squid, fish and crustaceans, while males have a more coastal distribution and feed primarily on seabird and mammal carrion (Hunter 1983, Forero *et al.* 2005, González-Solís *et al.* 2008, Copello *et al.* 2011). Both sexes have been found to be attracted to fishing vessels for the consumption of discards on the south Atlantic Ocean and Indian Ocean (Otley *et al.* 2007, González-Solís *et al.* 2008, Thiers *et al.* 2014, Krüger *et al.* 2017). Due to their diverse habitat associations and top predator/scavenger position in the Antarctic trophic web, SGPs are a potential platform for monitoring the state of Antarctic populations and environments.

In this study, we show that, by continuously tracking movements of a single SGP population using GPS tracking devices, it is possible to assess a large array of areas and habitats along the Antarctic Peninsula. First, we describe foraging trip metrics and define foraging areas and important sites for the SGP population during reproduction using fine-scale GPS data and then run step-selection functions (SSFs) to identify which variables are responsible for sexes selecting a specific habitat, considering interindividual variability. Considering the known spatial and dietary segregation of the species, we expect males to make shorter trips, forage closer to the colony and be associated with penguin colonies and seal haul-out sites, and we expect females to make farther and longer trips, forage on productive, pelagic areas and, to a larger extent than males, to use areas with fishing activities.

2. Material and Methods

2.1 Tracking breeding southern giant petrels

Tracking data were obtained from SGPs breeding at Harmony Point, Nelson Island, Maritime Antarctica (62°18'S, 59°11'W). During the 2019–2020 and 2021–2022 seasons, 67 birds (33 females and 34 males) were tagged with GPS tracking devices: 18 were tracked with solar-powered GPS-UHF KITE-L devices (Ecotone Telemetry, 58 × 27 × 18 mm; 17 g), 4 with Axy-Trek Marine GPS loggers (TechnoSmArt, 40 × 20 × 8 mm; 14g), 8 with CatLog ThermoSeal GPS devices (Mr. Lee, 53 × 26 × 7 mm; 20 g), 16 with CatLog GPS devices with an epoxy-filled enclosure (Mr. Lee, 53 × 45 × 20 mm; 50 g) and 20 with BirdCam, a GPS device coupled to a small video camera (Mr. Lee, 70 × 26 × 17 mm; 24 g). KITE-L devices were attached using a backpack harness of tubular Teflon tape and the other devices were attached to dorsal feathers with 3M #2800 series duct tape and Loctite super glue. KITE-L and CatLog ThermoSeal devices were set to collect a fix every 5 min and Axy-Trek, BirdCam and CatLog epoxy devices were set to collect a fix every 10 min due to their lower battery capacity. KITE-L tracking data were downloaded to a local base station each time a bird returned to the colony following a foraging trip. Data from the other devices were downloaded following recapture at the end of the tracking period. Devices were removed from the birds by cutting supporting feathers with scissors. Birds were tracked for an average of 40.6 ± 8.9 days from 30 November 2019 to 25 January 2020 and for an average of 21.8 ± 6.9 days from 12 December 2021 to 25 January 2022. The tracking periods corresponded to the late egg incubation stage and the chick-rearing stage, the latter starting *ca.* 12 January.

2.2 Data processing

GPS data were filtered to remove locations at the nest. Due to data gaps and differences in fix sampling rates between devices, tracks were interpolated using the '*track_resample*' function of the '*amt*' *R* package (Signer *et al.* 2019) by resampling all locations to an equal 30 min interval, which was the highest median interval. Regular sampling rates are required for SSFs, because selection is not scale-invariant (Barnett & Moorcroft 2007, Signer *et al.* 2017), and thus sampling rates should be similar for different individuals.

2.3 Trip metrics

To determine foraging trip characteristics, we split tracking data into individual foraging trips using the '*tripSplit*' function in the '*track2KBA*' *R* package (Beal *et al.* 2021). We defined trips as periods of ≥ 1 h spent away from the colony at a distance of 250 m, since some individuals can make short trips and feed on seal faeces at the nearby glacier (Corá *et al.* 2020). We then calculated trip length (days), cumulative distance travelled between all locations (km) and maximum distance from the colony (km; hereafter 'maximum range') using the '*tripSummary*' function. Incomplete trips (unknown beginning or end dates) were removed from the analysis. The normality (Shapiro-Wilk test) and homoscedasticity (Bartlett test) of the data were verified before each statistical test. Generalized linear mixed models (GLMMs) with a penalized quasi-likelihood parameter estimation were used with trip metrics as response variables to assess differences between sexes, breeding stage and years. To incorporate the dependency among observations of the same individual, ID was used as a random intercept. We used a gamma error distribution with an inverse link function for cumulative distance and trip duration data and a Gaussian distribution with a log link function for maximum range data. We first evaluated whether a mixed model was necessary by running a linear model without a random effect (ID) and checking whether there was residual variance by plotting the residuals against the levels of ID. As residual variance was confirmed, we proceeded to select the most adequate mixed model by decreasing model complexity and comparing Akaike information criterion corrected for small sample sizes (AICc) values between models. Those with the highest AICc values were selected.

2.4 Estimating foraging areas

To visually identify geographical areas used by female and male SGPs, we computed 25%, 50%, 75% and 95% kernel utilization distributions (KUDs) for individuals of each sex using the '*estSpaceUse*' function from the '*track2KBA*' *R* package (Beal *et al*. 2021). We used the scale of each sex's area-restricted search (ARS) as the kernel smoothing parameter (*h*), which was calculated using the '*findScale*' function. Females had an ARS scale of 9.5 km and males of 9.0 km. As at-sea distribution changes according to the breeding stage and associated breeding duties (González-Solís *et al.* 2008, Granroth-Wilding & Phillips 2019), we therefore estimated KUDs for incubation and chick-rearing stages separately. The 50% KUD is defined as the 'core' foraging area where birds spent 50% of their time (Ford & Krumme 1979, Soanes *et al.* 2013, Lascelles *et al.* 2016). To ensure that data were representative of the foraging distribution of the colony-level population (~480 breeding pairs), we used a bootstrapping approach implemented in the '*track2KBA*' *R* package (described in Lascelles *et al.* 2016), which analyses the representativeness of the foraging areas as a function of sample size. Finally, we identified and delineated important sites for the population, which are areas used by a substantial portion of the population. We used the '*findSite*' function that first calculates the proportion of individual core areas (i.e. % KUD areas) overlapping per grid cell. This proportion of overlapping tracks is then multiplied by the proportional representativeness of the tracked sample to adjust the sample-derived pattern by the degree of representativeness. The result is a scaled estimate of the proportion of the source population that predictably uses each grid cell in the study region during the season of interest.

2.5 Habitat characteristics

To assess characteristics of foraging habitats, we classified track points according to their speed and turning rate using the Expectation-Maximization Binary Clustering ('*EmBC*') *R* package (Garriga & Bartumeus 2016). Foraging locations were defined as those with low speed (< 1.0 ms^{-1}) and high turns (> 0.48 rad), parameters that characterize an intensive search behaviour. At these points, we extracted values of sea-surface chlorophyll *a* (which is a proxy for primary productivity), sea-surface temperature (SST), gradients of SST (SSTg; which indicate the positions of fronts more clearly), terrestrial and sea-ice concentration (SIC; referring to the proportion of the area that is covered by ice relative to open water, such as leads and polynyas), sea-bed depth and elevation (m; including both marine and terrestrial relief), distance from known penguin colonies (km) and distance from ice-free areas (km; which are potential unknown penguin colony sites or beaches used by seals as haul-out sites). Dynamic variables, except for ice concentration, were downloaded as December and January mean composite 'netCDF' files from Giovanni Browser (https://giovanni.sci.gsfc.nasa.gov/giovanni/). Chlorophyll *a* concentration (mg m^{-3}) and SST at night (°C) were downloaded for a spatial resolution of 0.04° (~4 km). SIC (%) data were obtained as daily composites from the Sea Ice Remote Sensing Data browser - University of

Bremen (Spreen et al. 2008), https://seaice.uni-bremen.de/databrowser/) as georeferenced .tiff images with a 6.25 km spatial resolution. Bathymetric data were obtained from the ETOPO1 Global Relief Model (www.ngdc.noaa.gov/mgg/global/ global .html) with a spatial resolution of 0.01° (~1 km). Penguin colony distribution (Fig. 2) was obtained from the Mapping Application for Penguin Populations and Projected Dynamics online database (MAPPPD; http://www.penguinmap.com). This dataset includes data on emperor penguin (*Aptenodytes forsteri*), Adélie penguin (*Pygoscelis adeliae*), chinstrap penguin (*Pygoscelis antarcticus*) and gentoo penguin (*Pygoscelis papua*) colonies in Antarctica. Penguin colony distribution data in southern South America were obtained as published maps and then georeferenced in *ArcMap* 10.3 (ESRI, Redlands, CA, USA). Data were obtained for southern rockhopper penguins (*Eudyptes c. chrysocome* (Baylis *et al.* 2013) gentoo penguins (Baylis *et al.* 2013), king penguins (*Aptenodytes patagonicus)* (Pistorius *et al.* 2012) and Magellanic penguins (*Spheniscus magellanicus*) (Global Penguin Society; https://www.globalpenguinsociety.org/portfolio-species-15.html). Euclidean distances to penguin colonies were calculated with the Spatial Analyst tool in *ArcMap* 10.3. SST gradients were calculated as the standard deviation of SST in a 0.3° × 0.3° moving filter in Spatial Analyst. NetCDF files were first converted to raster files and then averaged into 2-month composites. Ice concentration data were first averaged into monthly composites and then averaged into a single mean composite for each summer. Each environmental variable was resampled to the same spatial grid of 0.06° (~6 km, the coarsest scale of the environmental datasets) to allow spatial comparison and combined modelling. All environmental variables were scaled using the '*scale*' function in *R*. Processing of variables was done using the '*raster*' *R* package (Hijmans & Van Etten 2021).

As SGPs are known to interact with fisheries (Otley *et al.* 2007, Jiménez *et al.* 2011), we obtained data on daily fishing effort (hours, all gear types) from the Global Fishing Watch database (https://globalfishingwatch.org) with a spatial resolution of 0.01° (~1 km). Fishing effort was only available for the 2019/2020 summer, and population-level overlap was too little to include this variable in the habitat selection analysis. We thus visually investigated the overlap of foraging areas (KUD 50%) and polygons of krill fishing areas obtained from Krüger *et al.* (2019b) and with areas where toothfish (*Dissostichus* spp.) research-driven exploratory fisheries are allowed in Antarctica (Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), https://gis.ccamlr.org/). Toothfish fishing usually occurs during periods of low sea-ice coverage, and its occurrence is evaluated on a yearly basis depending on the trends of toothfish populations (e.g. Hanchet *et al.* 2015). Longline fishing effort is relatively low compared with longline fishing elsewhere (e.g. Clay *et al.* 2019), and, given the strict measures adopted for longline fishing in the area, seabird bycatch is also very low (Hanchet *et al.* 2015, Collins *et al.* 2021). Therefore, the impact of toothfish fisheries is expected to be low and restricted within those areas. Krill fishing polygons encompass the summed area of fishing activity during the summers of 2013–2017. We also investigated whether SGP foraging areas were within confirmed marine Important Bird Areas (IBAs; BirdLife International, https://maps.birdlife.org/marineibas/), which are areas of significant importance for birds and therefore are priority areas for conservation.

2.6 Habitat selection

Habitat selection was evaluated as the probability of individuals choosing a specific step (two consecutive observed positions) among other available locations (random steps) in relation to the environmental covariates available within reach.

Firstly, geographical positions were translated into a step, which is composed of the step length and turning angle (deviation from previous bearings), using the '*steps_by_burst*' function in the '*amt*' *R* package. We then fitted gamma distributions to the step lengths and von Mises distributions to turn angles using maximum likelihood to generate nine random steps for each observed step based on these distributions (Signer *et al*. 2019). Random steps were generated using the '*random_step*' function of the '*amt*' *R* package. Environmental variables were extracted at the end of all steps to evaluate which variables were responsible for the animal choosing a specific habitat.

We then applied a SSF by fixing a mixed conditional Poisson model with individual-specific random slopes for each variable. We used steps of foraging points as the binary response variable (observed step = 1, random step = 0), environmental variables, stage and step length as covariates and individual ID as a random effect (following Muff *et al.* 2020). We fixed the random effect variance to 10^6 because small values that could be selected by models tend to shrink the intercepts (Muff *et al.* 2020). Models were run separately for each sex. Analysis was conducted in the *glmmTMB R* package (Brooks *et al.* 2017), which uses a frequentist GLMM approach.

We used AICc model selection to distinguish among a set of candidate models describing the relationship between environmental variables, step length and step selection and the interaction between stage and environmental variables. The best-fit model for both was the most complex. Variables used in the final model were sea-surface chlorophyll *a*, SST, SSTg, distance from known penguin colonies, SIC and depth. Distance from ice-free areas was not included in the analysis as it was strongly correlated with distance from known penguin colonies (Pearson correlation, $r = 0.73$).

The probability of movement in relation to seal haul-out sites was not evaluated due to the lack of a complete dataset of these sites in the Antarctic Peninsula. However, the occurrence of SGPs on haul-out sites was verified by cross-checking Google Earth Pro satellite and drone imagery (only for Harmony Point) of terrestrial ice-covered areas overlapped by SGP foraging fixes. Cloud-free images of these sites, when existent, were inspected for the presence of seals, which can be identified as long black spots over the ice (LARUE *et al.*, 2011). Drone images of Harmony Point were taken with a Mavic Pro II drone (DJI, Shenzhen, China) as part of another study (see Corá *et al.* 2020). Drone flight was authorized by a permit from Instituto Antártico Chileno (No. 1046/2019).

3. Results

We were able to recover 58 tags and retrieve data from 47 (21 in 2019–2020 and 26 in 2021–2022), a 70% data recovery rate success. Seven devices that were attached with tapes were lost, all of them attached to females. No device that was attached with a harness backpack was lost.

3.1 Foraging distribution and behaviour

A total of 34 complete foraging trips (13 from females and 21 from males) were obtained in 2019–2020 and 68 complete trips were obtained in 2021–2022 (26 from females and 42 from males). Individuals engaged in 1–14 days long trips between the Weddell and Bellingshausen seas and the southern tip of Tierra del Fuego, foraging up to ~2100 km away from the colony to the west of the Antarctic Peninsula, 1317 km to the south-east and 950 km to the north (Fig. 1). As expected, breeding stage and sex, but not individual ID and year ($P = 0.303$ and $P = 0.301$, respectively), influenced the maximum range, cumulative distance of trips and trip duration. Females tended to engage in longer foraging trips than males (Table I), both in the number of days (GLMM: *t*-value = 2.294, df = 34, $P = 0.028$) and in the maximum trip range (GLMM: *t*-value = -2.690, df = 34, $P = 0.011$) and had higher cumulative trip distances (GLMM: *t*-value = 3.041, df = 34, $P = 0.004$). For both sexes, incubation trips lasted longer

(GLMM, days: *t*-value = -7.292, df = 34, *P* = 0.000) and reached greater distances (GLMM, maximum distance: *t*-value = -5.206, df = 34, *P* = 0.000) than in the chick-rearing stage (Fig. 1 & Table I).

Males fed extensively in the surroundings of their breeding colony, the nearby islands, the Bransfield Strait and the Trinity Peninsula, Graham Land (Fig. 1). Only one male foraged out of Antarctica, over waters to the south of Tierra del Fuego and in the same trip foraged up to -70°S (Fig. 1c). Females, despite also foraging near the colony and by the northern Antarctic Peninsula, showed a more widespread distribution, and many foraging locations were parallel to the Antarctic Peninsula. Eight females foraged south of -70°S in waters facing the Eltanin Bay in the Bellingshausen Sea and in the Weddell Sea. During incubation, one female reached longitude -103°W (Fig. 1a, b), travelling the farthest distance (2009.7 km from the colony) and covering the greatest cumulative distance (5293.5 km) of all individuals. The trip lasted 7.2 days.

Our estimates show that 96.2% of the core foraging areas (KUD 50%) used by the general Harmony Point population are captured by the sample of 47 tracked birds. Despite the variability in the foraging distribution, key areas for the species, which are areas used by a substantial portion of the population, are located around the breeding colony and by the tip of the northern Antarctic Peninsula and the Prince Gustav Channel, between Trinity Peninsula and James Ross Island (Fig. 1e). About a third of this key area is within IBA 'Hope Bay Marine - Antarctic Sound', but it also overlaps with smaller IBAs, such as 'Duroch Islands' and 'Devil Island' (Fig. 1e).

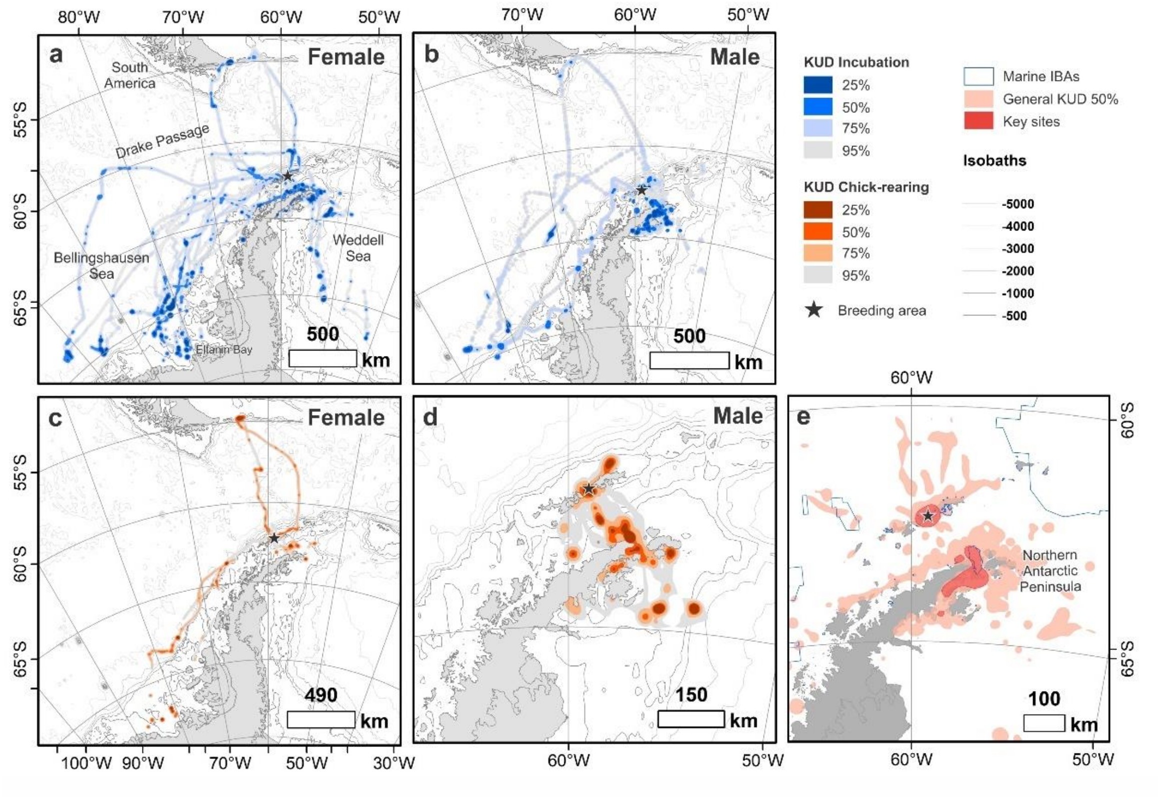

Fig. 1. Kernel usage density (KUD) of (**a.** & **c.**) female (*n* = 21) and (**b.** & **d.**) male (*n* = 26) breeding southern giant petrels (*Macronectes giganteus*) from Harmony Point, Nelson Island (black stars), tracked between December 2019 and January 2020 and between December 2021 and January 2022. Incubation and chick-rearing stages are depicted in blue and orange colours, respectively. Population-level 50% KUD and marine Important Bird Areas (IBAs; https://maps.birdlife.org/marineibas/) are depicted in **e**. Dark red polygons are key sites for the tracked population. Antarctic coastline polygons and bathymetric isolines were obtained from Gerrish *et al.* (2021) and The International Bathymetric Chart of the Southern Ocean Version 2 (Dorschel *et al.* 2022), respectively.

3.2 Habitat selection

Water depth had a weak but positive effect (0.65) on male habitat selection, while distance from penguin colonies had a strong negative effect (-5.38). Water depth and the interaction between breeding stage and SIC had positive effects (0.76 and 0.75, respectively) on female habitat selection. Distance from penguin colonies and the interaction between stage and depth had negative effects (-1.03 and -0.75, respectively), meaning that, although with a weaker effect, females were also attracted by proximity to penguin colonies and to shallower waters during the chick-rearing stage (see Fig. 2).

Males mainly selected areas with shallow to intermediate depths related to the coastal and continental shelf and foraged at shallower depths during the chick-rearing stage (Fig. 3a). They selected areas near penguin colonies with a median distance of 6.44 km during incubation and chick-rearing (see Figs 3c, 4c & 5). During incubation, females mainly selected areas with intermediate to deep depths related to the continental shelf, shelf slope and pelagic habitats, and, as with males, they foraged at shallower depths during the chick-rearing stage (Figs 1 & 3a). During incubation, females selected areas slightly more distant from penguin colonies than males (median: 20.37 km), but during chick-rearing the distance was similar (Fig. 3c). Although ice concentration alone had a negligible effect on habitat selection, both sexes used areas with varied ice concentrations (Fig. 3d), using habitats ranging from 0% to 99.8% ice coverage during incubation. Females tended to select habitats with markedly lower ice concentrations during chick-rearing (Fig. 3d).

Evidence of overlap between seal haul-out sites and foraging fixes of both sexes was found (Fig. 4a,b). At Harmony Point, where drone imagery allowed closer inspection, it was possible to determine that, when at land, birds frequently used ice-covered areas where Weddell seals (*Leptonychotes weddellii*) hauled out to rest (Fig. 4a).

There was also substantial overlap with areas consistently used by krill fisheries in previous years and exploratory toothfish fisheries, especially by females (Fig. 5). Overlap with toothfish fishery areas was mainly on research block 88.3_4 located over the Bellingshausen Sea and blocks 48.1_1, 48.1_2 and 48.1_3 on the Weddell Sea (Fig. 5a). One female and one male also overlapped their foraging range with areas with low fishing effort at the southern Patagonian Shelf slope, next to Isla de los Estados (Argentina), where trawlers and bottom longline vessels were fishing during the period when birds were using the area (Fig. 5a). The female foraged at this region during both the incubation and chick-rearing stage, while the male foraged there only during incubation.

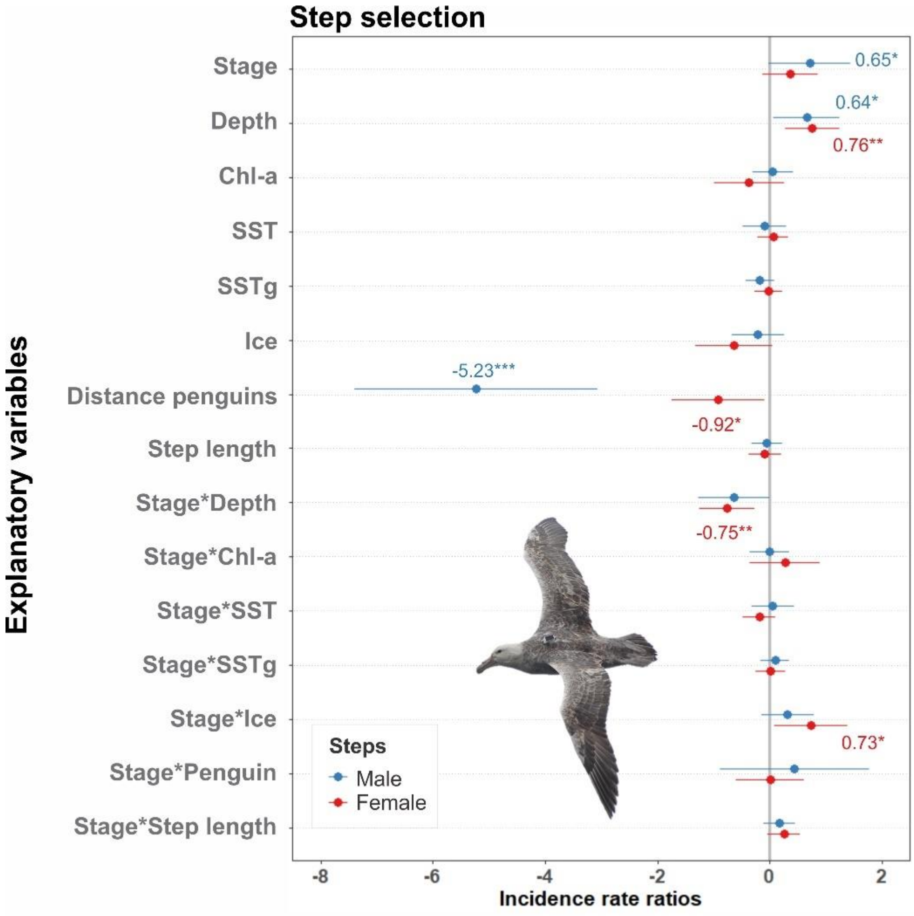

Fig. 2. Estimates and confidence intervals (95%) from the binomial step-selection model of breeding southern giant petrels. Significance codes: ****P* = 0.001, ***P* = 0.01, **P* = 0.05. Chl-a = chlorophyll *a*; SST = sea-surface temperature; SSTg = gradients of sea-surface temperature.

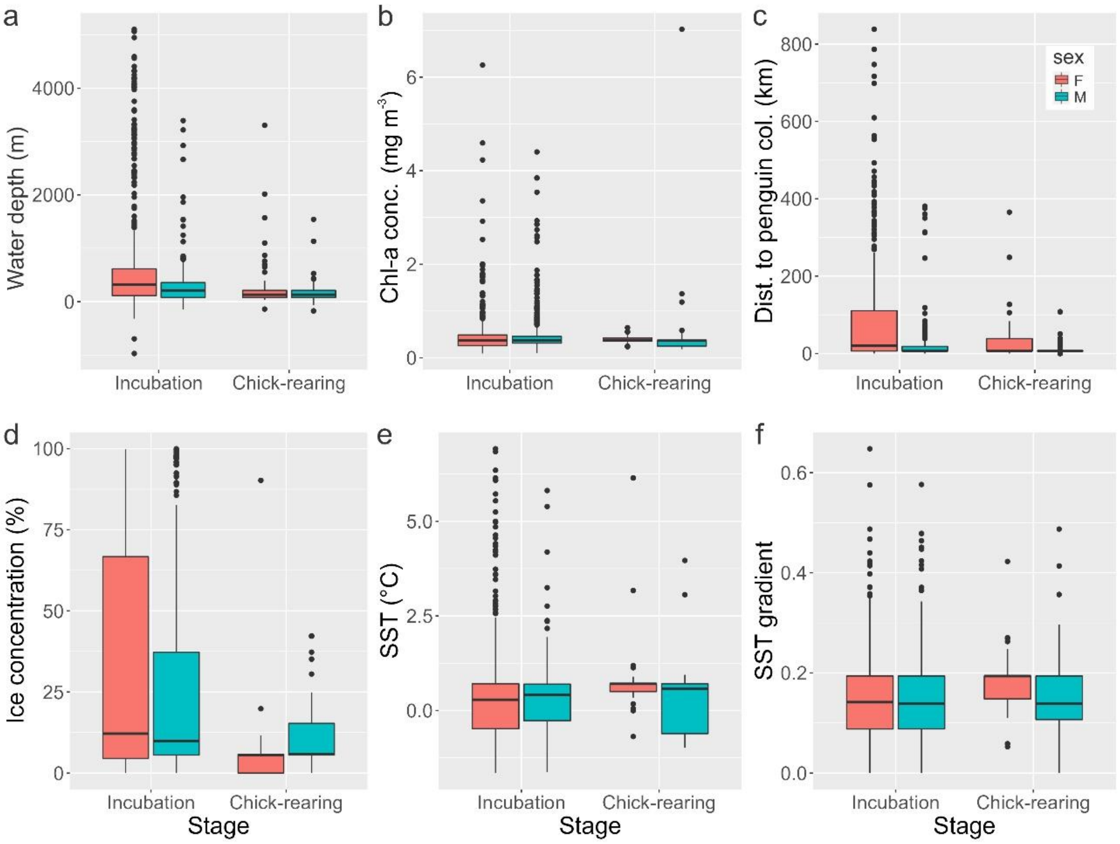

Fig. 3. Median values for the different environmental variables characterizing foraging areas of female (red) and male (blue) southern giant petrels from Nelson Island, Maritime Antarctica, during the incubation and chick-rearing stages. **a.** Water depth; **b.** chlorophyll *a* (Chl-a) concentration; **c.** distance to penguin colonies; **d.** sea-ice concentration; **e.** sea-surface temperature (SST); **f.** gradient of SST.

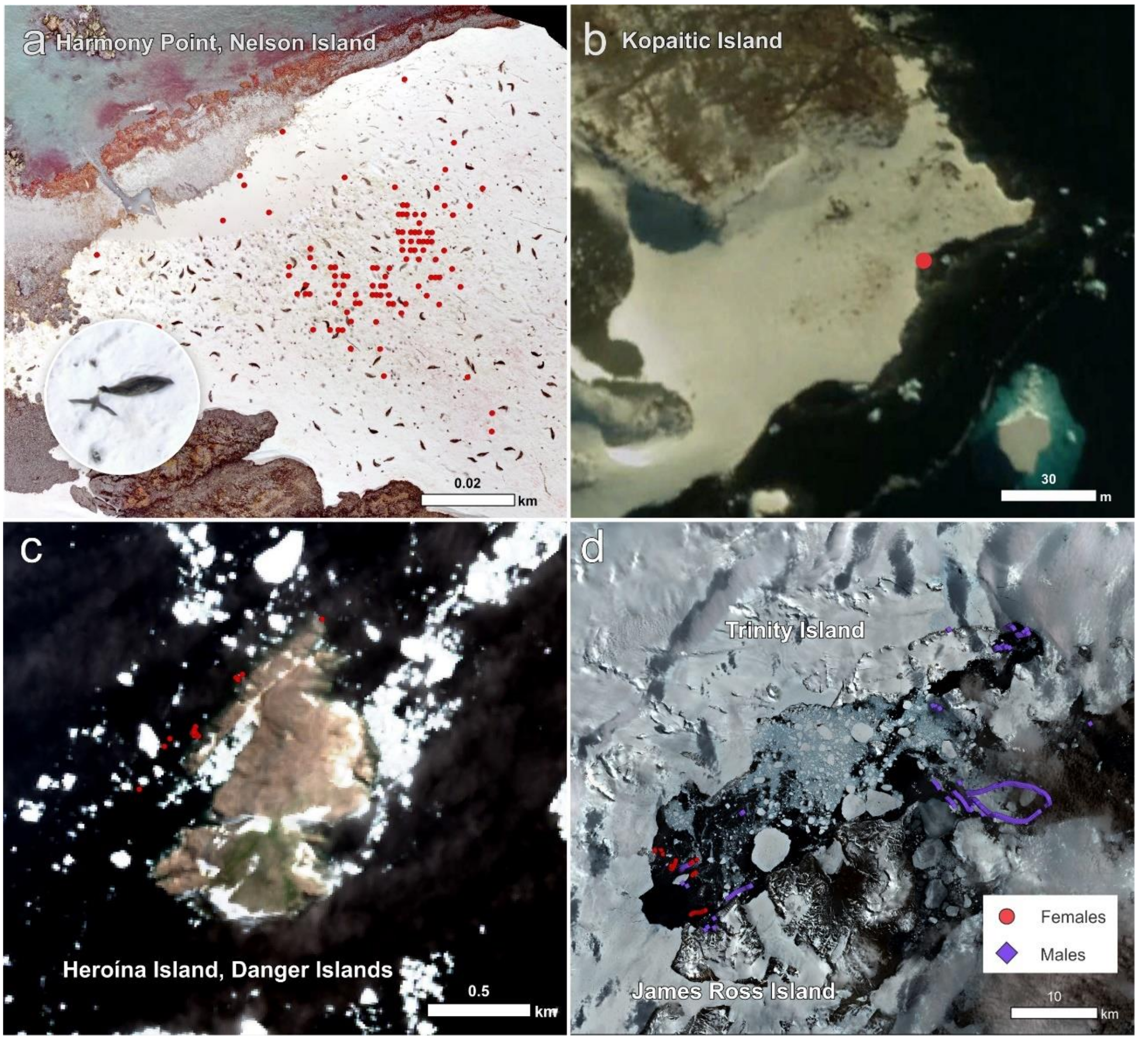

Fig. 4. Distinct habitats used by breeding southern giant petrels. **a.** Glacier edge at Harmony Point, Nelson Island, a haul-out site of Weddell seals (aerial drone image taken in January 2020); in detail is a southern giant petrel feeding on seal faeces. **b.** Ice-covered coast of Kopaitic Island where hauled-out seals are visible (Google Earth Pro image from 14 March 2015). **c.** Breeding colonies of Adélie penguins at Heroína Island (Danger Islands) in the Weddell Sea, where 292 363 breeding pairs were counted in 2015 (Borowicz *et al.* 2018). **d.** Open water amid fast ice in the Prince Gustav channel, Weddell Sea (satellite image from 30 December 2019 freely obtained from Sentinel2, https://apps.sentinel-hub.com/eo-browser).

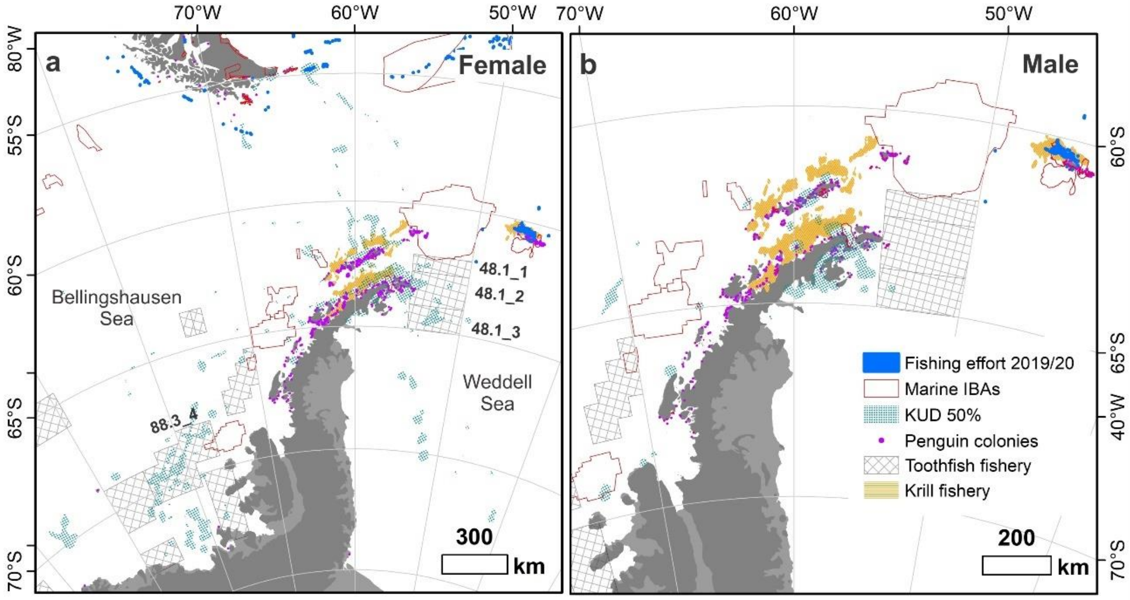

Fig. 5. Foraging areas (kernel usage density (KUD) 50%) of **a.** female and **b.** male southern giant petrels breeding at Harmony Point, Nelson Island, and the distribution of known penguin breeding colonies (Humphries *et al.* 2017), confirmed marine Important Bird Areas (IBAs; BirdLife International, https://maps.birdlife.org/marineibas/), research blocks of exploratory toothfish (*Dissostichus* spp.) fisheries (Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), https://gis.ccamlr.org/), areas used by Antarctic krill (*Euphausia superba*) fisheries in recent years (Krüger 2019b) and longline fishing effort during December 2019 and January 2020 (Global Fishing Watch, https://globalfishingwatch.org).

4. Discussion

This study presented the fine-scale foraging distribution of a generalist marine top predator of the Antarctic, the SGP, and described its relationship with environmental variables during the breeding season. The survey, staged at Nelson Island, Maritime Antarctica, is the first to assess the fine-scale distribution of a SGP population breeding above 60°S.

Tracked birds used a wide area of the Antarctic Peninsula and adjacent islands, demonstrating that even by tracking a small number of individuals it is possible to assess conditions of a large area of the Antarctic, especially during the incubation period. The only previous tracking survey of SGPs breeding above 60°S was performed at Elephant Island (61°13'S, 55°21'W) using coarse-scale light-level geolocators (Krüger *et al*. 2017, 2018). SGPs from Elephant Island foraged mainly to the north of the island on the Drake Passage and less frequently in the northern Antarctic Peninsula. Birds from the present study, on the other hand, showed a marked southerly distribution in relation to their breeding colony (Nelson Island) and used a great share of the coast of the western and northern Antarctic Peninsula and the Bellingshausen and Weddell seas as foraging grounds, exploring ice-covered sea and land.

Previous studies tracking SGP populations across the Southern Ocean (e.g. Bird Island, South Georgia: González-Solís *et al.* 2008, Granroth-Wilding & Phillips 2019; Argentine Patagonia, Copello *et al.* 2011; Crozet Island, Thiers *et al*. 2014) in general showed that, during the breeding season, females made farther, longer and more pelagic trips than males and fewer coastal trips (Granroth-Wilding & Phillips 2019). This pattern is confirmed in the present study. Granroth-Wilding & Phillips (2019) suggest that females use terrestrial and coastal areas to scavenge, which has been previously assumed as a male-dominated behaviour (Forero *et al*., 2005b; González-Solís, 2004; Hunter, 1983). The positive effect of proximity to penguin colonies on female habitat selection and consistent use of confirmed seal haul-out sites confirm this suggestion, but female coastal behaviour might also be related to coprophagy, a recently described behaviour for the species and specifically confirmed for the tracked population (Corá *et al.* 2020).

Males also showed a high probability of selecting foraging areas nearby penguin colonies. Males are known to actively predate on penguins (Le Bohec *et al*. 2003, Ryan *et al*. 2008) and adults and chicks of other seabirds on breeding colonies (Dilley *et al*. 2013; Grohmann Finger *et al*. 2021; Risi *et al*. 2021). It is possible to infer that some of the land areas visited by males, whose habitat selection was also positively influenced by water depth and elevation, could represent areas with an unknown presence of penguin colonies. Small penguin colonies are less likely to be spotted in satellite images (Fretwell & Trathan 2021) such as Sentinel2 (which has an open-source interface). Therefore, the foraging tracks of SGPs could provide clues as to where to invest field effort or where to use paid-for high-definition satellite images to verify the presence of small penguin colonies and to identify seal haul-out sites.

The same areas used by SGPs from Nelson Island have been identified as Areas of Ecological Significance (AESs) of the Southern Ocean (Hindell *et al*. 2020), fig. 1 of that study). Several confirmed marine IBAs (Fig. 5; https://maps.birdlife.org/marineibas/) were also visited, especially IBA 'Hope Bay Marine - Antarctic Sound', which was created due to large foraging aggregations of breeding Adélie penguins. AESs are areas preferred by multiple predator species and indicate high levels of lower trophic biomass and biodiversity (Hindell *et al.* 2020). Due to their high productivity, they can also be targeted by fishing activities throughout the year (Fig. 4; Grémillet *et al*. 2018, Krüger 2019b). SGP mortality associated with longline fishery, although low, has been recorded outside Antarctica (Gianuca *et al*., 2017; Sullivan *et al*. 2006). The consistent use of usual fishing areas in the southern Patagonian Shelf by breeding SGPs shows that even during the breeding season the species could be interacting with fishing boats outside the CCAMLR management areas. While seabird bycatch in longline fisheries has been reduced to a minimal within the CCAMLR areas due to strict measures and regulations (SC-CAMLR-40/BG/23, https://www.ccamlr.org/en/sc-camlr-40/bg/23), seabird mortality associated with krill fisheries (warp strikes and bycatch) has become a recent issue, with records of SGPs attending fishing nets and feeding on mammal bycatch (SC-CAMLR-40/BG/23, SC-CAMLR-40/BG/26, https://www.ccamlr.org/en/sc-camlr-40/bg/26, SC-CAMLR-40/BG/27, https://www.ccamlr.org/en/sc-camlr-40/bg/27). Krill fisheries have been recently changing their period of activity on the western Antarctic Peninsula towards the end of summer and early autumn (Krüger 2019b; Krüger *et al*. 2021b); therefore, further data would be necessary to quantify any potential interaction of SGPs with krill fishing vessels. Although IUU longline fishing within the CCAMLR areas is currently not a great concern, unidentified fishing gear is retrieved from time to time (CCAMLR-40/06, https://www.ccamlr.org/en/ccamlr-40/06), indicating that such activity does occur. In this case, as IUU fisheries are unregulated, they might pose more risks to seabirds. SGPs, therefore, could be used as a means of monitoring any suspicious activity throughout the western Antarctic Peninsula; for instance, using the Automatic Identification Systems from vessels and radar detection tracking devices (Votier *et al*. 2010; Weimerskirch *et al*. 2020) and bird-borne cameras (Votier *et al*., 2013).

Due to the large spatial scale of the Antarctic Peninsula, challenging field conditions and high logistical costs, monitoring the environment and the state and distribution of seabird and mammal populations is a challenge for researchers. In this sense, marine top predators have already been used as oceanographic platforms (Fedak 2013; Ohshima *et al*. 2013) and as indicators of past and current environmental change by tracking shifts in dietary (Carpenter-Kling *et al*. 2019), foraging (Miller & Trivelpiece 2008), demographic (Trivelpiece *et al*. 2011) and phenological parameters (Lynch et al. 2012). Optimal sentinel species should be conspicuous and easy to access and be sensitive and respond to changes in the environment in a timely and a detectable manner, which is usually associated with a reliance on a small diversity of or singular prey species (Hazen *et al*. 2019). SGPs are, however, a highly opportunistic and generalist species (Hunter 1984, Granroth-Wilding & Phillips 2019, Grohmann Finger *et al.* 2021), whose status in Antarctica seems to be stable or increasing (e.g. Petry *et al*. 2018, Krüger

2019a). Populations of the southern Atlantic Ocean, including the mid-latitudes of the Antarctic, have been favoured by climate change (Petry *et al.* 2018, Gianuca et al. 2019) and the consumption of discards associated with increased fishing activity (Krüger *et al*. 2017). However, in a few sites, local population declines have been recorded and attributed to the stress caused by constant human activities, such as scientific activities and tourism (e.g. Nelson Island: Silva *et al*. 1998; Signy Island: Conroy 1972). But as for populations breeding in higher latitudes or with more southerly breeding distributions, such as the one from Harmony Point, major causes of population variability are yet to be investigated. Therefore, although demographic studies of SGPs still might not be optimal tools for investigating environmental changes in the Antarctic, the large size, conspicuousness, accessibility of colonies and wide and diverse spatial distribution of SGPs make them useful monitoring platforms. Females can be particularly useful for investigating IUU fisheries, while both sexes can be used to investigate seal haul-out sites and penguin colonies. A long-term study joining GPS tracking, animal-borne cameras and diet analysis should provide researchers with a large amount of data on the condition and occurrence of penguin colonies, Weddell seal haul-out sites and IUU fisheries at different spatial and temporal scales.

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Ethics approval

Animal study ethics were evaluated and approved by Instituto Antártico Chileno and the Comité Ético Científico de la Universidad de Magallanes. Entrance to Harmony Point Antarctic Specially Protected Area was authorized by Instituto Antártico Chileno (Permits No 1045/2019, No 662/2021 and No 433/2022). Sampling was authorized by Instituto Antártico Chileno (Permits No 1046/2019 and No 654/2021).

Author contributions

JVGF and LK conceived the ideas and designed the study; JVGF, LK and DHC collected the data; JVGF and LK analysed the data; JVGF led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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Table I. Foraging trip metrics of breeding female and male southern giant petrels (n = 47). Results for metrics are given as median [quartile 1–quartile 3], with ranges given in parentheses.

Stage	**2019–2020**		**2021–2022**	
	Female (*n* = 10)	**Male (*n* = 11)**	**Female (*n* = 11)**	**Male (*n* = 15)**
Incubation trips	*n* = 10	*n* = 14	*n* = 16	*n* = 28
Duration (days)	7.8 [3.5–9.1] (1.2–12.1)	6.2 [3.7–7.5] (0.01–13.2)	6.6 [3.4–8.1] (1.2–14.6)	4.1 [1.8–5.7] (0.1–10.2)
Maximum cumulative distance (km)	1648.2 [60.5–2054.7] (31.5–3498.2)	603.9 [150.3–1119.6] (5.9–1625.9)	2317.5 [926.6–4326.5] (122.2–5293.5)	919.1 [229.4–1049.2] (2.0–5797.4)
Maximum range (km)	295.1 [12.5–522.7] (8.0–1401.3)	191.2 [28.4–271.9] (2.9–662.0)	301.9 [228.5–1037.7] (10.3–2099.7)	202.7 [33.6–248.7] (1.0–1491.4)
Chick-rearing trips	*n* = 3	*n* = 7	*n* = 10	*n* = 14
Duration (days)	1 [1.0–1.25] (1.0–1.5)	1.3 [0.8–1.95] (0.4–3.0)	1.1 [1.0–1.85] (0.4–3.5)	0.8 [0.4–1.5] (0.01–4.9)
Maximum cumulative distance (km)	272.7 [175.7–275.45] (78.7–278.2)	147.1 [82.4–249.7] (14.9–315.2)	253.2 [154.5–536.1] (120.3–2419)	194.2 [34.3–323.1] (1.6–1540.1)
Maximum range (km)	46.9 [31.9–46.7] (16.8–106.4)	18.8 [17.35–95.8] (7.4–113.8)	56.6 [27.2–86.1] (22.0–872.2)	22.5 [11.2–126.1] (0.8–385.7)

Capítulo 2

Personality does not predict short-term consistency in the foraging behavior of a highly dimorphic Antarctic seabird

CAPÍTULO 2

Personality does not predict short-term consistency in the foraging behavior of a highly dimorphic Antarctic seabird

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Abstract

Individual variation in foraging behavior has been correlated to personality in seabirds. The southern giant petrel (*Macronectes giganteus*) is a generalist top predator from the Southern Ocean with the most elaborate social behaviors of its family. Despite its wide repertoire, the role of personality in the foraging behavior of the species has been poorly explored. The goal of this study was to test if personality influences individual consistency (fidelity) in foraging areas and foraging strategies of breeding giant petrels. Petrels (n=67) from the Antarctic were tracked with GPS devices in during the 2019-20 and 2021-22 breeding seasons to investigate foraging areas and calculate foraging trip metrics throughout the season. Individual personality was described based on boldness level, which was quantified using the behavioral test: ‘response to a novel object’, which consists of presenting a novel object to an individual and recording its behavioral responses. The most frequent behavior, both among (86.4%) and within individuals (46.2 ± 29.8%), was moving the head, followed by pecking/lunging towards the object (52.3%) and bending the bill (47.7%), both agonistic displays. 18 birds were classified as shy and 26 as bold. Males had higher boldness scores than females. Therefore, sex was included as fixed effect in the analysis. Individuals varied in their level of foraging site fidelity, with some birds being highly consistent, and others never repeating foraging areas. The population had an intermediate level of fidelity. Boldness neither sex influenced site fidelity levels. Individuals showed repeatability in maximum range from the colony and trip duration, but not in cumulative travel distance. Repeatability, however, was not related to boldness. Even though boldness did not influence foraging site fidelity and metrics, we found considerable residual variation on these traits, and this could be related to other factors, such as age and variations in body morphology.

Key words: personality, foraging, site fidelity, foraging metrics, southern giant petrels

1. Introduction

Individuals within a population can vary in the range of resources they use, the areas they forage and in their foraging behavior (Araújo et al., 2011; Bolnick et al., 2003). This intra-specific variation can be related to sexual differences (González-Solís et al., 2008; Phillips et al., 2011), breeding status and stage (Quillfeldt et al., 2015), age (De Grissac et al., 2016), morphology (Krüger et al., 2018) and individual specialization (Ceia & Ramos, 2015; González-Solís et al., 2017). The latter can be defined as the extant residual variance in a trait, after the effects of other factors have been considered. An individual is specialized when it consistently uses only a subset of available areas or resources and therefore shows a narrower niche than that of the whole population (Bolnick et al., 2003).

Foraging site fidelity is a common behavioral specialization where individuals consistently use a specific location across time (Wakefield et al., 2015). At population-level this fidelity is thought to result from intraspecific competition for resources (Bolnick et al., 2003), but populations are often comprised of individuals of varying levels of site fidelity, resulting in the coexistence of behavioral specialists and generalists (Patrick & Weimerskirch, 2017; Wakefield et al., 2015). This variation in the level of consistency of foraging behavior has been interpreted as a variation in personality (Patrick & Weimerskirch, 2014).

The intra-specific or intra-population niche variation not only reduces competition but has implications in predator-prey interactions and the structure of food webs (Bolnick et al., 2011; Svanbäck & Bolnick, 2006). In addition, it shapes the ability of populations to cope with environmental changes (Nussey et al., 2007) and their resilience under anthropogenic impacts, such as pollution and fisheries (Granadeiro et al., 2014). More variate species may be better buffered against them, as individuals are likely to respond in different ways to changes in the environment (Dias et al., 2011; Masello et al., 2013; Phillips et al., 2009). Hence, characterizing divergent foraging strategies can provide insights into the ecology, evolution, conservation and management of the species (Ramírez et al., 2016a; Thiemann et al., 2011; Wakefield et al., 2015).

Individual choices in foraging areas are affected by many variables, including the quality and distribution of food patches in the environment and the cost of travelling between them (Charnov, 1976; Mehlhorn et al., 2015). For species that forage in environments where resources can be patchily distributed over large areas in different levels of predictability (Fauchald et al., 2000; Weimerskirch, 2007), such as seabirds in the ocean, the competition for resources creates a trade-off between obtaining information about where to feed (exploration) and feeding itself (exploitation) (The exploration–exploitation (EE) trade-off; (Cohen et al., 2007; Eliassen et al., 2007; Kramer & Weary, 1991; Mehlhorn et al., 2015). Recent studies have shown that an individual’s choice of foraging strategy, i.e., where it lies on the exploration–exploitation trade-off, is highly correlated to its personality on the bold-shy continuum (Patrick et al., 2017). Bold birds tend to show higher levels of aggressive behavior in response to novel objects, compared to shyer birds (Patrick et al., 2013).

The southern giant petrel (SGP; *Macronectes giganteus*) is a generalist top predator from the Southern Ocean (Hunter, 1985) with a wide and varied breeding distribution (Finger et al. in press; González-Solís et al., 2008; Krüger et al., 2017; Thiers et al., 2014a). The species forages in terrestrial, coastal and pelagic areas preying upon living seabirds, such as penguins (Le Bohec et al., 2003; Ryan et al., 2008), albatrosses (Dilley et al., 2013; Risi et al., 2021), small petrels (Jones et al., 2019) and chicks of conspecifics (Grohmann Finger et al., 2021) and marine mammals (De Bruyn and Cooper, 2005; Dilley et al., 2013; Towers and Gasco, 2020; Nagel et al., 2022). They can also feed off carcasses of birds and mammals and their feces (Corá et al., 2020; Hunter, 1983). Females mainly prey on pelagic species, such as fish, squid and krill

(Copello et al., 2008; Hunter, 1983) and both sexes are known to feed from fishery discards and offal (Copello et al., 2008; González-Zevallos & Yorio, 2006). As a colonial surface breeder, the species has one of the most elaborate social behavior repertoires than any other Procellariidae (Bretagnolle, 1988). Social behaviors are related to the functional aspects of territoriality (food and nest), social hierarchy, predator avoidance, etc., unlike sexual behavior which is related to pair formation, copulation and pair relationships (Bretagnolle, 1988). Despite its wide repertoire, the role of personality in the foraging behavior has been poorly explored for this species (but see De Bruyn and Cooper, 2005).

Different individual personalities tend to prefer different foraging strategies (Krüger et al., 2019; Patrick et al., 2017; Patrick & Weimerskirch, 2014). In a relatively unpredictable environment where food is patchily distributed, bolder personalities tend to favour exploration; they will move quickly around the environment and visit more foraging patches that are not necessarily of great quality (i.e. do not have high amounts of food). Shyer personalities favour exploitation: they will spend longer searching for a patch and therefore visit fewer patches with a high quality and fully exploit each patch they visit (Jeffries et al., 2021; Patrick et al., 2017).

SGP, however, besides foraging at the sea, also forage in terrestrial environments, especially during the breeding season when their prey (i.e. penguins and marine mammals) is also breeding or when there is availability of carrion, placenta or seal faeces (Corá et al., 2020; Hunter, 1983). Terrestrial environments are more predictable in terms of food availability as the location of penguin colonies and seal haul-out sites are more static and consistent throughout many years. Male giant petrels, which are known to display highly aggressive behaviours to defend resources (De Bruyn & Cooper, 2005), usually dominate resources at land, while females, which at sex level are more submissive, forage at sea (González-Solís et al., 2008). Therefore, we expect bolder males to forage closer to the colony in terrestrial and shallower areas, as higher agonistic behavior gives them advantage over resources by competitive exclusion, while shyer males should look for resources in areas more distant from the colony where competitive interactions may be reduced. Females are known to engage in longer foraging trips, in areas farther away from the colony, covering greater distances than males (González-Solís et al., 2008; Granroth-Wilding and Phillips, 2019; Thiers et al., 2014; Finger et al., in press). As they forage in a patchier and more unpredictable environment than males, we expect them to follow the exploratory-exploitation trade-off theory, with bolder females showing a more explorative behavior, therefore, foraging for longer and further than shyer females, who will favor spending more time in fewer areas and exploring less areas. As bolder birds should engage in an exploratory strategy, we expect them to show less consistency in their foraging habitats, whereas shy birds should be faithful to specific sites with known food availability.

2. Methods

2.1 Study area

The study was conducted at Harmony Point (62°18′S; 59°10′W), Nelson Island (South Shetland Islands, maritime Antarctic) during December and January of the 2019-20 and 2021-22 austral summers. Southern giant petrels breed on plateaus and on relatively flat areas close to the beach (ca. 480 breeding pairs; Krüger, 2019).

2.2 Boldness test

Individual personality was described based on boldness level (Réale et al., 2007), which was quantified by means of the behavioral test: ‘response to a novel object’. This test consists of presenting a novel object to an individual bird and recording its behavioral responses and has been used in previous studies of seabird personality (cf. Harris et al., 2020a; Krüger et al., 2019; Patrick & Weimerskirch, 2014). In this study, we used a remote-control car with an action camera (GoPro® Hero 7) coupled to its top as the novel object (Supplementary Fig. S1). The car was taken to the nest by an observer, and it was placed in front of the individual, at the external edge of the nest cup. After leaving the car the observer would always stay out of sight of the breeding birds. We registered the reaction to the object’s presence after the observer was out of sight for 90 seconds. Tests were conducted during incubation, only when a single adult was attending the nest. The sex of each bird was determined using the length of the upper mandible, which was measured using a caliper. Females have shorter bills than males (<95mm) (Copello et al., 2006), therefore, the smaller individual of each pair was regarded as female. A total of 74 individuals were tested, however we only analyzed birds that we were able to retrieve tracking data (n = 44).

Videos were analyzed by a single observer using BORIS (Behavioral Observation Research Interactive Software) (Friard and Gamba, 2016). From the second the object was placed at the nest, we recorded the proportion of the subsequent 90s the focal bird spent in each of the 13 behaviors described in Table 1. Behavioral responses were described and categorized according to their function (Bretagnolle, 1988; Warham, 1962) into six categories: elementary acts (EA), which are behaviors unrelated to social signaling (e.g., preening, yawning, stretching) that were excluded from the analysis, submission displays (SD), related to an appeasement posture in relation to the object (e.g., raised bill, move away); agonistic displays (AD), which involve warning behaviors, such as uttering growls; threat displays (TD), which involve attack behaviors, such as sustaining a stretched neck towards the object; and inquisitive behaviors (IB), which are behaviors related to the exploration of the object, such as inspecting the object with the bill and pecking it. Examples of behavioral responses of bold and shy females and males can be seen in videos attached in the supplementary material S1.

To estimate individual boldness, we used a non-metric multi-dimensional scaling (NMDS) to assign the recorded behaviors along a shy/bold gradient using the '*vegan*' R-package (Euclidean distance, 20 minimum and 100 maximum random starts, Wisconsin standardization and 'monoMDS' engine) (Oksanen et al., 2013). To obtain a single estimate of boldness per bird we used scores from the first NMDS axis (see Table S1 in the Supplement). Individuals were classified as bolder (higher values on first NMDS axis) or shyer (lower values on first NMDS axis). Elementary acts were not included in the analysis as they do not represent social responses and could bias results. We tested for sex differences in boldness estimates in a linear model with sex as a fixed effect. Boldness level was influenced by sex (Estimate: 0.233, p = 0.015) and males had higher boldness scores than females (Fig. S2). Therefore, we analyzed data by including sex as fixed effect.

2.3 Foraging area fidelity

We used GPS devices to track 67 SGPs during the late egg incubation stage and the chick-rearing stage. Birds were equipped with one out of four different GPS models (Solar powered Kite-L, Ecotone Telemetry; Axy-Trek Marine, TechnoSmArt; CatLog Gen2 and BirdCam, both from Mr. Lee). Devices were set to collect a fix every 5 minutes or every 10 minutes depending on battery capacity. Kite-L devices were attached using a backpack harness of tubular Teflon tape and the other devices were attached to dorsal feathers with 3M #2800 series duct tape and Loctite super glue. We were able to retrieve data from 44 birds. Birds were tracked an average of 40.6 ± 8.9 days from 30 November 2019 to 25 January 2020 and for an average of 21.8 ± 6.9 days from 12 December 2021 to 25 January 2022.

To estimate individual site fidelity, we first split tracking data into individual foraging trips using the '*tripSplit*' function in the '*track2KBA*' R package (Beal et al., 2021). We defined trips as periods of ≥ 1 h spent away from the colony at a distance of at least 250 meters, since some individuals can make short trips and as proven in the case of birds from Harmony Point, feed on seal faeces at the nearby glacier (Corá et al., 2020) or on penguins from nearby colonies (LK pers. Com.). Then we estimated the home range of each trip. We applied a 95% fixed kernel utilization density (95KUD) to all GPS locations outside of the colony area. Utilization distributions quantify not only which locations an animal uses but what proportion of their time they spend in each area (Fieberg & Kochanny, 2005). We computed 95KUDs with the '*kernelUD'* function of the '*adehabitatHR*' R package (Calenge et al. 2006) and created a contour for each KUD using the '*getverticeshr'* function. We specified an Epanechnikov kernel, a smoothing bandwith (*h*) of 0.1° and a grid resolution = 100. Trip KUDs were compared for each bird using the Bhattacharyya's affinity (BA) index (Bhattacharyya, 1943). This index is a statistic used to determine the amount of spatial overlap, that is, overall similarity in KUDs. Values of zero describe KUDs with no overlap, while values of one indicate 100% overlap (Fieberg and Kochanny, 2005). BAs between pairs of trips were calculated with the '*kerneloverlap*' function also in the '*adehabitatHR*' package. The formula, rationale, and evaluation of BA relative to other overlap metrics are described in detail by Fieberg and Kochanny (2005). We computed the overlap indexes between the first trip of each animal in relation to the following trips of the same stage. The first trip occurred during incubation, but since birds are more spatially constrained after the chick hatches, we compared consistency within and between breeding stages (consistency between areas used during incubation and the ones used during chick rearing). Only 7 birds had two or more trips recorded during chick rearing. We used a Generalized linear mixed model (GLMM) with a penalized quasi-likelihood parameter estimation to test if site fidelity was influenced by stage and by boldness. We used mean BA values for each stage and within stage as the response variable and owing to distinctly foraging behaviour between sexes (Finger et al. in press; see Fig. 1 of that paper), boldness, sex and stage were used as fixed effects and individual ID as the random intercept. We used a gamma error distribution with an inverse link function.

2.4 Foraging trip characteristics

Wide-ranging animals such as seabirds can be specialized in aspects of space use besides spatial locations of foraging areas. To quantify other measures of foraging specialization, we examined three summary metrics of foraging trips: trip length (days), cumulative distance travelled between all locations (km) and maximum distance from the colony (km; hereafter "maximum range"). We calculated foraging trip metrics using the ‘*tripSummary*’ function from the ‘*track2KBA’* R package. Due to lack of battery or GPS failure, 21 trips had incomplete records. These trips were excluded from the calculations of cumulative distance, but maximum range was still calculated for those trips where the gap occurred when the bird was already on its way back to the colony (14 trips out of 21).

To test if boldness levels within each sex could affect foraging characteristics, we applied GLMMs with a penalized quasi-likelihood parameter estimation with boldness scores, sex and stage as fixed effects and Trip ID nested within bird ID as a random effect to adjust for multiple trips per individual. We used a gamma error distribution with an inverse link function for cumulative distance and trip duration data and a Gaussian distribution with a log link function for maximum range data. We first evaluated whether a mixed model was necessary by running a linear model without a random effect (ID) and checking whether there was residual variance by plotting the residuals against the levels of ID. As residual variance was confirmed, we proceeded to select the most adequate mixed model by decreasing model complexity and comparing Akaike information criterion corrected for small sample sizes (AICc) values between models. Those with the highest AICc values were selected.

To test whether giant petrels were consistent on trip characteristics and if this consistency was influenced by boldness levels, we calculated the adjusted repeatability (R) of each foraging metric using a mixed effects model framework implemented in the ‘*rptR’* R package (Stoffel et al., 2017, 2019). The adjusted repeatability is an estimate of repeatability controlling for fixed effects and was calculated as $R_{adj} = V_A/(V_A + V_W)$, where V_A is the variance across random intercepts (i.e. the between-individual variance) and V_W is the residual variance (i.e. the within-individual variance). We used Gaussian models with sex and stage as fixed effects to account for their variance and individual identity and boldness as random effects and grouping factors. Parametric bootstrapping (1000 bootstraps) was used to quantify the confidence intervals (CI) of repeatabilities and likelihood ratio (LRT) and permutation tests were used to test the null hypothesis that between-individual/group variance equals within-individual/group (Stoffel et al., 2017). We cube-root-transformed cumulative distance and maximum range and square-root-transformed trip length to improve normality. Before we run the analysis, we grouped individuals by boldness scores, since repeatability is a group-level measure of individual consistency. All birds placed on the negative scores of the first NMDS axis were categorized as ‘shy’ and on the positive scores as ‘bold’, resulting in 18 shy birds and 26 bold individuals.

2.5 Ethical Note

This study was developed on an Antarctic Specially Protected Area (ASPA). Entrance and permanence on APSA No. 133 - Harmony Point, Nelson Island was authorized by the Chilean Antarctic Institute (permits No 1045/2019, No 662/2021 and No 433/2022). Ethical approval for data collection were granted by Comité Ético Científico de la Universidad de Magallanes and the Chilean Antarctic Institute (permits No 1046/2019 and No 654/2021).

3. Results

3.1 Boldness

We recorded 13 social behaviors. Two were classified as agonistic displays, four as inquisitive behavior, one as low intensity inquisitive behavior, two as submission displays and four as threat displays (Table1). NMDS1 scores varied from -0.478 to 0.920 (Fig. 1), with lowest values representing birds that only displayed the low intensity inquisitive behavior (i.e., move the head while keeping the bill in a horizontal position) and highest values representing birds that displayed agonistic and inquisitive behaviors during a higher proportion of the test length. Low values of NMDS1 were interpreted as 'shy' or less exploratory responses and high values as 'bold' and exploratory responses. The most frequent behavior, both among (86.4%) and within individuals (46.2 ± 29.8%), was moving the head, followed by pecking/lunging (52.3%) and bending the bill (47.7%), both agonistic displays (Table 1). Almost half of the birds (45.5%) inspected the object by touching it with the bill or approaching it with the head only. A third of all females only displayed the low intensity inquisitive behavior, while only 2 out of 23 males displayed this behavior exclusively. 57% of females showed inquisitive behaviors and 42% displayed agonistic responses (mainly pecking/lunging). Interestingly, three females moved the object with the bill, a highly inquisitive behavior, while only one male did it. 61% of all males showed inquisitive behaviors and 90% displayed agonistic responses. Thus, although practically half the females were bold (10 out of 21), males were proportionally bolder than females (16 out of 23) (Fig. S2).

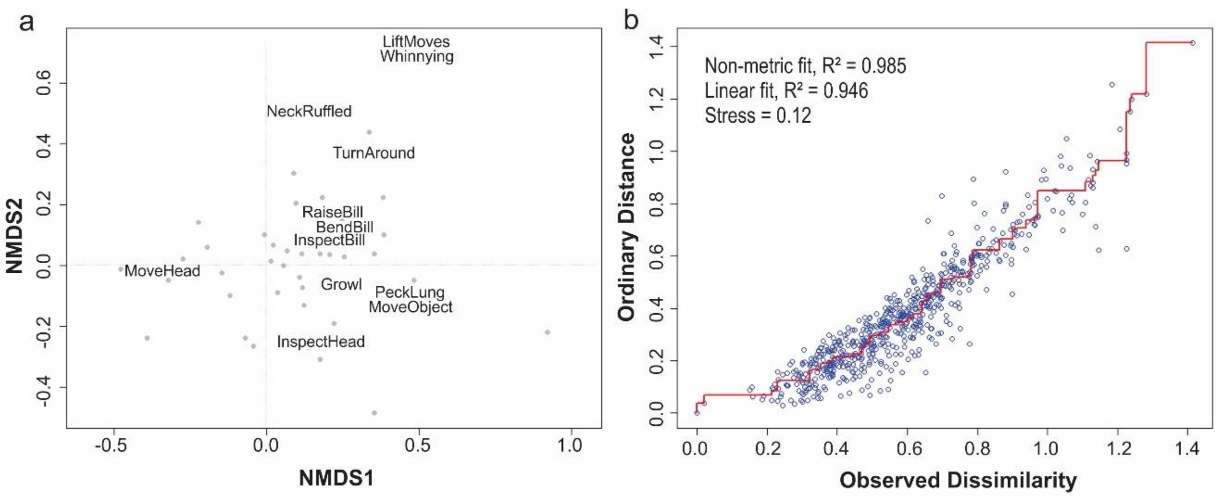

Fig. 1 a. Non-metric multi-dimensional scaling (NMDS) of southern giant petrel's (*Macronectes giganteus*) personality sampled at nest using the 'response to a novel object' method. Behaviors are described in Table 1. **b.** The NMDS ordination distance presented a high non-metric and linear fit (R2) to the observed dissimilarity, and a low stress level, indicating the analyses were accurate.

3.2 Foraging area and trip characteristics

In total, we recorded 78 foraging trips from 41 individuals during incubation (30 trips from females and 48 from males). Of these, 22 individuals had more than one foraging trip during incubation. During the chick-rearing stage, we recorded 33 foraging trips from 17 individuals (17 trips from females and 16 from males), and 13 of these had more than one trip (Fig. 2). Thirteen trips from seven individuals were recorded after the birds had failed breeding. Boldness did not affect foraging metrics (all models: $p > 0.5$) (Fig. 2).

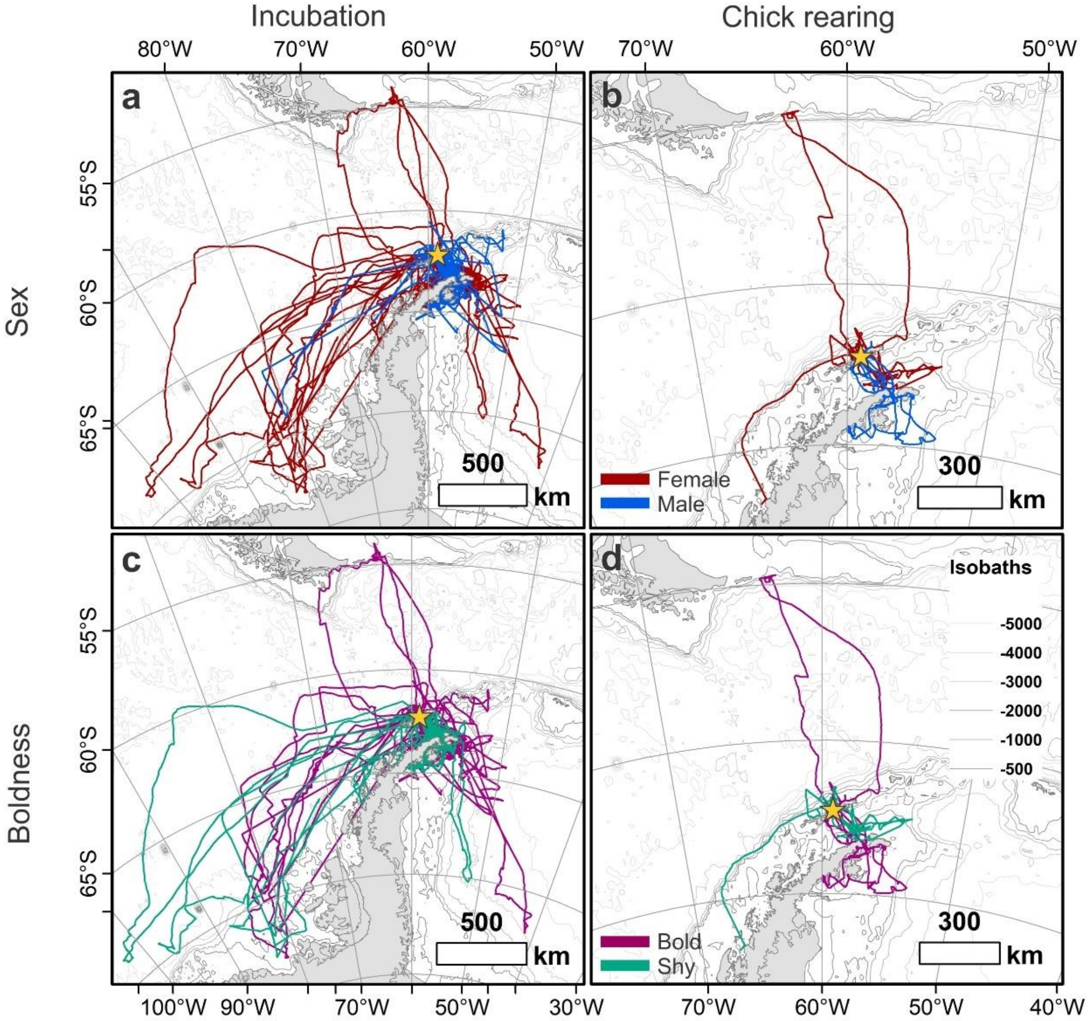

Fig. 2 Foraging trips of breeding southern giant petrels (*Macronectes giganteus*) from Harmony Point, Nelson Island (yellow stars) tracked during two breeding seasons (2019-20, 2021-20). Trips are shown according to breeding stage (**a** & **c**: incubation; **b** & **d**: chick rearing), sex (females vs. males) and boldness level (bold vs. shy). Antarctic coastline polygons and bathymetric isolines were obtained from Gerrish et al. (2021) and The International Bathymetric Chart of the Southern Ocean Version 2 (Dorschel et al. 2022), respectively.

3.3 Foraging area fidelity

There was considerable among individual variation in foraging area fidelity levels (e.g. Fig. 3). Birds varied from very low (BA: 0.088) to high fidelity (BA: 0.851) (see supplementary Fig. S2 for individual variation in BA). There was also significant individual repeatability (R^2_{adj} = 0.528, p_{LRT} = 0.048) in fidelity level among stages (Table 2). This means that not all birds are faithful to specific areas, but most are consistent in their behavior. Population-level fidelity did not differ between breeding stages (Incubation: BA: 0.411 ± 0.253, Chick rearing: BA: 0.490 ± 0.250). Consistency of sites used during chick rearing in relation to those used in incubation (between stages consistency) was slightly smaller (BA: 0.378 ± 0.250) than within stages, although this difference was not significant (LMM: Effect: 0.699, df = 10, p = 0.350). Boldness (LMM: Effect: 0.63, df = 20, p = 0.332) neither sex (GLMM: t-value: 0.204, df = 21, p = 0.839) influenced site fidelity levels (Table 2).

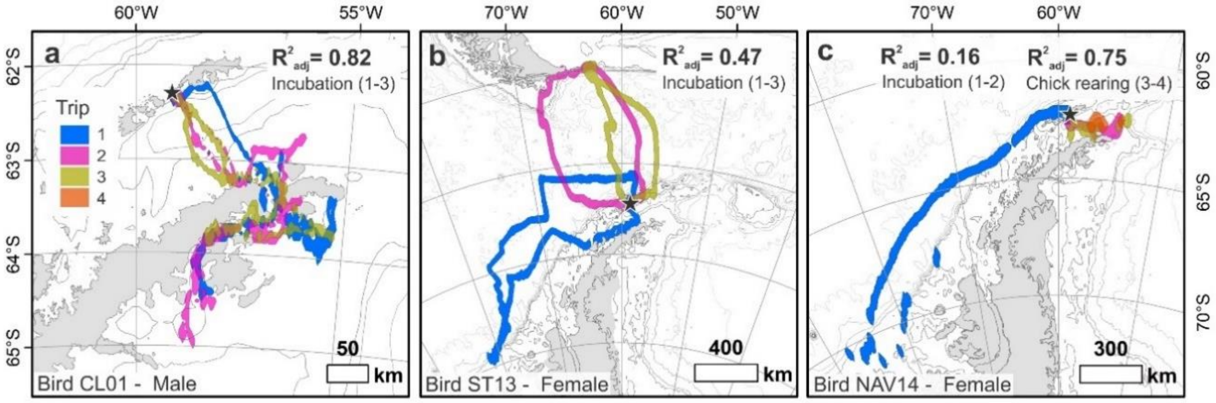

Fig. 3 Differences in foraging area specialization between individual southern giant petrels: (a) high, (b) medium and (c) low foraging site fidelity (R^2_{adj}). Individual in (c) showed low consistency within the incubation stage, but high consistency in the chick-rearing stage. Trips are color-coded chronologically. Colony location is marked by a black star.

3.4 Consistency in foraging behavior

We found significant individual repeatability in maximum range from the colony (R^2_{adj} = 0.432, p_{LRT} < 0.0001) and trip duration (R^2_{adj} = 0.334, p_{LRT} = 0.009), but not in cumulative travel distance (R^2_{adj} = 0, p_{LRT} = 1) (see Table 2 for SE values and confidence intervals). Repeatability, however, was not related to boldness level (R^2_{adj} = 0, p = 1). Repeatability associated with fixed effects (sex and stage) was high, especially for trip duration (R^2_{adj} = 0.553) and cumulative distance (R^2_{adj} = 0.573) (Table 2). This means that sex and stage explained 57% of the repeatability of cumulative travel distance, while individual ID explained 47% of maximum range from the colony and 33% of trip duration.

Table 2. Repeatability (R^2_{adj}) ± Standard Error (Confidence Interval) of within-season foraging area consistency and foraging behavior in breeding of southern giant petrels (*Macronectes giganteus*) in the maritime Antarctic. Contribution of fixed effects indicates how much repeatability is explained by the variance of fixed effects, which are breeding stage in the BA index and stage and sex for trip metrics.

	R^2adj ± SE (CI)		
Metric	**ID**	**Boldness**	**Fixed effect**
BA index	**0.528 ± 0.225** (0 - 0.86)	0.011 ± 0.085 (0 - 0.29)	0.03 ± 0.07 (0.0 - 0.27)
Trip duration	**0.334 ± 0.153** (0 - 0.53)	0 ± 0.137 (0 - 0.45)	0.553 ± 0.191 (0.28 - 1.01)
Max. range	**0.432 ± 0.108** (0.18 - 0.62)	0 ± 0 (0 - 0)	0.377 ± 0.157 (0.16 - 0.78)
Cum. distance	0 ± 0.104 (0 - 0.37)	0.39 ± 1.7 (0 - 0.608)	0.573 ± 0.213 (0.28 - 1.12)

Values in bold are significant $p_{LRT} < 0.05$.

4. Discussion

In this study we investigated the occurrence of short-term consistency in the use of foraging areas and in the foraging behavior of southern giant petrels and whether this consistency varies as a function of boldness, sex and breeding stage. We found that giant petrels show consistency both in foraging areas and in foraging behavior during the breeding season. However, contrary to what we expected, this consistency was not influenced by boldness levels. Also, boldness did not influence foraging trip distances and duration.

Influence of boldness in consistency and in foraging parameters has been found for many seabird species (e.g., albatrosses: Patrick and Weimerskirch, 2014b, shearwaters: Krüger et al., 2019 and kittiwakes: Harris et al., 2020). These studies, however, haven't found an effect of sex over boldness. Compared to other Procellariiformes, giant petrels show the highest sexual dimorphism of all species (Copello et al., 2006). Males are 40% heavier and have bills 15% longer than females (Copello et al., 2006). Giant petrels also show a highly developed social behavior system, and males are known to be markedly more agonistic than females. In a study describing the social behavior of giant petrels, Bretagnolle (1988) found that from 481 displays performed by individuals at the colony, only 22.5% of these were performed by females. Males were more prone to show agonistic and threat displays, and females usually showed an appeasement behavior. Therefore, for giant petrels, inter sexual differences can be more relevant to shape behavioral traits than individual variation. Differences in foraging behavior and choice of foraging areas are, therefore, more affected by sexual differences in foraging than personality.

Although boldness did not influence foraging metrics, the only two females that foraged in waters outside the Antarctic zone (<-60°S) were bold ones (Fig. 2). Both females foraged at a specific area of the Patagonian continental shelf where trawler and longline fishery activities frequently occur (Copello and Quintana, 2009; Finger et al, in press). One of the females used the same zone, both in the incubation and chick-rearing stages. Competition for discards can be high around fishing boats (Arcos et al., 2001) and therefore this should favor bold birds, or in the case of breeding giant petrels, bolder females. Seabirds are highly threatened by fisheries that do not use mitigation measures (Dias et al., 2019). Bycatch (incidental capture) in longline hooks, collision and entanglement in trawler cables and nets are the main forms that surface-feeding seabirds are negatively affected by fisheries (Oliveira et al., 2022). However, consumption of offal and discards from fisheries during the non-breeding season has been correlated to population increases of giant petrels from the maritime Antarctic (Krüger et al., 2017) and from Patagonia (Copello et al., 2008; Copello & Quintana, 2009; Quintana et al., 2006). Boldness could be influencing the use of areas with fishing activity, but there is too little data to confirm this hypothesis. If with a bigger sample size this hypothesis turns out to be confirmed, it would represent bold females could be more threatened by fisheries' interactions than the rest of the population, or in some cases, benefited by the consumption of discards. This highlights the importance of taking individual specialization into account when analyzing threats to a population.

Reproduction is one of the major drivers of changes in spatial distribution and foraging in the annual cycle. Breeding seabirds are bound to constantly return to the colony to shift incubation bouts with the partner or feed the chick, and thus, display the central place foraging behavior (Burke & Montevecchi, 2009). The different stages of the breeding cycle impose varied levels of foraging constrains as the demands of nest-attendance change across incubation, brood guard and chick rearing (Phillips et al., 2017). During incubation, adults are only foraging for themselves. Therefore, high consistency in foraging areas throughout the incubation period is expected, as individuals should favor areas where they have previous knowledge of food availability (Ceia & Ramos, 2015; Wakefield et al., 2015; Weimerskirch, 2007).

Marine predators will often target regions characterized by local physical features or processes, including eddies, frontal systems, upwelling zones and shelf breaks, that increase primary production or serve to aggregate various types of prey (Arthur et al., 2015; Kappes et al., 2010; Louzao et al., 2011; Pinet et al., 2011; Wakefield et al., 2015). The recurrent use of similar areas may increase familiarity with feeding conditions, including fine-scale resource availability and distribution (Hamer et al., 2007; Ramírez et al., 2016b). After the chick hatches, parents must frequently feed the chick with a high-quality diet (e.g., lipid-rich fishes, carrion) (Raya Rey et al., 2012) with a specific size that chicks can ingest. Therefore, adults might need to adjust their distribution to select prey with these characteristics in areas closer to the colony. This change in chick requirements is the main cause of changes in the foraging distribution and trip characteristics between stages in this study.

Age is another factor that could explain residual variance in foraging behavior and consistency, but it was not explored in this study since it is not possible to define age among mature individuals, unless they have been ringed as nestlings. However, older breeders may have greater efficiency in locating profitable feeding areas, as shown for Cory’s shearwater (*Calonectris diomedea*), whose site fidelity to productive areas was higher in experienced age classes (Haug et al., 2015). Senescence, however, can also negatively affect foraging behavior. Catry et al. (2006) showed that old grey-headed albatrosses (*Thalassarche chrysostoma*) undertook longer trips and gained less mass than middle-aged birds. Similarly, old male wandering albatrosses undertook longer trips to remote foraging grounds and showed less foraging activity (Lecomte et al., 2010).

Morphological variation can also have an effect over spatial distribution. Krüger et al. (2018) showed that during the non-breeding season, within the same population, smaller giant petrels were found to be associated with lower latitudes where warmer conditions prevailed, whereas large males tended to be associated with higher latitudes and colder conditions near the ice edge. During the non-breeding season, individuals are free from breeding duties and can move freely and match their distribution with preferred environmental conditions. This was not investigated, but larger males could also be more capable of defending resources near the colony and therefore, occupy areas closer to the colony during the breeding season. This intrasexual morphological variance should be considered in following studies.

At last, although boldness did not influence consistency in foraging areas and metrics analyzed in this study, other factors such as scale and location of Area-Restricted Search behavior (a decrease in speed and increase turning angles in response to food availability) and residence time in each food patch could matter more in terms of the role of personality, as bolder individuals are expected to show a more exploratory behavior and shyer ones, a more exploitative behavior. We cannot rule out, however, that for giant petrels, the response to a novel object in an experiment or particularly the object used in this study, might not reflect the underlying boldness level in natural situations. We recommend that other objects should be used to test boldness and that the response to the presence of an observer before the test should be considered.

5. Conclusion

At population level, southern giant petrels show a medium degree of foraging site fidelity and there was individual repeatability in the degree of fidelity among stages. As expected, fidelity decreases slightly between incubation and chick-rearing stages. Individuals also showed consistency in maximum range of foraging and trip duration. Giant petrels have varied responses to a novel object, but males were, on average, bolder than females. Contrary to our expectations, boldness level, when excluding sex effects, did not explain foraging site fidelity or trip characteristics. Use of fishery areas in the Patagonian shelf by this population might be biased to bolder females, but a bigger sample size is required to confirm this hypothesis.

CRediT Roles

Júlia Finger: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Visualization **Lucas Krüger:** Conceptualization, Methodology, Investigation, Resources, Writing - Review & Editing, Supervision, Project administration, Funding acquisition **Maria Virginia Petry:** Resources, Writing - Review & Editing, Supervision

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Table 1. Behaviors displayed by southern giant petrels (*Macronectes giganteus*) in response to a novel object placed in front of its nest for 90 seconds. Social displays are classified according to the following behavioral categories: agonistic display (AD), inquisitive behavior (IB), low intensity inquisitive behavior (LIB), submission display (SD) and threat display (TD). Proportion birds: Proportion of birds that displayed each behavior (%) and Proportion of 90 secs: mean ± SD proportion of time each bird spent displaying each behavior during test length (90 seconds).

Behavior	**Description**	**Abbreviation**	**Behavioral Category**	**Proportion birds (%)**	**Proportion (%) of 90 secs (mean ± sd)**
Bent bill	Bird bent the bill downwards	Bent Bill	AD	47.7	11.3 ± 8.7
Pecking/Lunging	Bird charged against the object and bitted, touching the object (pecking) or not touching the object (lunging).	Peck Lung	AD	52.3	15.9 ± 20.4
Inspecting Object with Bill	Bird touched the object but did not peck or open the bill	Insp Bill	IB	45.5	15.3 ± 21.1
Inspecting Object with Head	Bird moved its head in the direction of the object, without opening the bill nor biting, nor touching the object.	Insp Head	IB	45.5	8.9 ± 9.4
Move Object with Bill	Bird moves the object with bill	Move Object	IB	9.1	3.7 ± 3.5
Lift and moves	Bird slightly lifts the body and moves closer to the object	Lift Moves	IB	2.3	2.6
Move Head	Bird moved the head while keeping the bill in a horizontal position	Move Head	LIB	86.4	46.2 ± 29.8
Turn Around	Bird turned around	Turn Around	SD	13.6	8.7 ± 10.6
Raised bill	Bird raised the bill	Raised Bill	SD	27.3	7.3 ± 5.5
Neck feathers ruffled	Bird ruffled neck feathers	Neck Ruffled	TD	2.3	8.2
Up stretched neck	Bird kept its neck stretched	Up Neck	TD	2.3	1.6
Whinnying	Bird vocalized a whinnying sound	Whinnying	TD	2.3	1.7
Growling	Bird vocalized a growling sound	Growl	TD	9.1	4.8 ± 2.9

Supplementary information

Personality does not predict short-term consistency in the foraging behavior of a highly dimorphic Antarctic seabird

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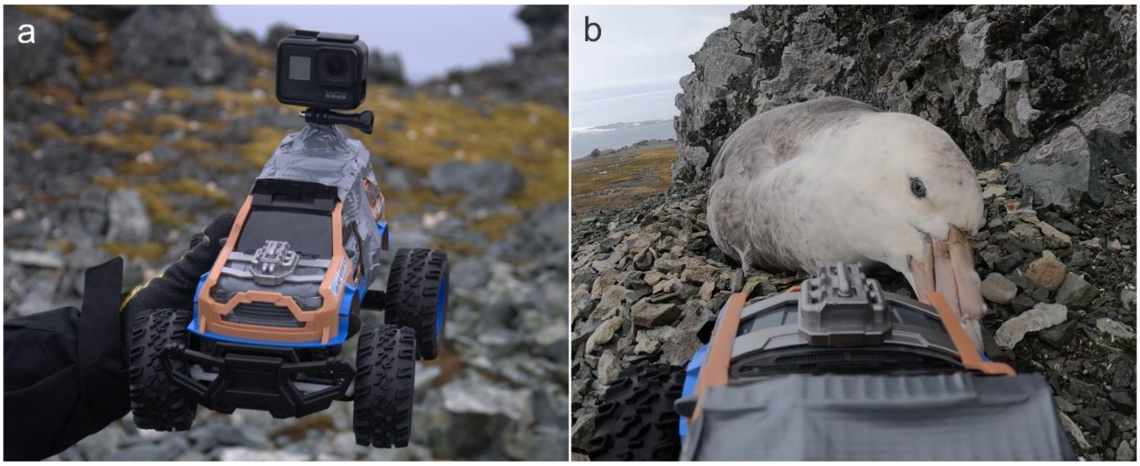

Fig. S1 a. GoPro camera attached to a remote-control car used to record the response of southern giant petrels (*Macronectes giganteus*) to a 'novel object' **b.** Individual reacting to the presence of the object.

Examples of behavioral responses of bold and shy females and males can be seen in the following link: PGS Boldness test examples

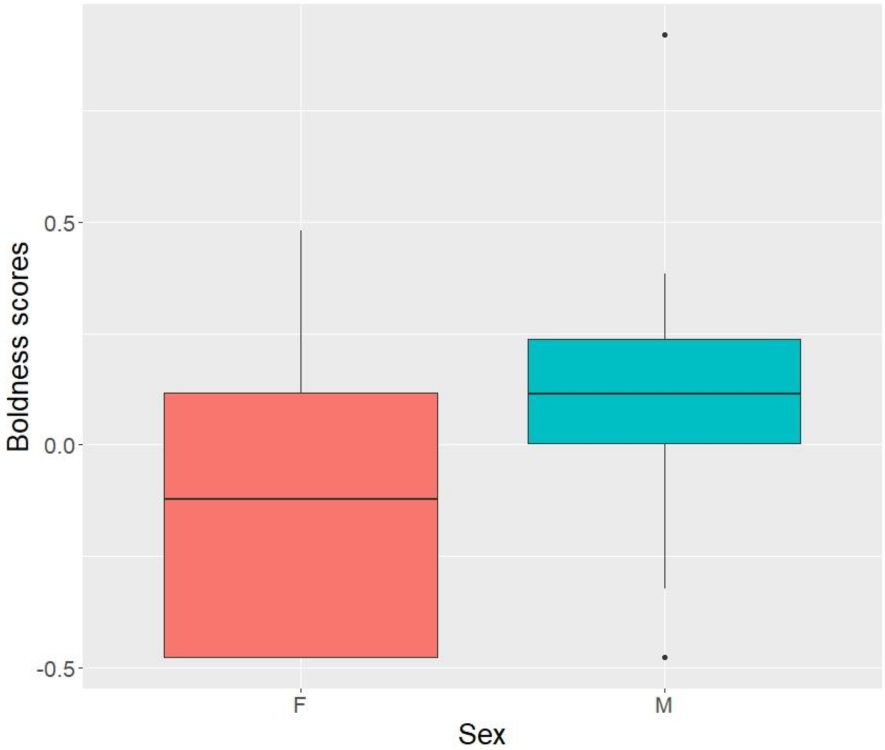

Fig. S2 Boldness scores of female and male southern giant petrels.

Table S1. Summary of individual Non-Metric Multi-Dimensional Scaling (NMDS) outputs for boldness scores

Bird ID	sex	MDS1	MDS2
BC07	F	-0.47836	-0.01315
CL01	F	-0.47836	-0.01315
CL04	F	-0.07111	-0.23924
CL07	F	-0.47836	-0.01315
CL08	F	0.248258	0.145985
HP10	F	-0.47836	-0.01315
HP20	F	-0.47836	-0.01315
NAV02	F	0.351853	-0.4844
NAV04	F	0.220928	-0.18982
NAV08	F	0.211171	0.092782
NAV11	F	-0.22351	0.141775
NAV14	F	-0.12202	-0.09741
NAV16	F	-0.47836	-0.01315
NAV18	F	0.066556	0.048265
NAV19	F	0.034489	-0.08964
ST03	F	-0.27426	0.022504
ST07	F	0.482219	-0.04819
ST10	F	-0.19649	0.060558
ST11	F	0.335915	0.43815
ST13	F	0.055572	0.001212
ST15	F	-0.47836	-0.01315
BC01	M	-0.04474	-0.26507
BC03	M	0.353418	0.037494
BC05	M	-0.14665	-0.02387
BC06	M	0.380871	0.224472
BC13	M	0.021655	0.067479
BC19	M	0.383168	0.100295
BC20	M	0.253583	0.029163
BC23	M	0.183282	0.22405
CL06	M	0.175678	0.039532
HP2021	M	0.205446	0.035876
NAV01	M	0.116382	-0.07267
NAV03	M	-0.47836	-0.01315
NAV05	M	0.122321	-0.12976
NAV07	M	0.920664	-0.21984
NAV09	M	0.175859	-0.30827
NAV12	M	-0.00771	0.10063
NAV13	M	0.094424	0.20438
NAV15	M	-0.3233	-0.04743
NAV17	M	0.087179	0.303328
NAV20	M	0.106799	-0.03818
ST08	M	-0.47836	-0.01315

ST12	M	0.013001	0.015539
ST14	M	0.114365	0.038633

Table S2. Summary of the Non-Metric Multi-Dimensional Scaling (NMDS) scores for each behavior

Behavior	**MDS1**	**MDS2**
Move Head	-0.34152	-0.01846
Neck feathers ruffled	0.127502	0.50555
Inspecting Object with Head	0.181737	-0.25728
Inspecting Object with Bill	0.197209	0.094599
Raised bill	0.220915	0.174082
Growling	0.238358	-0.05899
Bent bill	0.250183	0.129958
Turn Around	0.339632	0.365804
Pecking/Lunging	0.463913	-0.1106
Move Object with Bill	0.478449	-0.12882
Lift and moves	0.491287	0.730255
Whinnying	0.491287	0.730255

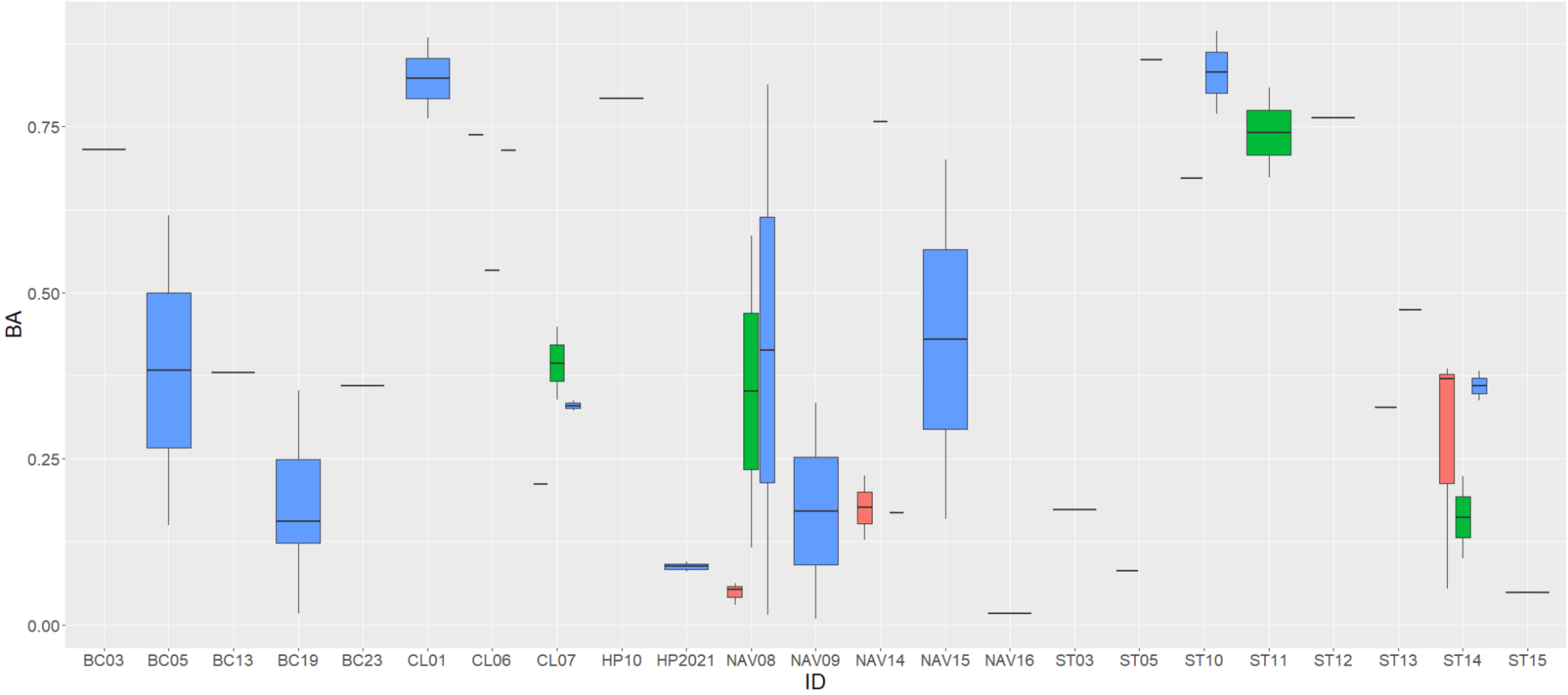

Fig. S3 Overlap index (Bhattacharyya's affinity, BA) of 95% KUDs from the first and consecutive trips of southern giant petrels occurring during the incubation stage (blue), from the first trip of chick rearing and the following trips (green) and between the first trip of incubation and the trips that occurred during the chick-rearing stage (red). Plain lines indicate where overlap was only calculated for the first and second trip.

Capítulo 3

Cannibalism in southern giant petrels (*Macronectes giganteus*) at Nelson Island, maritime Antarctic Peninsula

CAPÍTULO 3

Cannibalism in southern giant petrels (*Macronectes giganteus*) at Nelson Island, maritime Antarctic Peninsula

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Abstract

Southern giant petrels (*Macronectes giganteus*) are a scavenger and predatory species with highly opportunistic feeding habits. Although cannibalism is a likely behavior for a predatory and colonial species, there are no confirmed records of this behavior for giant petrels. In this study, we describe two cases of cannibalism in a population of southern giant petrels breeding at Harmony Point (62°18’S; 59°10’W), Nelson Island. In both cases, a male giant petrel preyed upon a nestling. Our records confirm that heterocannibalism is part of the behavior repertoire of male southern giant petrels.

Keywords Predation · Heterocannibalism · Feeding behavior · Seabirds · South Shetland Islands

1. Introduction

Cannibalism is defined as the consumption of eggs or significant parts of the body of conspecifics (Stanback and Koenig 1992; Fouilloux *et al.* 2019). Among birds, the most widespread and common form of cannibalism is heterocannibalism, in which non-kin eggs or chicks are eaten (Stanback and Koenig 1992). Cannibalistic bird species share common characteristics, such as carnivory, colonial breeding habits and a beak morphology that allows them to tear pieces of flesh rather than having to eat the whole prey (Stanback and Koenig 1992). Seabirds share many of these characteristics, and in fact, cannibalism has been reported for many species (Peter *et al.* 1990; Stanback and Koenig 1992; Daigre *et al.* 2012; Hayward *et al.* 2014; Neves *et al.* 2015). The southern giant petrel *Macronectes giganteus* (SGP) is a seabird species with scavenger and predator habits. Its diet includes both marine and land-based prey and carrion, such as, crustaceans, cephalopods, fishes, penguins, flying seabirds, seals and even whales (Hunter and Brooke 1992; Petry *et al.* 2010; Corá *et al.* 2020; Mills *et al.* 2021) However, records of petrels preying on conspecifics are speculative or unconclusive. We report the first confirmed cases of intergenerational cannibalism for SGP breeding in the Antarctic and explore hypothesis that could explain the occurrence of this behavior.

2. Material and methods

Harmony Point (62°18’S; 59°10’W) at Nelson Island (South Shetland Islands, maritime Antarctic) is home to large breeding population of seabirds (Silva *et al.* 1998). SGPs breed on plateaus and on relatively flat areas close to the beach (ca. 480 breeding pairs; Krüger 2019). Two breeding groups are located at 60 m (east-southeast) and 160 m (south-southwest) from the Francisco de Gurruchaga Argentine shelter (62°14’3”S; 59°10’2”W). Both lie near the sea level. One lies within a rock outcrop with small blocks and the latter is surrounded by rocks of 10 m height. During the 78 days (between 20 November 2019 and 5 February 2020) we stayed in the area, we frequently observed southern giant petrels from the shelter’s window. We recorded and photographed any unusual activity using a 300 mm lens coupled to a Nikon D90 DLSR camera from inside the shelter. In one of the two occasions when cannibalism occurred, one researcher moved towards the nest and recorded/photographed the behavior from a 20 m distance.

3. Results

We recorded two cases of cannibalism for SGPs during the breeding season of 2019/2020, which are described below. In both cases, one adult, possibly male due to bill length and 'jizz', was preying upon a nestling of the same species. On January 17, we sighted a SGP carrying in its beak a living conspecific chick of ca. 10 days of age. The adult was about 20 m to the north of a petrel colony (the furthest from the shelter), where adults were brooding their chicks. We did not see if the bird himself removed the chick from the nest. The bird started to peck the chick's rump (Fig. 1a), when two brown skuas (*Catharacta antarctica*) came flying towards him. As the skuas started to invest towards the chick, the adult carried it backwards and displayed an aggressive behavior characterized by a low intensity-standing attitude with an erected (but not fanned) tail and slightly lowered wings aside the body (Fig. 1a). Two minutes later, the petrel was able to tear flesh, but soon after the skuas stole the chick from him. While one skua took the chick a few meters away, another started to attack the petrel by ground and by air (Fig. 1b). The SGP reacted by uttering whinnying and growling calls and displaying and erected tale and ruffled neck feathers (Fig. 1c). A few seconds later, he was able to return to the chick, which was still alive, and eat a few pieces of the chick's rump muscle (Fig. 1d). However, after a few seconds the adult left the chick for the skuas and flew away without further conflict. During this act, no other giant petrel approached the area trying to defend or feed from the chick.

The second case was registered in January 27. We saw another adult male feeding on a nestling of about 20 days of age (Fig. 2, see also Online Resource 1 for a video footage). Before the incident, we noticed that the chick was alone in the nest and there was no apparent sign of its parents near the colony, which was the same colony where the first case occurred. Then we saw the adult pulling the chick out of the nest by its neck. We then moved towards the colony to better record the behavior at a 20 m distance. By the time we approached the scene the chick was already dead. The adult then started to tear the chick's chest skin and eat its muscle (Fig. 2). Few adults were in the colony at this moment and they once again did not approached the one that was preying the nestling. There were no skuas nearby when this second predation event started.

Fig. 1 A male southern giant petrel *Macronectes giganteus* feeding on a living conspecific chick at Nelson Island, Maritime Antarctic Peninsula while disputing it with skuas. **a** Adult pecking the chick's rump in attempt to tear flesh. **b** Skuas stealing the chick. **c** Adult displays aggressive behavior towards the skuas. **d** Recover of the chick by the adult, which was finally able to tear the skin and feed from the chick's muscle

Fig. 2 Another male southern giant petrel *Macronectes giganteus* feeding from a conspecific chick after removing it from its nest at Nelson Island, maritime Antarctic (see Online Resource 1 for a video footage https://link.springer.com/article/10.1007/s00300-021-02859-8#Sec5)

4. Discussion

There are no previous records of cannibalism in procellariiformes birds. Literature, however, reports a possible case for SGP registered by Conroy (1972) in Signy Island, South Orkneys. In his report, he wrote, “one (*chick*) was possibly cannibalized—at one site, a chick showed a marked increase in weight following the disappearance of an adjacent chick, and a fresh giant petrel tarsus bone was found in the nest with the chick; and one chick died for no ‘apparent reason’”. Although Conroy gathered evidence to suggest that record the act itself.

SGP is mostly a colonial species (Conroy 1972) which usually breeds in loose aggregations (e.g. Croxall and Prince 1980; Krüger 2019). During late chick rearing when chicks acquire thermal independence, adults leave the chicks alone in the nest for hours or even days (Warham 1962), when they become exposed to potential predation by other giant petrels. Since SGPs are opportunistic when it comes to their feeding choices (Hunter and Brooke 1992), an unguarded chick of about 20 days could be easily preyed by an adult.

Cannibalism is recorded usually in association with food shortages or high population density (Hayward *et al.* 2014; Fouilloux *et al.* 2019), which is not the case for Harmony Point, with its large populations of avian prey (e.g. large colonies of chinstrap and gentoo penguin; Silva *et al.* 1998) and decreased SGP density (Krüger 2019). Studies on other groups of seabirds suggest cannibalism can be a specialized behavior displayed under certain environmental conditions, rather than being simply opportunistic (Hayward *et al.* 2014), therefore it would be an interesting aspect to be further evaluated on SGP populations. We also cannot rule out that the presence of researchers on the area and frequent approximation to colonies over 78 days caused physiological stress to the birds, which could have influenced the cannibalistic behavior. SGP have shown to increase their heart rates in 63% when approached to 20 m during incubation (Pfeiffer and Peter 2004). This increase might transcribe into increments in energy expenditure since heart rate and oxygen consumption are directly related (Nolet *et al.* 1992; Weimerskirch *et al.* 2002). However, giant petrels, such as wandering albatrosses (*Diomedea exulans*), have large body sizes and reserves that could buffer them from the impact of energy expenditure caused by frequent stress (Weimerskirch *et al.* 2002). We also stress out that, when both cannibalism events started, we were inside the shelter, which sits 160 m away from the colony, therefore, it was not a consequence of our direct interference —usually, non-breeding SGPs fly away with human proximity, so it is very unlikely the cannibalism events would have started with our presence nearby the colony. Furthermore, only a small fraction of breeding SGPs tend to leave the nest with the proximity of a single person in Harmony Point (around 3% of a sampled population, Krüger 2019).

Our record shows that heterocannibalism is part of the behavior repertoire of male SGPs. In fact, it might be more common than expected, since two cases were registered only ten days apart at one breeding group of Harmony Point. The lack of previous reports of cannibalism for the species could not only be related to variance in the frequency of this trait in different populations, but also to unreported cases.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s00300- 021- 02859-8.

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Author contributions

JVGF, DHC, LK made the observations. JVGF wrote the original draft. All authors read, edited, and approved the manuscript.

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Declarations

Conflict of interest

The authors declare no conflicts of interests in this study.

Ethical approval

Animal ethics were evaluated and approved by ‘Instituto Antártico Chileno’ and the ‘Comité Ético Cientifico de la Universidad de Magallanes’.

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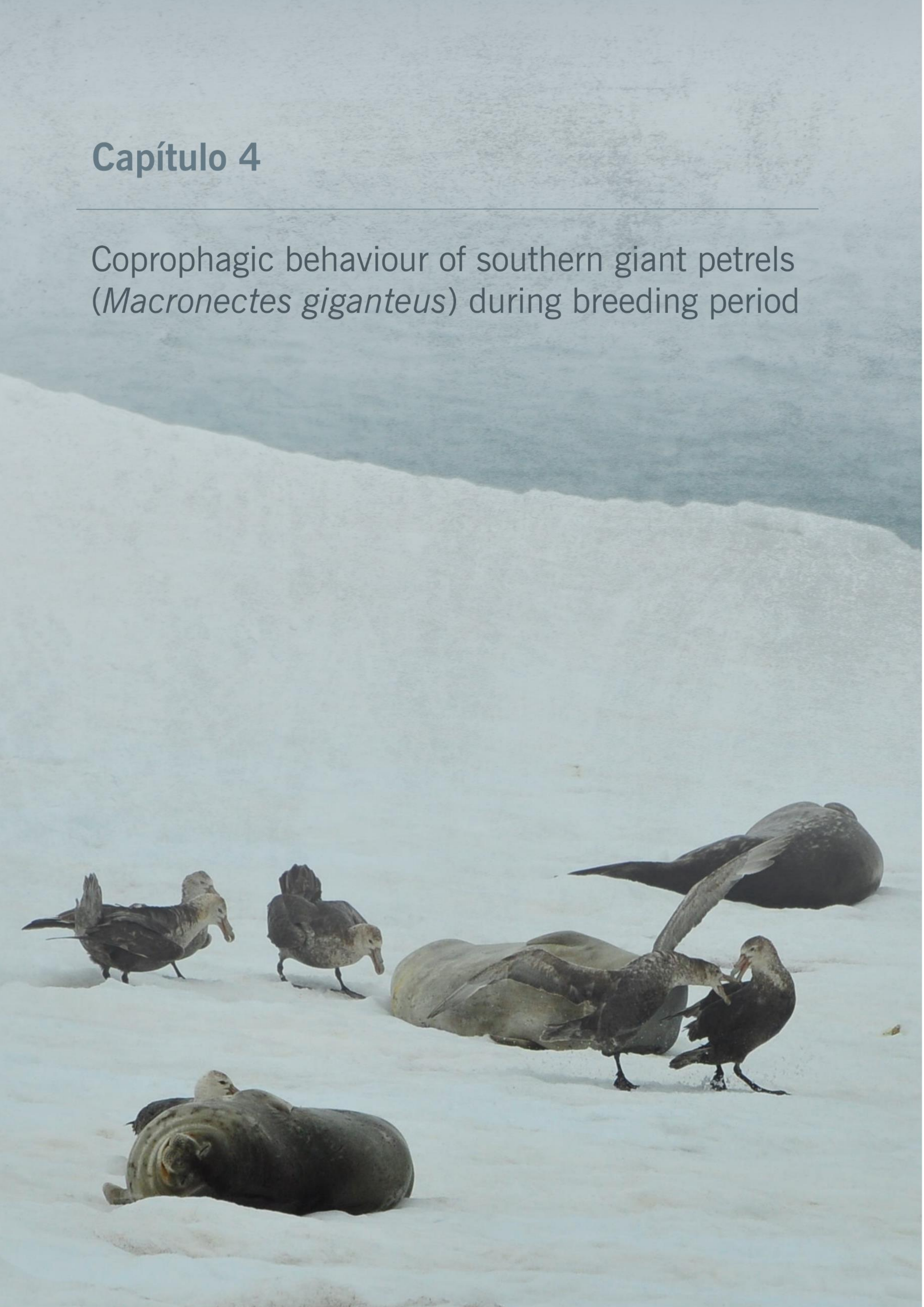
Capítulo 4

Coprophagic behaviour of southern giant petrels (*Macronectes giganteus*) during breeding period



CAPÍTULO 4

Coprophagic behaviour of southern giant petrels (*Macronectes giganteus*) during breeding period

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Abstract

Southern giant petrels (*Macronectes giganteus*) are opportunistic generalists whose feeding strategies include hunting, scavenging and fishing. While seals are important for southern giant petrels as a source of carrion, we documented that live seals also provide feeding opportunities for southern giant petrels. We tracked breeding southern giant petrels from Harmony Point, Antarctica, during incubation and chick rearing with solar-powered GPS UHF devices. Tracking results showed that animals often visited confirmed haul-out sites of seals, mainly Weddell seals (*Leptonychotes weddellii*). Feeding on seal faeces was confirmed by direct observation. Southern giant petrels were more likely to visit haul-out sites during incubation than during chick-rearing. This behaviour suggests that the birds fed on seal faeces mainly when fasting, which could last as long as 15 days. Seal faeces could be a resource consumed to quickly recover from the fast before leaving for a longer trip.

Keywords: Antarctica; coprophagy; diet; foraging

1. Introduction

Breeding is an energetically demanding activity during which seabirds invest great effort in successfully raising a chick (Markones *et al.* 2009). Scavenging on fur seal (*Arctocephalus gazella*), Weddell seal (*Leptonychotes weddellii*) and southern elephant seal (*Mirounga leonina*) carcasses and placentas provides an important source of food during breeding for giant petrels (*Macronectes* spp.), especially during the post-hatching period (Hunter 1984; de Bruyn *et al.* 2007). Carcasses also play an important role in the growth and survival of chicks due to their high energetic and nutritional value (de Bruyn *et al.* 2007). However, living seals can also provide feeding resources for giant petrels. Casaux *et al.* (1997) briefly described southern giant petrels (*M. giganteus*) gathering around hauled-out Weddell seals at Harmony Point (Nelson Island, Maritime Antarctic Peninsula) to feed upon faeces and regurgitations. They suggested that this source of food should be further inspected, as many diet items recorded for southern giant petrels could have been consumed through scavenging on Weddell seal scat and vomit. In this study, we quantified the incursions of southern giant petrels tracked with GPS to areas where Weddell and elephant seals haul out to rest or moult at Harmony Point and showed that breeding southern giant petrels frequently feed on seal faeces. We thus provide evidence that coprophagy is a common behaviour for Southern giant petrels in the studied population. We also discuss possible causes and consequences of this behaviour.

2. Materials and methods

We monitored feeding behaviour and movements of breeding southern giant petrels from a population breeding at Harmony Point (Fig. 1a). The area holds a large southern giant petrel population of ca. 480 breeding pairs (Krüger 2019). While Weddell and elephant seals haul out at Harmony Point throughout the warm season (October to February), there is no recent local evidence of breeding behaviour by either seal species [although three female elephant seals were recorded with pups in 2001 (Carlini *et al.* 2003; Harris *et al.* 2015)]. Non-breeding adult fur seals start arriving at the area at the end of January, after the breeding season.

Therefore, seal placentas and carrion are scarce or even absent in the area, and faeces is the main resource provided by seals [regurgitations are produced less frequently than faeces at seal haul-out sites (Casaux *et al.* 1997)]. We equipped 10 breeding pairs of southern giant petrels with solar-powered GPS-UHF (Ecotone Kite- M, 20 g) attached with Teflon harnesses. We continuously tracked the 20 southern giant petrels between 3 December 2019 and 31 January 2020. GPSs were programmed to collect a geographical fix every 5 min. A foraging trip was considered to comprise all fixes recorded after the bird's departure from the breeding colony—following the arrival of its breeding pair—until its return.

As we focussed our efforts on inspecting areas that were accessible by foot (so we could confirm birds' behaviours *in situ*), we selected GPS fixes positioned inside the Harmony Point area. We excluded all fixes within 100 m from the colonies, so that positions taken when individuals were incubating, resting by the nest or arriving/leaving the colony were not mistaken with feeding areas (Fig. 1b). By applying a kernel utilization distribution (KUD) function using the 'kernelUD' command of the 'adehabitatHR' R package (Calenge 2011), KUDs were calculated for each individual separately, and were averaged a posteriori to generate a non-biased population-level KUD. We specified an Epanechnikov kernel (Samiuddin and El-Sayyad 1990), a smoothing bandwidth (h) of 250 m and a grid size of 1000 m. Areas with a greater density of fixes are represented by 50% KUD contours (Fig. 1b). Aiming to obtain visual confirmation of faeces ingestion by southern giant petrels, we visited accessible places used by tracked individuals at least once (frames 2–6, Fig. 1b). We took aerial photographs using a MAVIC 2 Pro DJI drone to characterize main seal haul-out sites at Harmony Point (Fig. 1). Sites 1 and 6 are on the border of glaciers and covered by snow year-round (Fig. 1). Only Weddell seals were seen resting on the ice. Site 2 is a pebble beach covered by beached sea algae; the site is used as a haul-out site by elephant seals. Site 3 is located close to the beach at the distal end of a talus slope (Rodrigues *et al.* 2019) and is covered by ice most of the summer. Again, only Weddell seals were seen resting over the ice. Sites 4 and 5 are beaches formed by thin sand, where both elephant and Weddell seals haul out. The substrate of sites 1 and 3–6 were classified as homogeneous and that of site 2 as heterogeneous.

The frequency of visits to haul-out sites was compared between sexes using a binomial linear mixed model in the 'lmerTest' R package (Kuznetsova *et al.* 2018), using both individual ID and foraging trip number as random factors. Incubation occurred until early January, when eggs started to hatch. The number of complete trips (including points from the start to the end of the foraging trips) and the number of visits to seal haul-out sites were calculated for each individual, and a Poisson generalized linear model was used to test whether the number of visits was proportional to the number of foraging trips.

3. Results

We recorded 55 foraging trips by 20 southern giant petrels. A total of 38 trips from 16 southern giant petrels were completed. Out of the 38 foraging trips, 28 (73.7%) evidenced that 14 southern giant petrels (7 males and 7 females) visited 6 seal haul-out sites at Harmony Point (50% and 95% KUDs, Fig. 1b) at least once (min. = 1, max. = 4). Females and males used the haul-out sites with the same frequency ($z = -1.14$, $\beta = -1.5$, $p = 0.255$), but the effect of random terms (individual ID and foraging trip number) was significant (Fig. 2). Southern giant petrels were more likely to repeatedly visit seal haul-out sites during incubation than during chick-rearing (Fig. 2). The individual number of visits to seal areas was associated with the total number of trips, with a general trend of animals visiting seal areas on half the trips ($z = 2.75$, $\beta = 0.48$, $p = 0.006$). All except one haul-out site (site 2, with heterogeneous substrate) were not visited by southern giant petrels. Out of the seven areas frequently used by southern giant petrels at Harmony Point, two were not haul-out sites, but chinstrap penguin (*Pygoscelis antarcticus*) colonies (Fig. 1). Ground observations confirmed southern giant petrels were feeding on Weddell seal faeces (Fig. 3), displaying resource defence behaviour patterns (Fig. 3b, c).

4. Discussion

Our results show that seals provide feeding resources to southern giant petrels not only as carrion (i.e. Hunter 1984; de Bruyn *et al.* 2007). When at Harmony Point, tracked southern giant petrels visited Weddell seal haul-out sites more often than other areas, including those with penguin rookeries. Although we did not quantify the number of times that petrels consumed faeces, at each of our visits to haul-out sites 1, 3 and 6 (Fig. 1), at least one petrel was consuming Weddell seal faeces. Tracking data showed that areas with homogeneous substrate (i.e. accumulated snow, glaciers, or thin sand beaches) were more often visited by southern giant petrels. The substrate probably influenced detection of faeces and increased faeces accumulation, thereby facilitating feeding. This could be the reason why no tracked birds visited site 2 (Fig. 1). Its heterogeneous substrate probably favours outflow of faeces, making detection by southern giant petrels more difficult.

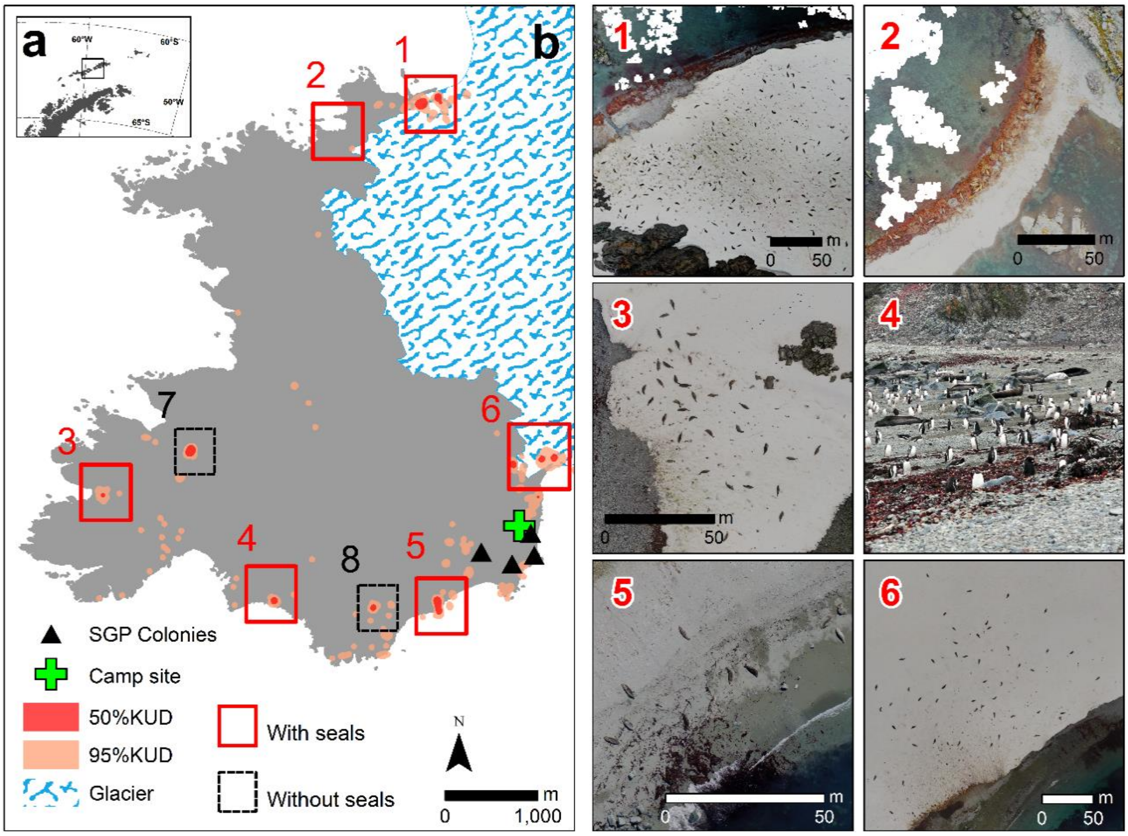

Fig. 1 a Location of Nelson Island on the Maritime Antarctic Peninsula and b location of Harmony Point on Nelson Island; b at-land kernel usage density of southern giant petrels (*Macronectes giganteus*) at Harmony Point; red squares with solid contour are areas where we registered groups of seals resting; black squares with dashed contour are areas frequented by southern giant petrels where no seals were observed. Frames 1 to 6 present pictures of the areas identified by numbers in a. Frames 1, 3 and 6 are resting areas exclusively used by Weddell seals (*Leptonychotes weddellii*), whereas frames 2, 4 and 5 are also used by elephant (*Mirounga leonina*) and fur seals (*Arctocephalus gazella*)

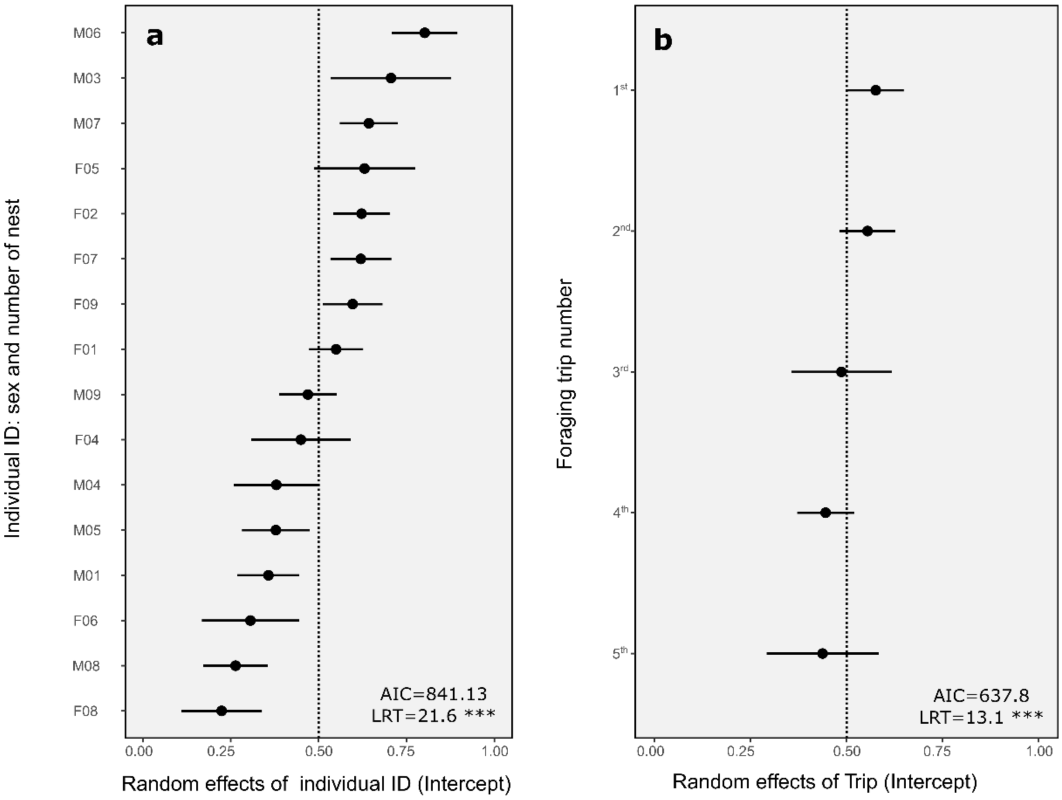

Fig. 2 Random effects (intercept) of binomial linear mixed models comparing the probability of breeding southern giant petrels (*Macronectes giganteus*) visiting seal haul-out sites at Harmony Point, Nelson Island, during foraging trips. a Individual identification is based on sex (F females, M males) and nest number; individuals with the same nest number are breeding pairs; b foraging trip number estimated based on date of GPS deployment on each bird. Akaike information criteria (AIC) is a measure of prediction error; the smaller the AIC, the better the model. The likelihood ratio test (LRT) compares differences among models with and without a random term. ***p < 0.001

Fig. 3 a Weddell seals *(Leptonychotes weddellii*) at haul-out site surrounded by southern giant petrels (*Macronectes giganteus*) (dashed black circles). Solid red circles depict seal faeces—this area corresponds to frame 1 in Fig. 1. **b, c** Group of southern giant petrels disputing access to faeces. **d–e** Evidence of seal faeces consumption by southern giant petrels. Arrow in e indicates a tagged individual feeding on faeces

Breeding southern giant petrels undergo long periods of fasting during incubation, when female and male alternate long bouts of incubation (González-Solís *et al.* 2000; Schulz *et al.* 2014). The southern giant petrels we tracked carried out foraging trips that lasted between 5 and 15 days. Fasting can decrease body reserves before the return of the pair to the nest, thereby reducing the probability of survival (González-Solís *et al.* 2000). Our data show that southern giant petrels visited seal haul-out sites mostly at the start of foraging trips, before going to forage for a longer distance out at sea, and visits to haul-out sites were more likely to occur during incubation when fasting was longer. Weddell seals' diet includes cephalopods, crustaceans and fishes, and a part of the nutrients and fat present in prey can be retained in faeces (Casaux *et al.* 1997, 2006). We hypothesise that, after a long period of fasting, southern giant petrels ingest seal faeces as a way to gain a quick intake of energy before starting a long foraging trip in search of more energetic food. However, faeces are probably a less important item after the chick hatches. To promptly attend the chick's energetic demands, southern giant petrels shift to shorter foraging trips, and consequently undergo shorter fasting periods at the nest. They also focus on feeding the chick with high-energy-content prey, such as penguin and seal carrion (Forero *et al.* 2005; Raya Rey *et al.* 2012), while seal faeces possibly do not contain sufficient energy to boost chick growth. This study reinforces the importance of mammals as sources of food for southern giant petrels during the breeding season. Finally, it adds coprophagy as a further behaviour to the broad feeding repertoire of southern giant petrels.

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Declarations

Conflict of interest

The authors declare no conflicts of interest.

Author’s contribution

LK idealized the study. DHC, JVGF and LK equally contributed to data sampling, analysing and manuscript writing.

Ethics Approval

Animal ethics were evaluated and approved by ‘Instituto Antártico Chileno’ and the ‘Comité Ético Cientifico de la Universidad de Magallanes’.

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2 CONSIDERAÇÕES FINAIS

Os capítulos da presente tese trazem contribuições inéditas ao conhecimento sobre a ecologia espacial e trófica de um dos principais predadores de topo do ecossistema antártico e principal espécie necrófaga do Oceano Austral.

2.1 Distribuição em fina escala e seleção de habitat

Especificamente, esse estudo apresentou a distribuição marinha em fina escala espacial de uma população antártica de petrel-gigante-do-sul (daqui em diante, petrel-gigante) e descobriu que durante o período reprodutivo, fêmeas de petrel-gigante forrageiam em zonas até 2.100 km distantes da colônia e utilizam áreas de atividade pesqueira fora da Antártica. Ou seja, ainda que na Antártica a pesca seja regulada pela CCAMLR e seja pouco frequente durante o período reprodutivo, uma parcela da população está vulnerável a atividades antrópicas fora da legislação da CCAMLR ou do Tratado da Antártica. De fato, desde 2018 quando o grupo de pesquisa iniciou as atividades em Ponta Harmonia, entre dois e três anzóis de espinhel foram encontrados anualmente em ninhos de petréis-gigantes (Lucas Krüger, observação pessoal). Há possibilidade que esse número seja ainda maior, pois a varredura não foi exaustiva.

A proximidade a colônias de pinguim foi a variável com maior efeito sobre a seleção de habitat de forrageio de machos, enquanto para fêmeas a profundidade da coluna d'água foi a que apresentou maior efeito positivo. Através da sua ampla distribuição em ambas as faces da Península Antártica, de uma seleção de habitat associada a zonas marinhas variadas e proximidade a colônias de pinguins, bem como o uso de áreas de descanso de foca e de atividade pesqueira, a espécie se configura como uma importante plataforma para monitorar populações isoladas e atividades de pesca ilegal dentro e fora da Antártica. A utilização de dispositivos de rastreamento com detecção de radares de embarcações pesqueiras e câmeras "*animal-borne*", como já feito em albatrozes (*e.g.*, WEIMERSKIRCH *et al.*, 2020), pode contribuir para a detecção de embarcações *IUU* dentro e fora da região antártica, assim como para detectar e monitorar tamanhos populacionais de pinguins e focas.

2.2 Consistência individual, nível de ousadia e a ausência de influência sobre as estratégias de forrageio: considerações para trabalhos futuros

Outro aspecto descoberto é que petréis-gigantes apresentam consistência individual nas áreas de forrageio e nas métricas das viagens, a saber: distância máxima e duração das viagens de alimentação. Conforme o esperado, essa consistência foi maior entre viagens do mesmo estágio reprodutivo.

Ainda que o uso de áreas fora da região antártica tenha sido baixo dentre a população, uma das fêmeas forrageou consecutivamente em uma área de pesca de merluza-negra com espinhel de fundo na Patagônia Argentina, levantando a hipótese de que faça uso consistente de descartes pesqueiros na sua alimentação.

Os petréis-gigantes apresentaram um repertório amplo de respostas comportamentais a um objeto novo e os comportamentos exibidos estiveram dentro do repertório comportamental descrito por Bretagnolle (1988). O viés sexual também se confirmou, visto que machos foram, em média, mais responsivos e, portanto, mais ousados que fêmeas. Apesar da existência de variação de personalidade entre indivíduos da população ter sido corroborada pelo estudo, aqui caracterizada pelo nível de ousadia, a hipótese do estudo não se confirmou, uma vez que a personalidade não influenciou na consistência das áreas de forrageio, nem nas características das viagens. A principal fonte de variação no período reprodutivo se deu em termos de estágio reprodutivo e sexo. A ausência de influência da personalidade sobre o comportamento de forrageio contraria os achados mais recentes para aves marinhas, que demonstram que indivíduos ousados e tímidos diferem nas suas estratégias alimentares (e.g. HARRIS *et al.*, 2020; KRÜGER *et al.*, 2019; PATRICK; PINAUD; WEIMERSKIRCH, 2017). Frente a esse resultado, algumas limitações devem ser consideradas.

A maioria dos estudos com aves que utilizaram o nível de ousadia como *proxy* para a personalidade, valeram-se ou do teste de resposta a um objeto novo (HARRIS *et al.*, 2020; KRÜGER *et al.*, 2019) ou da resposta a um humano se aproximando da ave no seu ninho (JEFFRIES; PATRICK; POTTS, 2021; PATRICK; PINAUD; WEIMERSKIRCH, 2017; PATRICK; WEIMERSKIRCH, 2014). As características da área reprodutiva de cada espécie são um dos fatores que influenciam na escolha do método, uma vez que, aves que reproduzem em superfícies abertas acabam por entrar em contato visual com o observador antes de verem o objeto novo. Portanto, inicialmente, a metodologia proposta para o presente estudo era a utilização de um carro de brinquedo remotamente tripulado como objeto novo, de modo que o observador não precisasse se aproximar do indivíduo a ser testado. Todavia, tanto o terreno acidentado, quanto as limitações de bateria e de força do veículo empregado, impossibilitaram a utilização remota do veículo de forma sistemática. Sendo assim, valemo-nos de uma combinação não só de um objeto novo, mas também da aproximação direta de um observador. Não obstante, apenas a resposta ao objeto em si foi usada como variável para determinar o nível de ousadia.

2.3 Informações extras e implicações dos registros de novos comportamentos alimentares para a espécie

O presente estudo também descreveu dois comportamentos inéditos para a espécie, aumentando o já amplo repertório alimentar dos petréis-gigantes. Ainda que o canibalismo fosse um hábito possível para a espécie devido às suas características morfológicas e dieta com base na estratégia oportunista, este comportamento não havia sido descrito em literatura. Posteriormente à publicação do artigo, fui contatada por um guia de expedição e uma bióloga que me relataram outros casos não publicados de canibalismo para a espécie. Um caso foi registrado em 2016 na Ponta Hannah, na Ilha Livingston, também parte do arquipélago das Ilhas Shetland do Sul (Jim Wilson, comunicação pessoal) e outro em 2020, na Ilha Gough (Michelle M. Risi, comunicação pessoal). Possivelmente, o registro de Conroy (1972) na Ilha Signy, no arquipélago das Órcades do Sul, de um filhote de petrel-gigante que desaparecera do ninho enquanto o filhote do ninho ao lado ganhara peso rapidamente também seja um caso de canibalismo. Na estação reprodutiva seguinte à publicação do artigo (2021/2022), nosso grupo observou mais um caso de canibalismo realizado por um macho na mesma área do estudo aqui apresentado (Ponta Harmonia). Esses outros registros demonstram a difusão do comportamento mesmo em populações que reproduzem em regiões distantes umas das outras (Gough no Atlântico Sul, Shetland do Sul na Antártica Marítima e Órcades do Sul a 604 km da Península Antártica), e salientam que o canibalismo não é um comportamento isolado ou necessariamente recente para petréis-gigantes.

A ocorrência de canibalismo intergeracional em uma baixa frequência na população e em um período com ampla abundância de outras presas (i.e., filhotes de pinguins) ressalta seu caráter oportunista (o filhote estava vulnerável e disponível) e possivelmente a existência de especialização individual no uso desse recurso, como ocorre em gaivotas-prateadas (*Larus argentatus*) e gaivotas-ocidentais (*Larus occidentalis*) (PARSONS 1971; PIEROTTI; ANNETT, 1987). Ou seja, nem todos os indivíduos canibalizam, ainda que possam fazê-lo. De fato, no registro feito durante a estação reprodutiva de 2021/22, foi observado que diversos indivíduos adultos se aproximavam do filhote que estava sozinho no ninho, um até tendo-o bicado algumas vezes sem machucar, mas nenhum o predou (Figura 5). Essa possível especialização abre o leque para a existência de outras especializações alimentares que podem estar associadas à consistência nas áreas de forrageio, mas não necessariamente.

Figura 5 – Registro de adultos de petrel-gigante-do-sul investigando um filhote deixado sozinho no ninho, uma hora antes dele ser canibalizado por outro macho adulto. O indivíduo de morfotipo branco bicou o filhote algumas vezes sem machucá-lo externamente ou retirá-lo do ninho

Fonte: Registrada pela autora

Os casos de canibalismo observados no presente estudo ocorreram após a saída do adulto da colônia e a consequente permanência do filhote desacompanhado no ninho. A saída do adulto faz parte da estratégia reprodutiva da espécie. Assim que o filhote alcança homeotermia, ele já pode permanecer sozinho no ninho por horas a dias, permitindo ao adulto forragear em áreas mais distantes ou por mais dias seguidos para reabastecer suas reservas energéticas (WARHAM, 1962; OTOVIC *et al.*, 2018; FINGER *et al.*, *in press*). Devido à sua menor força e menor eficiência em regurgitar o óleo estomacal, cuja função é repelir agressores

(WARHAM, 1962), filhotes menores estão, teoricamente, mais vulneráveis à predação por conspecíficos do que filhotes um pouco mais maduros.

A duração do turno de guarda é definida por um *trade-off* entre a condição corporal do adulto presente no ninho e a capacidade do parceiro forrageando no mar de retornar antes que a condição corporal de seu parceiro tenha se degradado e ele seja forçado a sair para se alimentar (TVERAA; CHRISTENSEN, 2002). Portanto, é plausível levantar a hipótese de que os pares que melhor conseguem coordenar suas viagens de alimentação e, que, portanto, evitam a evasão prematura do adulto em guarda, conseguem maximizar a chance de sobrevivência de seu filhote em áreas onde a predação por petréis ou skuas é alta (*Catharacta* spp.). OTOVIC *et al*., (2018) investigaram o ciclo anual do petrel-gigante em duas das áreas reprodutivas mais remotas para a espécie, situadas na porção continental da Antártica Leste, e observaram que a duração do período de guarda diferia entre as duas áreas. A duração média variou de 24 ± 7 na Ilha Nelly a 35 ± 6 dias na Ilha Hawker. Portanto, na Ilha Hawker, os petréis guardaram seus filhotes, em média, 11 dias a mais que na Nelly.

Os autores mencionam que, devido à ausência de predadores da espécie nas duas áreas, a diferença na duração da guarda não poderia ser explicada por esse fator. No entanto, lanço aqui a hipótese de que petréis de hábitos canibais atuam como predadores nessas áreas, mas em uma frequência distinta. Sendo assim, exercem uma pressão positiva sobre a duração do período de guarda, que deve ser mais longo onde eles são mais frequentes. Ainda que isso não tenha sido investigado no presente estudo, o monitoramento diário de ninhos na Ponta Harmonia foi realizado durante as atividades de campo na área. Alguns dos petréis começaram a deixar os seus filhotes sozinhos no ninho a partir de 15 dias após a eclosão, mesmo com a presença de petréis canibais, o que configura um período de guarda muito mais curto que na Antártica Leste. No entanto, as condições ambientais e severidade do clima são muito distintas entre as duas regiões e é possível que a duração da guarda no continente seja influenciada pelas menores temperaturas. Dessa forma, não é possível fazer uma comparação direta.

O consumo de fezes de foca-de-Weddell e a visita frequente a áreas de descanso de focas por grande parte dos machos e fêmeas rastreados, reforça a importância de recursos providos por mamíferos marinhos durante o período reprodutivo de petréis-gigantes e de seu potencial para monitorar as populações de focas que utilizam essas áreas. Além disso, lança luz e reforça o fato de que fêmeas também forrageiam em ambientes terrestres durante a incubação, mesmo na presença de machos. Ainda que machos exibam comportamentos agonísticos contra outros indivíduos durante o consumo das fezes, como o *display* ‘*sealmaster’*, a competição ainda é muito menor do que no entorno de uma carcaça, possivelmente devido ao menor valor nutricional das fezes. Sendo assim, fêmeas conseguem ter acesso a esse recurso. Resta ainda saber qual, de fato, é a contribuição nutricional desse alimento em grande parte já digerido ou mesmo, quais os possíveis impactos negativos (e.g. carga parasitária, subnutrição) que o consumo de fezes pode oferecer a petréis-gigantes reprodutores.

Os comportamentos aqui registrados e as frequentes publicações sobre novos hábitos e itens alimentares para a espécie, ressaltam o generalismo e oportunismo de petréis-gigantes e a sua capacidade de adaptação a cenários com diferentes disponibilidades de alimento. Publicações sobre comportamentos inéditos também são importantes para acessar o impacto que essa espécie predadora possa ter sobre espécies ameaçadas, especialmente no cenário atual de mudanças climáticas e ambientais. Por exemplo, uma população de albatroz-de-nariz-amarelo-do-atlântico (*Thalassarche chlororhynchos*), classificado como “Em Perigo” de extinção a nível global de acordo com a lista vermelha da União Internacional para Conservação da Natureza (BIRDLIFE, 2023), pode estar sofrendo declínios devido à predação inusitada por petréis-gigantes.

Na ilha Gough, filhotes dessa espécie estão sendo atacados e predados por camundongos invasores e, recentemente, adultos também estão sendo atacados por petréis-gigantes-do-sul machos (RISI *et al.*, 2021). A perda de adultos reprodutivos pode ter um impacto negativo muito maior sobre essa espécie já ameaçada do que a perda de filhotes pela predação de camundongos. Petréis-gigantes são capazes de predar outras aves menores e filhotes de albatrozes, mas o ataque a adultos era inédito. Segundo a hipótese dos autores, esses eventos de predação estão associados à fragilização dos adultos pelo distúrbio constante dos camundongos, o qual aumenta a cada ano devido ao crescimento da população de roedores (JONES *et al.*, 2019). Os camundongos, que antes sofriam baixas populacionais durante o inverno, agora se beneficiam de invernos cada vez mais amenos para sobreviver (MCCLELLAND *et al.*, 2018). Dessa maneira, petréis-gigantes podem estar atuando sinergicamente com as mudanças climáticas e predadores invasores para o declínio de uma espécie já ameaçada.

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APÊNDICE A – LICENÇAS DE ACESSO E DE COLETA DE AMOSTRAS BIOLÓGICAS

Instituto Antártico Chileno
Ministerio de Relaciones Exteriores
Gobierno de Chile
Chile en marcha

PERMISO Nº 1045 / 2019
INGRESO A ZONA PROTEGIDA

El Subdirector Nacional del Instituto Antártico Chileno, INACH, que suscribe, en virtud de la Resolución Exenta Nº 647 del INACH, de fecha 24 de octubre de 2017, autoriza a las siguientes personas el ingreso a la Zona Antártica Especialmente Protegida que se indica, conforme a la Decisión 1 (2002) de la XXV-RCTA, sobre el Sistema de Zonas Protegidas, y a lo establecido en el Anexo V del Protocolo de Madrid, con el propósito de realizar tareas de investigación:

1. NOMBRES:	Lucas Krüger, Julia Grohmann y Denyelle Corá.
2. ÁREA PROTEGIDA:	ZAEP Nº 133, punta Armonía, isla Nelson, islas Shetland del Sur.
3. PAÍS E INSTITUCIÓN:	CHILE. Instituto Antártico Chileno (INACH).
4. PROYECTO:	FI_01-18, Descifrando la dinámica entre pesquerías y especies de aves marinas forrajeadoras de aguas antárticas: Una perspectiva de manejo.
5. PERÍODO:	22 de noviembre de 2019 al 20 de febrero de 2020
6. ACTIVIDADES:	Monitoreo de la variación espacio-temporal de los parámetros del ciclo de vida del petrel gigante, *Macronectes giganteus*; captura y liberación de un máximo de 60 individuos de petreles gigantes y registro fotográfico de las colonias de reproducción mediante drones.
7. ADMINISTRACIÓN:	Las personas individualizadas han recibido el plan de administración de la ZAEP Nº133, comprometiéndose a cumplir a cabalidad con sus recomendaciones y a entregar el informe de visita correspondiente, luego de ejecutada la actividad. De la misma forma, se comprometen a cumplir las Directrices medioambientales para la operación de sistemas de aeronaves dirigidas por control remoto (RPAS) en la Antártida del Tratado Antártico.

"POR FACULTAD DELEGADA DEL DIRECTOR DEL SERVICIO"

SUBDIRECTOR

DR. EDGARDO VEGA ARTIGUES
Subdirector Nacional
Instituto Antártico Chileno

Punta Arenas, 15 NOV 2019

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Instituto Antártico Chileno
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PERMISO Nº 661 / 2021
INGRESO A ZONA PROTEGIDA

La Subdirectora Técnica (S) del Instituto Antártico Chileno, INACH, en virtud de la Resolución Exenta Nº 204 del INACH, de fecha 14 de julio de 2021, mediante este documento autoriza a las siguientes personas el ingreso a la Zona Antártica Especialmente Protegida que se indica, conforme a la Decisión 1 (2002) de la XXV-RCTA, sobre el Sistema de Zonas Protegidas, y a lo establecido en el Anexo V del Protocolo de Madrid, con el propósito de realizar actividades de investigación científica:

1. NOMBRES:	Lucas Krüger, Júlia Grohmann, Solenne Belle y Cristina Hernández.
2. ÁREA PROTEGIDA:	ZAEP Nº132, punta Armonía, isla Nelson.
3. PAÍS E INSTITUCIÓN:	CHILE. Instituto Antártico Chileno (INACH).
4. PROYECTO:	AMP_01-18, Áreas Marinas Protegidas: Monitoreo de las condiciones oceanográficas, predadores topes y hábitats bentónicos en el oeste de la Península Antártica - AVES.
5. PERÍODO:	1 de diciembre de 2021 al 28 de enero de 2022.
6. ACTIVIDADES:	Captura y liberación de individuos de *Macronectes giganteus*, *Pygoscelis antarcticus* y *P. papua*, y recolección de muestras de plumas de petreles gigantes, para estudios poblacionales.
7. ADMINISTRACIÓN:	Las personas individualizadas han recibido el plan de administración de la ZAEP Nº128, comprometiéndose a cumplir a cabalidad con sus recomendaciones y a entregar el informe de visita correspondiente, luego de ejecutada la actividad.

"POR FACULTAD DELEGADA POR EL DIRECTOR DEL SERVICIO"

SUBDIRECTOR (S)

PRISCILLA AGUAYO MUÑOZ
Subdirectora Técnica (S)
Instituto Antártico Chileno

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INGRESO A ZONA PROTEGIDA
RECTIFICACIÓN PERMISO N° 661/2021

El Subdirector Técnico del Instituto Antártico Chileno, INACH, en virtud de la Resolución Exenta N° 204 del INACH, de fecha 14 de julio de 2021, mediante este documento rectifica el permiso N° 661/2021 que autoriza a las siguientes personas el ingreso a la Zona Antártica Especialmente Protegida que se indica, conforme a la Decisión 1 (2002) de la XXV-RCTA, sobre el Sistema de Zonas Protegidas, y a lo establecido en el Anexo V del Protocolo de Madrid, con el propósito de realizar actividades de investigación científica:

1. NOMBRES: Lucas Krüger, Júlia Grohmann, Solenne Belle, Cristina Hernández y Francisco Santa Cruz.
2. ÁREA PROTEGIDA: ZAEP N°133, punta Armonía, isla Nelson.
3. PAÍS E INSTITUCIÓN: CHILE. Instituto Antártico Chileno (INACH).
4. PROYECTO: AMP_01-18, Áreas Marinas Protegidas: Monitoreo de las condiciones oceanográficas, predadores topes y hábitats bentónicos en el oeste de la península Antártica - AVES.
5. PERÍODO: 1 de diciembre de 2021 al 28 de enero de 2022.
6. ACTIVIDADES: Captura y liberación de individuos de *Macronectes giganteus*, *Pygoscelis antarcticus* y *P. papua*, recolección de muestras de plumas de petreles gigantes e instalación de cámaras trampa para estudios poblacionales.
7. ADMINISTRACIÓN: Las personas individualizadas han recibido el plan de administración de la ZAEP N°133, comprometiéndose a cumplir a cabalidad con sus recomendaciones y a entregar el informe de visita correspondiente, luego de ejecutada la actividad.

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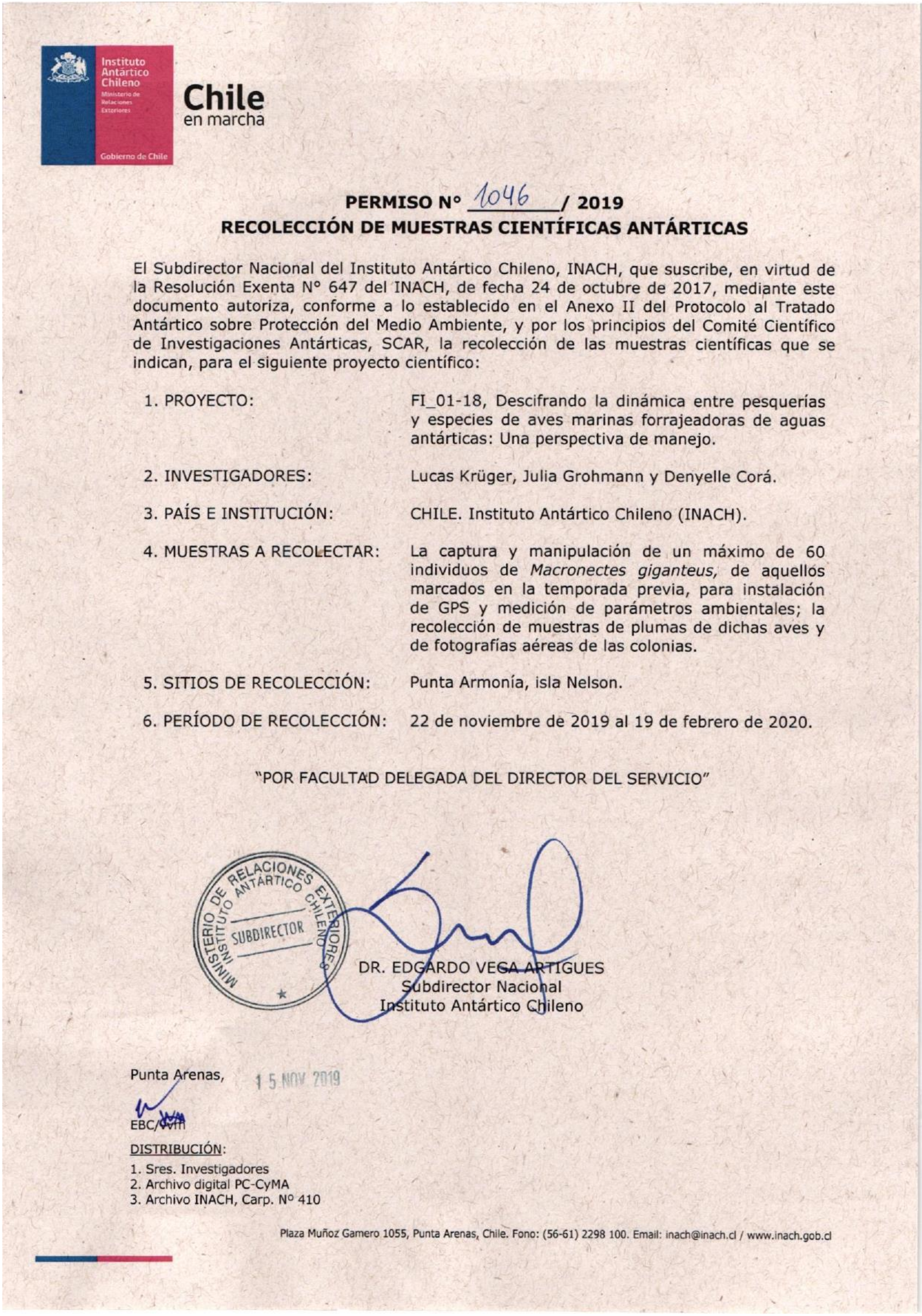

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RECOLECCIÓN DE MUESTRAS CIENTÍFICAS ANTÁRTICAS

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1. PROYECTO:	FI_01-18, Descifrando la dinámica entre pesquerías y especies de aves marinas forrajeadoras de aguas antárticas: Una perspectiva de manejo.
2. INVESTIGADORES:	Lucas Krüger, Julia Grohmann y Denyelle Corá.
3. PAÍS E INSTITUCIÓN:	CHILE. Instituto Antártico Chileno (INACH).
4. MUESTRAS A RECOLECTAR:	La captura y manipulación de un máximo de 60 individuos de *Macronectes giganteus,* de aquellos marcados en la temporada previa, para instalación de GPS y medición de parámetros ambientales; la recolección de muestras de plumas de dichas aves y de fotografías aéreas de las colonias.
5. SITIOS DE RECOLECCIÓN:	Punta Armonía, isla Nelson.
6. PERÍODO DE RECOLECCIÓN:	22 de noviembre de 2019 al 19 de febrero de 2020.

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La Subdirectora Técnica (S) del Instituto Antártico Chileno, INACH, en virtud de la Resolución Exenta Nº 204 del INACH, de fecha 14 de julio de 2021, mediante este documento autoriza, conforme a lo establecido en el Anexo II del Protocolo al Tratado Antártico sobre Protección del Medio Ambiente, y por los principios del Comité Científico de Investigaciones Antárticas, SCAR, la recolección de las muestras científicas que se indican, para el siguiente proyecto científico:

1. PROYECTO:	AMP_01-18, Áreas Marinas Protegidas: Monitoreo de las condiciones oceanográficas, predadores topes y hábitats bentónicos en el oeste de la Península Antártica - AVES.
2. INVESTIGADORES:	Lucas Krüger, Júlia Grohmann, Solenne Belle y Cristina Hernández.
3. PAÍS E INSTITUCIÓN:	CHILE. Instituto Antártico Chileno (INACH).
4. MUESTRAS A RECOLECTAR:	La captura, y posterior liberación, de un máximo de 26 individuos de *Macronectes giganteus* para la instalación de geolocalizadores; la captura y posterior liberación de un máximo de 20 individuos de *Pygoscelis antarcticus* y de 10 individuos de *P. papua*, para la instalación de geolocalizadores, y la recolección de un máximo de 50 plumas de petreles gigantes.
5. SITIOS DE RECOLECCIÓN:	Punta Armonía, isla Nelson.
6. PERÍODO DE RECOLECCIÓN:	1 diciembre de 2021 al 28 de enero de 2022.

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ANEXO A – FOLHA DE ROSTO DOS ARTIGOS DA TESE PUBLICADOS

Antarctic Science page 1 of 14 *(2023)* doi:10.1017/S0954102023000147

Habitat selection of southern giant petrels: potential environmental monitors of the Antarctic Peninsula

JÚLIA VICTÓRIA GROHMANN FINGER [1], LUCAS KRÜGER [2,3], DENYELLE HENNAYRA CORÁ [1] and MARIA VIRGINIA PETRY [1]

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Abstract: The southern giant petrel (*Macronectes giganteus*) is a widely distributed top predator of the Southern Ocean. To define the fine-scale foraging areas and habitat use of Antarctic breeding populations, 47 southern giant petrels from Nelson Island were GPS-tracked during the summers of 2019–2020 and 2021–2022. Step-selection analysis was applied to test the effects of environmental variables on habitat selection. Visual overlap with seal haul-out sites and fishing areas was also analysed. Birds primarily used waters to the south of the colony in the Weddell and Bellingshausen seas. Females showed a broader distribution, reaching up to -70°S to the west of Nelson Island, while males were mainly concentrated in waters off the northern Antarctic Peninsula. Habitat selection of both sexes was associated with water depth and proximity to penguin colonies. Both overlapped their foraging areas with fishing sites and females in particular overlapped with toothfish fishery blocks in Antarctica and with fishing areas in the Patagonian Shelf. Due to their habitat associations and overlap with fisheries, when harnessed with tracking devices and animal-borne cameras, giant petrels can act as platforms for monitoring the condition and occurrence of penguin colonies, haul-out sites and unregulated fisheries on various temporal and spatial scales in Antarctica.

Received 5 November 2022, accepted 29 May 2023

Key words: breeding distribution, Maritime Antarctic, monitor species, spatial distribution, spatial ecology, tracking

Introduction

The Antarctic Peninsula is the region of the Antarctic experiencing the fastest environmental changes (Convey & Peck 2019) and greatest local human impact (Tin *et al.* 2014). Loss of sea ice and the reduction in the length of the sea-ice season (Schofield *et al.* 2018, Vorrath *et al.* 2020), rapid glacier contraction (Silva *et al.* 2020), increased ice-free land (Lee *et al.* 2017), shifts in plankton communities (Schofield *et al.* 2018, Kim & Kim 2021, Schultz *et al.* 2021), probable biomass reduction and contraction in the southward distribution of krill (Atkinson *et al.* 2019, Trathan *et al.* 2022) are some of the observed environmental changes caused by warming. Increased fishing concentration (Nicol *et al.* 2012, Trathan *et al.* 2022, Santa Cruz *et al.* 2022) and increased human presence due to the intensification of tourism and scientific activities (Chown *et al.* 2012, Bender *et al.* 2016) have led to the contamination of several areas through the release of synthetic debris (Tirelli *et al.* 2020, Finger *et al.* 2021) and wastewater effluents, burning of fossil fuels, waste incineration and accidental spillage (Bargagli 2008). While it is important to continuously track these changes, it is challenging for researchers to simultaneously cover a substantial number of vulnerable areas.

Marine top predators have been considered as tools for monitoring ecosystem changes due to their large-scale distribution and because they amplify trophic information across multiple spatiotemporal scales (Sergio *et al.* 2008, Hazen *et al.* 2019). Seabirds, given their habitat associations (Tam *et al.* 2017, Velarde *et al.* 2019, Krüger 2022) and easier access in comparison to other groups of marine top predators, have been proposed as optimal ocean sentinels (Lascelles *et al.* 2012, Krüger 2022).

For instance, the strong associations of emperor penguins (*Aptenodytes forsteri*) with sea ice make them sentinels of climate change in Antarctica (Jenouvrier *et al.* 2021), while krill-specialist *Pygoscelis* spp. penguins can indicate the state of krill populations (Lynnes *et al.* 2004). On the other hand, population-level generalist seabird species are usually associated with a wide range of environmental conditions and/or habitats and can act as monitors of

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SHORT NOTE

Cannibalism in southern giant petrels (*Macronectes giganteus*) at Nelson Island, Maritime Antarctic Peninsula

Júlia Victória Grohmann Finger[1] · **Denyelle Hennayra Corá**[1,2] · **Maria Virginia Petry**[1] · **Lucas Krüger**[3]

Received: 23 March 2020 / Revised: 17 February 2021 / Accepted: 2 April 2021 / Published online: 5 May 2021

Abstract

Southern giant petrels (*Macronectes giganteus*) are a scavenger and predatory species with highly opportunistic feeding habits. Although cannibalism is a likely behavior for a predatory and colonial species, there are no confirmed records of this behavior for giant petrels. In this study, we describe two cases of cannibalism in a population of southern giant petrels breeding at Harmony Point (62°18′S; 59°10′W), Nelson Island. In both cases, a male giant petrel preyed upon a nestling. Our records confirm that heterocannibalism is part of the behavior repertoire of male southern giant petrels.

Keywords Predation · Heterocannibalism · Feeding behavior · Seabirds · South Shetland Islands

Introduction

Cannibalism is defined as the consumption of eggs or significant parts of the body of conspecifics (Stanback and Koenig 1992; Fouilloux et al. 2019). Among birds, the most widespread and common form of cannibalism is heterocannibalism, in which non-kin eggs or chicks are eaten (Stanback and Koenig 1992). Cannibalistic bird species share common characteristics, such as carnivory, colonial breeding habits and a beak morphology that allows them to tear pieces of flesh rather than having to eat the whole prey (Stanback and Koenig 1992). Seabirds share many of these characteristics, and in fact, cannibalism has been reported for many species (Peter et al. 1990; Stanback and Koenig 1992; Daigre et al. 2012; Hayward et al. 2014; Neves et al. 2015).

The southern giant petrel *Macronectes giganteus* (SGP) is a seabird species with scavenger and predator habits. Its diet includes both marine and land-based prey and carrion, such as, crustaceans, cephalopods, fishes, penguins, flying seabirds, seals and even whales (Hunter and Brooke 1992; Petry et al. 2010; Corá et al. 2020; Mills et al. 2021) However, records of petrels preying on conspecifics are speculative or unconclusive. We report the first confirmed cases of intergenerational cannibalism for SGP breeding in the Antarctic and explore hypothesis that could explain the occurrence of this behavior.

Material and methods

Harmony Point (62°18′S; 59°10′W) at Nelson Island (South Shetland Islands, maritime Antarctic) is home to large breeding population of seabirds (Silva et al. 1998). SGPs breed on plateaus and on relatively flat areas close to the beach (ca. 480 breeding pairs; Krüger 2019). Two breeding groups are located at 60 m (east-southeast) and 160 m (south-southwest) from the Francisco de Gurruchaga Argentine shelter (62°14′3″S; 59°10′2″W). Both lie near the sea level. One lies within a rock outcrop with small blocks and the latter is surrounded by rocks of 10 m height. During the 78 days (between 20 November 2019 and 5 February 2020) we stayed in the area, we frequently observed southern giant petrels from the shelter's window. We recorded and photographed any unusual activity using a 300 mm lens coupled to a Nikon D90 DLSR camera from inside the shelter. In one of the two occasions when cannibalism occurred,

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SHORT NOTE

Coprophagic behaviour of southern giant petrels (*Macronectes giganteus*) during breeding period

Denyelle Hennayra Corá[1] · **Júlia Victória Grohmann Finger**[2] · **Lucas Krüger**[3]

Received: 27 February 2020 / Revised: 21 September 2020 / Accepted: 25 September 2020 / Published online: 15 October 2020

Abstract

Southern giant petrels (*Macronectes giganteus*) are opportunistic generalists whose feeding strategies include hunting, scavenging and fishing. While seals are important for southern giant petrels as a source of carrion, we documented that live seals also provide feeding opportunities for southern giant petrels. We tracked breeding southern giant petrels from Harmony Point, Antarctica, during incubation and chick rearing with solar-powered GPS-UHF devices. Tracking results showed that animals often visited confirmed haul-out sites of seals, mainly Weddell seals (*Leptonychotes weddellii*). Feeding on seal faeces was confirmed by direct observation. Southern giant petrels were more likely to visit haul-out sites during incubation than during chick-rearing. This behaviour suggests that the birds fed on seal faeces mainly when fasting, which could last as long as 15 days. Seal faeces could be a resource consumed to quickly recover from the fast before leaving for a longer trip.

Keywords Antarctica · coprophagy · diet · foraging

Introduction

Breeding is an energetically demanding activity during which seabirds invest great effort in successfully raising a chick (Markones et al. 2009). Scavenging on fur seal (*Arctocephalus gazella*), Weddell seal (*Leptonychotes weddellii*) and southern elephant seal (*Mirounga leonina*) carcasses and placentas provides an important source of food during breeding for giant petrels (*Macronectes* spp.), especially during the post-hatching period (Hunter 1984; de Bruyn et al. 2007). Carcasses also play an important role in the growth and survival of chicks due to their high energetic and nutritional value (de Bruyn et al. 2007). However, living seals can also provide feeding resources for giant petrels. Casaux et al. (1997) briefly described southern giant petrels (*M. giganteus*) gathering around hauled-out Weddell seals at Harmony Point (Nelson Island, Maritime Antarctic Peninsula) to feed upon faeces and regurgitations. They suggested that this source of food should be further inspected, as many diet items recorded for southern giant petrels could have been consumed through scavenging on Weddell seal scat and vomit. In this study, we quantified the incursions of southern giant petrels tracked with GPS to areas where Weddell and elephant seals haul out to rest or moult at Harmony Point and showed that breeding southern giant petrels frequently feed on seal faeces. We thus provide evidence that coprophagy is a common behaviour for Southern giant petrels in the studied population. We also discuss possible causes and consequences of this behaviour.

Materials and methods

We monitored feeding behaviour and movements of breeding southern giant petrels from a population breeding at Harmony Point (Fig. 1a). The area holds a large southern giant petrel population of ca. 480 breeding pairs (Krüger 2019). While Weddell and elephant seals haul out at Harmony Point throughout the warm season (October to February), there is no recent local evidence of breeding behaviour by either seal species [although three female

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Submission Confirmation [US Research paper]

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ANEXO B – FOLHA DE ROSTO DE OUTROS ARTIGOS PUBLICADOS DURANTE O PERÍODO DO DOUTORADO

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Contrasting environmental conditions precluded lower availability of Antarctic krill affecting breeding chinstrap penguins in the Antarctic Peninsula

Nuria Salmerón[1], Solenne Belle[1], Francisco Santa Cruz[2], Nicolás Alegria[3], Júlia Victória Grohmann Finger[5], Denyelle Hennayra Corá[5], Maria Virginia Petry[5], Cristina Hernández[6], César A. Cárdenas[2,4] & Lucas Krüger[2,4]✉

Dramatic decreases of chinstrap penguin populations across the Antarctic Peninsula (AP) are thought to be influenced by climate-driven changes affecting its main prey, the Antarctic krill, however, empirical evidence supporting such hypotheses are scarce. By coupling data on breeding chinstrap penguins, environmental remote sensing and estimates of krill acoustic density, we were able to demonstrate that penguins substantially increased their foraging effort in a year of low krill availability, with consequent reduction in breeding success. A winter of low sea ice cover followed by a summer/spring with stronger wind and lower marine productivity explained the lower and deeper krill availability. Our results highlight the importance of environmental variability on penguin populations, as variability is expected to increase under climate change, affecting foraging behaviour responses.

One of the key species in the Antarctic food webs that has been affected by climate change is the Antarctic krill, *Euphausia superba*[1]. The increased vertical stratification caused by warming, freshening and sea ice decline, can alter nutrient availability within the surface mixed layer, with a direct impact on primary producers and, as a result, in krill availability[2]. The totality of changes in ocean warming and its consequences will probably influence the population dynamics of several species of krill-dependent predators by modifying behavioural responses[3]. While there is some variability across the Southern Ocean, krill recruitment and abundance depends on suitable habitat conditions usually influenced by sea-ice dynamics[4,5]. Low sea-ice coverage in winter also reduces food availability for krill larvae in the spring and summer, as sea ice melting releases nutrients responsible for algal blooms[6,7]. According to some studies, Antarctic krill stocks have declined between 38–81% between 1976 and 2003 in the Southwest Atlantic sector of the Southern Ocean with an alleged distribution displacement towards the Antarctic shelves[8].

The chinstrap penguin (*Pygoscelis antarcticus*) is an abundant species in the Antarctic Peninsula that, during breeding, feeds almost exclusively on Antarctic krill[9,10]. Studies have highlighted significant declines on chinstrap populations[11,12]. A study[13] proposed a holistic hypothesis for this decline, linking chinstrap penguin population with krill biomass. The main factors accepted to affect krill populations that could have cascading effects in chinstrap penguin abundance are the changes on sea ice cover caused by climate change[4,5,14], the increased competition for krill caused by the recovery of whale populations and the growth of krill-trawling fisheries[15–18]. A recent publication[19] also showed that the joint effects of sea ice, storms and cloudy conditions affect the phenology of low and mid trophic levels of marine ecosystems in the Antarctic Peninsula, therefore having a bottom-up effect over top-predators, particularly, causing a mismatch between the peak food availability and penguins' breeding.

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Marine Pollution Bulletin 167 (2021) 112337

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Note

Plastic ingestion by juvenile green turtles (*Chelonia mydas*) off the coast of Southern Brazil

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Júlia Victória G. Finger

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ARTICLE INFO

Keywords:
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Marine debris
Pollution
Sea turtles
Southwest Atlantic Ocean

ABSTRACT

Five of the seven extant sea turtle species in the world forage on the coast of Southern Brazil at least in some stage of their life cycle. The green turtle *Chelonia mydas* frequently strands on beaches of Rio Grande do Sul State. The species is currently classified as vulnerable to extinction in the region, and pollution by marine debris is one of the most conspicuous threats to its conservation. In this study, we quantified and characterized plastic ingestion by juvenile green turtles in waters off the southern Brazilian coast between 2013 and 2016. We analysed the gastrointestinal content of 17 beached carcasses and registered debris ingestion in 15 individuals (88%). On average, each green turtle ingested 38.4 ± 88.5 plastic fragments. White and transparent plastic bags and plastic sheets were predominant. Our results indicate a high interaction between juvenile green turtles and marine debris off the coast of Southern Brazil.

1. Introduction

Plastic derived from anthropogenic activities has become one of the main constituents of marine debris, of which the main sources are fisheries, industrial and consumer items (Barnes et al., 2009; Ivar do Sul and Costa, 2014). According to recent estimates, the annual amount of plastic entering the oceans worldwide is about 4–12 million tons (Jambeck et al., 2015). Plastic has quickly become a global threat to marine ecosystems due to its low rate of degradation in nature and because it is highly dispersive (Bergmann et al., 2015). From zooplankton to large marine mammals (Kühn et al., 2015), at least 700 species have been reported to ingest plastic in marine environments (Gall and Thompson, 2015). Among these species are all the seven extant taxa of sea turtles (Kühn et al., 2015), which are often considered as the vertebrate group most vulnerable to the impacts of plastic pollution (Ivar do Sul and Costa, 2014; Schuyler et al., 2014b; López-Martínez et al., 2021). Plastic ingestion by sea turtles has been reported since the 1980s (Balazs, 1984; Carr, 1987) and the frequency of ingestion has been increasing since then (Schuyler et al., 2014a; Nelms et al., 2015).

Habitat preferences and diets of sea turtles change over the course of life (Schuyler et al., 2014a). These changes might cause different loads of plastic ingestion between life stages due to distinct levels of pollution among habitats (Schuyler et al., 2014a). Green turtles (*Chelonia mydas*), for example, hatch on beaches in tropical and subtropical areas and then swim to pelagic habitats (Musick and Limpus, 1997; Bjorndal, 1997). Once in the open ocean, they drift to convergence zones and are susceptible to ingest floating plastic, which is congregated in such zones (Schuyler et al., 2012). Later stage juveniles then recruit to neritic and benthic zones in coastal environments where they forage also during adulthood (Reich et al., 2007; Arthur et al., 2008). In these zones they are also susceptible to pollution due to their proximity to urban centres (Schuyler et al., 2012; Carman et al., 2014). The green turtle is thus highly susceptible to the impact of marine debris in all life stages (Bugoni et al., 2001; Arthur et al., 2009; Schuyler et al., 2012; Ivar do Sul and Costa, 2014; Schuyler et al., 2014b; Di Beneditto and Awabdi, 2014).

Plastic ingestion by sea turtles has been reported since the 1980 (Balazs, 1984; Carr, 1987) and the frequency of ingestion has been increasing since then (Schuyler et al., 2014a; Nelms et al., 2015). In the southern coast of Brazil, where juveniles green turtles forage during winter and spring (Carman et al., 2012), several studies have reported the ingestion of marine debris by juvenile green turtles (Bugoni et al., 2001; Tourinho et al., 2010; Colferai et al., 2017; Rizzi et al., 2019) and the ingestion includes not only user plastic, such as plastic bags, plastic sheets and balloons but also waste of fishery activities such as lines,

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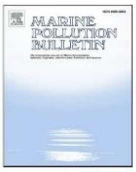

Anthropogenic debris in an Antarctic Specially Protected Area in the maritime Antarctic

Júlia Victória Grohmann Finger[a,*], Denyelle Hennayra Corá[a], Peter Convey[b,c], Francisco Santa Cruz[d], Maria Virginia Petry[a], Lucas Krüger[d]

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ARTICLE INFO

Keywords:
Nelson Island
Harmony Point
Marine debris
Macroplastics
Polar pollution

ABSTRACT

Antarctic Specially Protected Areas (ASPAs) provide the strongest environmental protection in Antarctica. However, they are not immune from anthropogenic pollution of marine or terrestrial origin. We document anthropogenic debris within ASPA No. 133 Harmony Point, Nelson Island, recovering 1544 items between November 2019 and January 2020. The majority (82.6 %) were found close to a national operator-constructed refuge and were smaller than 5 cm. Larger items (up to 300 cm) were present on beaches and plateaus. Charcoal and rubber were the most abundant items around the refuge and plastic and metal were the most abundant items on beaches and plateaus. Debris items likely arriving in the area by marine transportation (e.g. plastic) are of concern due to both risk of ingestion and their degradation leading to the release of hazardous chemicals. Such pollution contravenes the terms of the Protocol on Environmental Protection to the Antarctic Treaty and other regionally applicable regulations.

1. Introduction

Ocean pollution is a fundamentally important contemporary global issue (Eriksen et al., 2014). Pollution by synthetic anthropogenic debris, as with many other types of contamination, does not respect boundaries of marine protected areas or regions protected by treaties or agreements (Barnes et al., 2018). It is now globally pervasive and has been found in the most remote areas of the world, including the Arctic and Antarctica, commonly considered among the most pristine environments on Earth (Merrell, 1980; Ivar do Sul et al., 2011; Cózar et al., 2017; Barnes et al., 2018; Horton and Barnes, 2020; Tirelli et al., 2020). In the Antarctic, marine-derived synthetic debris, mostly macro- and microplastics, has been reported from surface waters of the Southern Ocean (Barnes et al., 2010, Ross Sea: Cincinelli et al., 2017) and off the Antarctic Peninsula (Lacerda et al., 2019), in shallow waters (King George Island: Waller et al., 2017; Terra Nova Bay, Ross Sea: Munari et al., 2017; Adelaide Island: Reed et al., 2018), in deep marine sediments (Cunningham et al., 2020), along the coasts of islands (e.g. South Shetland Islands: Torres et al., 1997; Torres and Gajardo 1985; Sander et al., 2009; Anfuso et al., 2020; South Orkney Islands: Barnes and Sanderson, 2000; the remote South Sandwich Islands: Convey et al., 2002; South Georgia Walker et al., 1997; Barnes and Sanderson, 2000; Convey et al., 2002), in freshwater (Livingston Island: González-Pleiter et al., 2020), in sea ice (Casey Station: Kelly et al., 2020) and, most recently, within a terrestrial micro-arthropod, the common Antarctic collembolan *Cryptopygus antarcticus* (Bergami et al., 2020).

The origin of such debris in Antarctica is sometimes associated with long-distance transport via oceanic currents (Obbard, 2018; Suaria et al., 2020; Van Sebille, 2015). However, it can also be traced to local sources such as fishing, tourism and research activities (Torres et al., 1997; Convey et al., 2002; Bargagli, 2008; Tin et al., 2009). The latter includes discharges of water from sewage plants of scientific stations (Cincinelli et al., 2017; Siriwardena and Stevens, 2004; Waller et al., 2017), old dumpsites and poorly managed waste from stations and refuge huts (Hughes and Nobbs, 2004; Peter et al., 2013).

The Antarctic Treaty System regulates all activities occurring south of latitude 60°S. The Protocol on Environmental Protection to the Antarctic Treaty (commonly known as the 'Madrid Protocol' or

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MORPHOMETRY AND SEXUAL DIMORPHISM IN THE YELLOW-LEGGED TINAMOU *Crypturellus noctivagus noctivagus* IN A RELICTUAL POPULATION FROM SOUTHERN BRAZIL

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Abstract: The Yellow-legged Tinamou (*Crypturellus noctivagus*) is a terrestrial forest bird endemic to Brazil. Females and males of the subspecies *Crypturellus noctivagus noctivagus* are indistinguishable at the naked eye and there is lack of knowledge regarding means to discriminate sexes in the field. We investigated morphometric differences between sexes of *C. n. noctivagus* to determine which measures should be used to distinguish sexes. We compared eight morphometric measurements and total body mass of adult birds from a relictual population living in the wild, in the state of Rio Grande do Sul. Birds were captured during the breeding seasons of 2015 and 2016. Sex identification of individuals (four females and seven males) was obtained by molecular analysis. Differences between sexes were tested through Student's t and Mann-Whitney's tests and a through Principal Component Analysis. On average, females were 9.9% heavier and had bills 11.8% longer than males. Males had middle toes 8.7% larger and tails 19.0% larger than females, the latter presenting the highest degree of dimorphism among all measurements. Our results show that, when molecular sexing is not feasible, morphometric variables may be used to determine the sex of *C. n. noctivagus* individuals.

Keywords: Intersexual differences; Molecular sexing; Tinamidae; Tinamiformes.

INTRODUCTION

Sexual dimorphism in size and shape is a widely distributed trait in invertebrate and vertebrate species (Fairbairn 1997). In birds, dimorphism is usually moderate (Amadon 1959), but extreme cases, such as the extravagant plumage of male birds of paradise and pheasants can also occur. Variations among sexes are mostly related to the type of social mating system and respective roles in parental care (Owens & Hartley 1998, Dunn *et al.* 2001), display agility (Szekely *et al.* 2007) and fecundity (Tubaro & Bertelli 2003). Sexual size dimorphism in birds is usually male-biased, with males being larger than females in total body size (Amadon 1959, Szekely *et al.* 2007). However, although much less common, the reverse (female-biased: females larger than males) also occurs in several taxa, such as raptors (Falconiformes), owls (Strigiformes), shorebirds (Charadridae), seabirds (Procellariiformes), tinamous (Tinamiformes) and rails (Rallidae) (*e.g.*, Handford & Mares 1985, Jehl & Murray 1986, Fairbairn & Shine 1993, Szekely *et al.*

ANEXO C – RESUMOS RELACIONADOS À TESE PUBLICADOS EM ANAIS DE EVENTOS CIENTÍFICOS

FINGER, J. V. G.; KRUGER, L.; PETRY, M. V. **Does personality predict individual consistency in foraging behavior of breeding southern giant petrels?** Aceito para apresentação no II Ornithological Congress of the Americas

Individual specialization in foraging behavior has been correlated to personality in seabirds. The goal of this study was to test if personality influences individual consistency (fidelity) in foraging areas and foraging strategies of breeding southern giant petrels [*Macronectes giganteus*], a predator with an elaborated social behavior. Petrels (n=67) from the Antarctic were tracked with GPS devices in two breeding seasons to investigate foraging areas and calculate foraging trip metrics throughout the season. Individual personality was described based on boldness level, which was quantified using the behavioral test: 'response to a novel object', which consists of presenting a novel object to an individual and recording its reaction. 13 social responses were recorded, e.g., moving the head (FO: 86.4%), lunging/pecking the object (52.3%) and bending the head (47.7%). 18 birds were classified as shy and 26 as bold. Males had higher boldness scores than females. Therefore, sex was included as fixed effect in the analysis. Individuals varied in their level of foraging site fidelity, with some birds being highly consistent, and others never repeating foraging areas. The population had an intermediate level of fidelity. Boldness neither sex influenced site fidelity levels. Individuals showed repeatability in maximum range from the colony and trip duration, but not in cumulative travel distance. Repeatability, however, was not related to boldness. Even though boldness did not influence foraging site fidelity and metrics, we found considerable residual variation on these traits, and this could be related to other factors, such as age and variations in body morphology.

KRUGER, L.; FINGER, J. V. G.; CORÁ, D. H.; PETRY, M. V. **Sensors on wings: southern giant petrel (*Macronectes giganteus*) distribution and its applications as environmental sentinels.** In: X Congreso de Investigaciones Antárticas, 2021, online. Libro de Resúmenes del X Congreso Antártico. Punta Arenas: Instituto Antártico Chileno, 2021. v. 0. p. 81-81.

El desarrollo de tecnologías de rastreo de animales silvestres en sus hábitats ha progresado al punto de que es posible tener disponibles datos de alta resolución espacio-temporal por largos periodos de tiempo. Actualmente no solo es posible tener datos de posición geográfica de los animales, sino también una infinidad de datos de su comportamiento y del hábitat utilizado. En este estudio, presentamos datos de distribución y uso de hábitat de poblaciones de petrel gigante que se reproducen en islas de la península antárctica (PA). Verificamos que, a lo largo de un año, los petreles gigantes pueden utilizar un área desde 70°S en el mar de Weddell hasta 40°S en la costa Atlántica y Pacífica de la América del Sur, donde pueden interactuar con actividades de pesca y zonas de asentamiento humano en la costa. Durante el periodo reproductivo estival, la mayoría de los individuos se concentraron en una distancia de hasta 100 km de su colonia reproductiva, sin embargo, algunos alcanzaron, en un periodo de hasta 15 días, distancias de más de 10 mil km hasta los mares de Bellingshausen y de Weddell. En esta área, utilizaron hábitats marinos pelágicos, hábitats terrestres (donde carroñan, cazan pingüinos e interactúan con focas), campos de hielo marino y bordes de glaciares. El amplio rango de distribución y flexibilidad en el uso del hábitat permite, además de monitorear las condiciones ambientales en las áreas que utilizan, monitorear el impacto de las actividades humanas desde el continente Antártico hasta Chile y Argentina. Estos animales, son centinelas ambientales y su uso como sensores alados permite contribuir al monitoreo y conocimiento del estado del ecosistema Antártico y sus conexiones con las áreas subantárticas.

FINGER, J. V. G.; CORÁ, D. H. ; PETRY, M. V. ; KRUGER, L. . **Cannibalism in southern giant petrels (*Macronectes giganteus*) at Nelson Island, Maritime Antarctic Peninsula.** In: 7th World Seabird Twitter Conference, 2021, Twitter. 7th World Seabird Twitter Conference Abstract Book, 2021.

Southern giant petrels (*Macronectes giganteus*) are a scavenger and predatory species with highly opportunistic feeding habits. Although cannibalism is an expected behavior for predatory and colonial species, there are no confirmed records of this behavior for giant petrels in literature. We describe two cases of cannibalism in a population of southern giant petrels breeding at Harmony Point (62°18’S; 59°10’W), Nelson Island, Maritime Antarctic. Within an interval of 10 days, two different male giant petrels preyed upon non-kin nestlings of 10- and 20-days age, respectively. Our records confirm that heterocannibalism is part of the behavior repertoire of male southern giant petrels.

FINGER, J. V. G.; CORÁ, D. H. ; KRUGER, L. . **Use of space places Southern Giant Petrels as useful monitors of Antarctic Peninsula.** In: SCAR Open Science Conference 2020, 2020, Online. SCAR Open Science Conference 2020 - Session 18, 2020. p. 32-32.

While Antarctic Peninsula (AP) experiences fast environmental change, it is challenging for researchers to cover simultaneously a substantial amount of sensible areas in order to properly monitor those changes. In this study, we show that, by continuously tracking throughout the breeding season individuals from a single population of Southern Giant Petrels SGP (*Macronectes giganteus*), it is possible to have access to environmental conditions in a large array of habitats along the whole AP. Breeding SGPs engaged on 5 to 15 days long foraging trips across a 5000 kilometers wide area between the Weddell and Bellingshausen seas. SGPs more likely reduced speed below 10 km/h, denoting foraging behavior, in low to intermediary ice cover conditions at land habitat, and in pelagic habitats when ice cover was >75%. SGPs also were more likely to reduce speed nearby penguin colonies in lower ice conditions. We also found evidence of association with glacier edges where Weddell seals (*Leptonychotes weddellii*) gather to rest. Therefore, tracking SGPs can give researchers access to conditions on a large variety of habitats and regions of the Antarctic Peninsula. A long-term study joining GPS tracking, animal-borne cameras and demography parameters on a small number of colonies should provide us with a large amount of data on distribution and condition of sea ice, glaciers, penguin and seal populations on different spatial and temporal scales.

ANEXO D – APRESENTAÇÃO DE TRABALHOS EM EVENTOS CIENTÍFICOS NO PERÍODO DO DOUTORADO

FINGER, J. V. G.; BELLE, S.; HERNANDEZ, C. B.; PETRY, M. V.; KRUGER, L. Mystery in the Shetland's: unexplained mortality of snow petrels at non-breeding areas of the maritime Antarctic. 2022. **10th SCAR Open Science Conference**.

BRUM, A. C.; FINGER, J. V. G.; LATHROP JR., R. G.; NILES, L. J.; PETRY, M. V. Northward migration of *Calidris canutus rufa* and environment connectivity of southern Brazil to Canada. 2022. **9th Western Hemisphere Shorebirds Group Meeting**

FINGER, J. V. G.; CORÁ, D. H.; CONVEY, P.; CRUZ, F. S.; PETRY, M. V.; KRUGER, L. Detritos antropogênicos em uma Área Antártica Especialmente Protegida na Antártica Marítima. 2022. **VII Simpósio Acadêmico de Biologia Marinha - SABMar 2022**

FINGER, J. V. G.; CORÁ, D. H.; PETRY, M. V.; KRUGER, L. Cannibalism in southern giant petrels (*Macronectes giganteus*) at Nelson Island, Maritime Antarctic Peninsula. 2021. **7th World Seabird Twitter Conference.**

FINGER, J. V. G.; BENEMANN, VICTÓRIA R.F.; PETRY, M. V. Marine debris ingestion by tube-nosed seabirds off Southern Brazil: are northern migrants winning the race against plastic pollution? 2021. **3rd World Seabird Conference.**

FINGER, J. V. G.; CORÁ, D. H.; KRUGER, L. Use of space places Southern Giant Petrels as useful monitors of Antarctic Peninsula. 2020. **9th SCAR Open Science Conference 2020.**

FINGER, J. V. G.; KRUGER, L.; MONTONE, R. C.; PETRY, MARIA V. Inter-sexual habitat and isotopic niche segregation of Antarctic Southern Giant Petrels (Procellariidae) during breeding. 2019. **XXVI Congresso Brasileiro de Ornitologia.**

ANEXO E – MINICURSOS MINISTRADOS NO PERÍODO DO DOUTORADO

FINGER, J. V. G. Pinguins e outras aves antárticas - Turma 3. 2022. **EcoSaber – Cursos Ambientais**

FINGER, J. V. G. Minicurso: Diversidade e ecologia de aves antárticas. 2022. **XXXII Semana Nacional de Oceanografia**, Itajaí – SC.

FINGER, J. V. G. Pinguins e outras aves antárticas - Turma 3. 2021. **EcoSaber – Cursos Ambientais**

FINGER, J. V. G. Mudanças Climáticas - Biologia, Conservação e Impacto do Aquecimento Global para Pinguins. 2021. **II Edição do Minicurso Online GEAS FCAV: Mudanças Climáticas.**

FINGER, J. V. G. Pinguins e outras aves antárticas - Turma 2. 2020. **EcoSaber – Cursos Ambientais**

FINGER, J. V. G. Pinguins e outras aves antárticas - Turma 1. 2020. **EcoSaber – Cursos Ambientais**

ANEXO F – DIVULGAÇÃO CIENTÍFICA: PALESTRAS E TEXTOS EM JORNAIS DE NOTÍCIAS/REVISTAS PUBLICADOS NO PERÍODO DO DOUTORADO

FINGER, J. V. G. Aves de Alto Mar. 2023. **Congresso Avistar 2023**.

KRUGER, L.; FINGER, J. V. G.; BELLE, S. Investigando aves marinas en la Antártica. 2022. **Expedición Antártica Escolar 2022** – Instituto Antártico Chileno

FINGER, J. V. G. Antártica: lar dos extremos. 2022. **XXIX Semana Polar Internacional - APECS Brasil.**

FINGER, J. V. G. Pesquisa e métodos em ecologia de aves antárticas. 2021. **Palestra na disciplina de Ecologia de Campo** – Programa de Pós-graduação em Biologia da Universidade do Vale do Rio dos Sinos

FINGER, J. V. G. Biodiversidade e Ecologia de Aves Antárticas. 2021. **XXVI Semana Polar Internacional – APECS-Brasil**

FINGER, J. V. G. Aves Marinhas do Oceano Austral. 2021. **Módulo de Maio GEAS UAM: Animais Marinhos**

FINGER, J. V. G. Vivendo no limite: ecologia e impactos antrópicos sobre a avifauna antártica. 2021. **XXVI Semana Polar Internacional – APECS-Brasil**

FINGER, J. V. G. O impacto das mudanças climáticas para os pinguins. 2021. **Semana de Extensão Veterinária da Anhembi Morumbi.** Módulo Medicina Veterinária de Animais Silvestres

FINGER, J. V. G. Convivendo com pinguins: vida e ciência no continente antártico. 2020. **XXV Semana Polar Internacional – APECS-Brasil.**

FINGER, J. V. G. Muito além de pinguins: a biodiversidade antártica como você nunca imaginou. 2020. **Unisinos Conecta +.**

FINGER, J. V. G. Pinguins e outras aves marinhas no continente antártico. 2020. **VIII Semana Acadêmica de Oceanografia - CEM UFPR.**

FINGER, J. V. G. Convivendo com pinguins: vida e ciência no continente antártico. 2020. **XXIX Semana Acadêmica da Biologia da Ulbra**

FINGER, J. V. G. Convivendo com pinguins: vida e ciência no continente antártico. 2020. **IV Ciclo de Palestras do GEAS UCS.**

FINGER, J. V. G.; BENEMANN, V.; SILVA, D. A. M. Live: Aves Pelágicas - Biologia e Conservação. 2020. **2° Festival de Aves de Ilhabela - Avistar Conecta**

FINGER, J. V. G. Convivendo com pinguins: vida e ciência no continente antártico. 2020. **Dia do Meio Ambiente** - Colégio Bom Conselho, Porto Alegre

FINGER, J. V. G.; BARBAT, M. M.; SOUZA, M. S.; NETTO, G. T. Mesa redonda: Novas abordagens e Tecnologias para as Ciências do Mar. 2020. **IX Semana Acadêmica de Oceanologia da FURG.**

FINGER, J. V.G. Meninas na ciência - relatos de uma pesquisadora no ambiente antártico. 2019. **Meninas na Ciência:** reconhecendo os méritos femininos.

FINGER, J. V. G. Convivendo com pinguins: vida e ciência no continente antártico. 2019. **XXII Semana Polar Internacional – APECS-Brasil.**

FINGER, J. V. G. Protecting Antarctica: The Antarctic Treaty System. 2019. **Model United Nations class,** Colégio Imperatriz, Guarapuava

FINGER, J. V. G. Pomba-antártica, a companheira de inverno das estações antárticas. **Infocirm**, Brasília, 01 set. 2022.

Pomba-antártica,

a companheira de inverno das estações antárticas

Com uma plumagem completamente branca e maneira de andar que lembra os pombos-domésticos, a pomba-antártica (Chionis albus) é na verdade uma ave do ambiente polar, bem distante das aves urbanas. As verrugas rosáceas presentes na sua face e as suas patas carentes de membranas entre os dedos são características únicas dentre as aves habitantes do ambiente antártico. Ao contrário das outras espécies, a pomba depende primariamente do ambiente costeiro para se alimentar, pois suas patas sem membranas não são adaptadas para o nado, mas por outro lado facilitam o deslocamento sobre rochas e terreno irregular. A espécie reproduz em áreas costeiras da Península Antártica e nas Ilhas Geórgia do Sul, Órcades do Sul e Shetland do Sul. Seus ninhos são construídos geralmente em cavidades abaixo de rochas e em fendas.

Oportunista, a pomba-antártica está fortemente associada às colônias de pinguins, aves voadoras e mamíferos marinhos, de onde obtém sua ampla gama de alimentos: krill regurgitado por pinguins, ovos, fezes e até pedacinhos de carcaças de aves e mamíferos. Destemida e curiosa, a pomba frequentemente se aproxima de humanos e pode se alimentar de lixo caso esteja exposto. Assim como o petrel-gigante, as skuas e os gaivotões que possuem hábitos saprófagos (consumir restos de outros animais), a pomba-antártica faz parte do time de limpeza das praias antárticas. Ao consumir carcaças e outros restos orgânicos, essas espécies controlam a dispersão de doenças associadas à decomposição.

Devido à redução na disponibilidade de alimentos durante o alto inverno, a maioria das aves antárticas migra para a América do Sul ou para o limite norte do gelo marinho. A pomba-antártica, no entanto, pode permanecer na região caso haja alimento disponível. Algas, moluscos, fezes e placentas de focas são alguns dos itens importantes durante o período não reprodutivo.

Pomba-antártica (Chionis albus) Foto: Júlia Finger

Nas Ilhas Shetland do Sul, essa pequena, mas robusta ave frequentemente é a única companheira terrestre dos grupos de militares e pesquisadores que invernam nas estações. Curiosamente, uma parte da população que se aventura a migrar para a América e a, portanto, cruzar o Estreito de Drake, desenvolveu uma estratégia oportunista para driblar sua falta de habilidade em se deslocar em alto mar: pegar carona em navios. Em 2018, pesquisadores do Laboratório de Ornitologia e Animais Marinhos da Unisinos reportaram ao menos seis indivíduos pegando uma carona de 30 horas no Navio Polar Almirante Maximiano.

Dessa forma, alguns espécimes podem chegar até ao Sul do Brasil, como demonstrado pelo caso recente de um indivíduo que foi registrado entre Rio Grande e Imbé, no Rio Grande do Sul. As pombas-antárticas podem até não ser tão carismáticas como os pinguins ou charmosas como os albatrozes, mas basta um olhar mais aprofundado para perceber que essa espécie também tem suas características fascinantes e uma capacidade admirável de tolerar as condições inóspitas do inverno antártico.

Pombas-antárticas pegando carona no NPo. Almirante Maximiano. Foto: Antônio C. de Brum

Por Me. Júlia Victória Grohmann Finger
Doutoranda no Programa de Pós-Graduação em Biologia da Universidade do Vale do Rio dos Sinos e pesquisadora do Laboratório de Ornitologia e Animais Marinhos

FINGER, J. V. G. Not one but two! Two-egg Southern Giant Petrel clutches spotted on Nelson Island. **ACAP Latest News**, Austrália, 2 Nov. 2022

Not one but two! Two-egg Southern Giant Petrel clutches spotted on Nelson Island.

A Southern Giant Petrel sits alongside its two chicks in the nest; photograph by Júlia Finger

Chilean seabird ecologist Júlia Finger has provided *ACAP Latest News* with an account of a rare sighting of two two-egg Southern Giant Petrel clutches spotted at Harmony Point, Nelson Island in maritime Antarctica. The clutches were observed whilst Julia and fellow team members were conducting fieldwork for a Chilean Antarctic Institute (INACH) project in the austral summer of 2022.

When asked about her reaction to the discovery Júlia stated, "I've been working with giant petrels for the last 10 years, so it was a huge surprise to see two-egg clutches for the first time after all these years. But if there's one thing that giant petrels can do well is to surprise us with novel behaviours (which later I found iweren't that novel)! The team was excited with the unusual find and also happy to see that the two chicks looked healthy and well-nourished. We could only hope for a two-chick fledge!"

Her official record states in translation:

On 23 January 2022 we first observed two Southern Giant Petrel *Macronectes giganteus* nests with two-egg clutches at Harmony Point, Nelson Island (maritime Antarctica). One nest had two chicks about two weeks old. One was younger than the other and was being guarded underneath the body of the male. The other was lying beside the adult. Chicks had similar body size to other chicks at the area. The other nest had two eggs, but we believe at least one was spoiled because it had a crack. Also, hatching was two weeks overdue. As we were about to leave the area a few days later, we did not check if the pair were able to successfully raise two chicks until fledging.

Two-egg clutches are rare for the species. In 1962, John Warham described the frequency of occurrence to be 0.14 to 0.18% (4 - 5) of all nests at Macquarie Island. Harmony Point holds a population of *ca* 480 nests, and after checking all nests from a distance, we assume the frequency of two-egg clutches in this population to be at least 0.41%. Warham also states that the birds were capable of covering both eggs during incubation. However, he wasn't able to confirm if the brood patch covered both eggs. Nevertheless, three of the nests Warham found did not hatch and in the other two nests that did, neither of the pairs succeeded in rearing both chicks. Other sites with records of two-egg clutches of Southern Giant Petrels are Îles des Pétrels in Terre-Adélie, Antarctica (Prévost 1953), where one nest among 120 was found to have two eggs; and Anvers Island, Western Antarctic Peninsula, where five nests were recorded (Shaughnessy 2017).

The second Southern Giant Petrel clutch containing two eggs; photograph by Júlia Finger

Two-egg clutches are also known to occur among albatrosses, with ACAP covering an account from Chris Jones and Michelle Risi of an Atlantic Yellow-nosed Albatross pair with a two-egg clutch on Gough Island in 2015.

With thanks to Júlia Finger for translating her account.

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Prévost J. 1953. Note sur l'écologie des pétrels de Terre Adélie. *Alauda* 21: 205-222.

Shaughnessy, P.D. 2017. A two-egg clutch or polygyny? Two white-phase chicks in the nest of a Southern Giant Petrel *Macronectes giganteus* at Macquarie Island. *Marine Ornithology* 45: 43-46. [click here for ACAP review]

ANEXO G – DIVULGAÇÃO CIENTÍFICA: ENTREVISTAS, PROGRAMAS E COMENTÁRIOS NA MÍDIA DURANTE O PERÍODO DO DOUTORADO

FINGER, J. V. G. Colisões de aves em vidraças: um impacto com solução. Programa Faixa Especial. 2022. (Rádio)

FINGER, J. V. G. Unisinos anuncia encerramento de 12 programas de pós-graduação e demissão de professores. 2022. (Entrevista para o jornal Brasil de Fato).

FINGER, J. V. G. Pesquisa em Ecologia e Biologia de Aves Antárticas. 2021. (Live Canal de YouTube - Antártica ou Antártida?).

FINGER, J. V. G. Vivendo no limite: ecologia e impactos antrópicos sobre a avifauna antártica. 2021. (Live Canal de YouTube - Ciência e Meio Ambiente).

FINGER, J. V. G. Pinguins e outras aves antárticas. 2021. (Live Canal do Instagram @moment_antar).

FINGER, J. V. G. Isolamento ao extremo: Como é ficar 78 dias acampada na Antártica? 2020. (Live Canal do Instagram @gelonabagagem).

FINGER, J. V. G. Antártica: perspectivas de uma bióloga sobre o continente gelado. 2020. (Live Canal do Instagram @histo.geo).

FINGER, J. V. G. Ep. 147: Meu Escritório é na Antártica. 2020. (Podcast Eu Tava Lá)

Um alerta sobre a poluição na Antártica. **Jornal Zero Hora**, Porto Alegre, p. 2 - 2, 13 set. 2021.

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Um alerta sobre a poluição na Antártica

Uma recente publicação científica com participação de pesquisadores gaúchos chama atenção para a poluição na Antártica. O artigo divulgado na quarta-feira no periódico internacional Marine Pollution Bulletin, uma das principais do mundo na área, mostra uma surpreendente presença de lixo em um local remoto e protegido, a Ponta Harmonia, na Ilha Nelson. Devido à significativa biodiversidade local, com a presença de aves e mamíferos marinhos, musgos e líquens, a região foi inserida em uma categoria rígida de conservação para o continente, a de Área Antártica Especialmente Protegida (ASPA, na sigla em inglês).

Mesmo assim, o trabalho conduzido por pesquisadores da Unisinos, Instituto Antártico Chileno e British Antarctic Survey encontrou mais de 1,5 mil itens entre garrafas plásticas, fragmentos de isopor, borrachas, esponjas, latas de cerveja, cordas navais e até um frasco de inseticida. A chegada deste lixo, observa Júlia Finger, bióloga, doutoranda na Unisinos e pesquisadora antártica, pode levar à região espécies exóticas de algas e crustáceos e acarreta risco de morte de animais pela ingestão de plásticos, por exemplo.

– Já fui em diversas outras ilhas antárticas, mas pela primeira vez neste local, e me chocou a poluição muito maior. Achamos importante reportar esta situação para a comunidade científica – diz Júlia.

Pinguim em frente a um tonel de metal

Frasco de inseticida encontrada na praia

A origem do lixo pode estar relacionada a cruzeiros que passam pela região e à existência de um refúgio usado como acampamento-base. A intenção da publicação é fazer um alerta sobre a necessidade de um maior esforço de proteção e cuidados na liberação de detritos em alto-mar, que acabam chegando em um local isolado, de acesso restrito, que deveria ser altamente conservado e tem grande importância para reprodução de pinguins. Júlia observa que a presença de resíduos antrópicos na Antártica não chega a ser uma novidade, mas neste caso é preocupante por estar ocorrendo em uma área que precisa ser superprotegida.

Reviravolta no caso do menino Teteo

Decisão da Justiça estadual inaugurou um novo capítulo no caso do menino Matteo Jardim, o Teteo, que tem atrofia muscular espinhal e precisa de um remédio que custa mais de R$ 10 milhões e só é produzido na Inglaterra.

O Tribunal de Justiça do Estado concedeu o efeito suspensivo à decisão que mandava o plano de saúde adquirir o medicamento, por entender que cabe à União, condenada em outra ação mais antiga na Justiça Federal, pagar a conta. A boa notícia para Teteo e para sua família foi que, mesmo sem obrigação, o plano de saúde depositou R$ 11,4 milhões na conta do laboratório inglês e, com isso, garantiu que o remédio chegue a Porto Alegre no menor prazo possível.

A decisão do plano de saúde é garantir o atendimento a Teteo enquanto, paralelamente, discute na Justiça com a União, que se manifestou contrária à decisão que a incumbe do pagamento.

Socorro com discrição

Equipe da Secretaria de Cidadania e Direitos Humanos de Esteio desenvolveu um aplicativo para facilitar que mulheres vítimas de violência denunciem as agressões de maneira discreta. O app ficará camuflado no aparelho celular, como se tivesse outra função.

O propósito é garantir a segurança das usuárias e dificultar a identificação pelo agressor. O aplicativo, que ainda não foi oficialmente lançado, poderá ser baixado em um link e por QR Code.

A denúncia de violência será recebida via WhatsApp por órgãos como a Patrulha Maria da Penha e outros da área de segurança.

Apesar de ser uma iniciativa do próprio município, já existe interesse de outras prefeituras na ideia.

Vida nova

Quatro jovens imigrantes venezuelanos vindo de Pelotas chegaram à Capital na tentativa de encontrar uma forma de irem até São Paulo, onde têm promessa de emprego e familiares. Estavam sem recursos para seguir a viagem e, na rodoviária, buscaram auxílio da Diretoria de Direitos Humanos da Secretaria Municipal de Desenvolvimento Social. Contatada, a Aclame conseguiu as passagens, cedidas gratuitamente pela empresa de ônibus Planalto.

Uso da terra

Novo estudo do MapBiomas mostra o quanto o país perdeu de vegetação nativa entre 1985 e 2020.

O Rio Grande do Sul tinha 60% de áreas naturais e 40% com uso antrópico. Agora, a proporção está 50% a 50%.

Argentina

Boca de uma

Investigadores describen dos primeros casos confirmados de canibalismo en petreles gigantes. **Ladera Sur**, Chile, 10 ago. 2021.

Investigadores describen dos primeros casos confirmados de canibalismo en petreles gigantes

Ciencia y Biodiversidad

por Colaborador Invitado

Consejos para no perder la cabeza durante la cuarentena. **Periódico La Segunda**, Santiago de Chile, p. 2 - 3, 16 abr. 2020.

Consejos para no perder la cabeza durante la cuarentena

Si piensa que su aislamiento es malo, así lo viven en la Antártida

Investigadores que han pasado semanas encerrados en una carpa recomiendan mantener una rutina y leer ficción.

Por Felipe O'Ryan

El año pasado, un científico ruso intentó apuñalar a su compañero en la estación base Bellingshausen, en la isla del Rey Jorge, en la Antártida. Tuvieron que llevarlo al hospital de Punta Arenas, dicen notas internacionales, pero salió bien. El móvil del crimen frustrado: la víctima no paraba de contarle el final de las películas.

Sin duda hay mejores formas para lidiar con la presión emocional que trae el encierro y aislamiento, cuentan chilenos y extranjeros que han pasado meses en la Antártida, y que en esta nota dan a conocer sus consejos para quienes enfrentan largas cuarentenas por el coronavirus.

Lo primero, dicen, es mantener una rutina de horarios lo más similar posible a la que se tenía antes del encierro, para no sumarle al estrés de estar en una situación diferente (es decir, al hecho de estar aislado), una nueva sensación de desorden.

"Hay que organizar rutinas día a día, eliminando las incertezas. Se deben dejar claros tiempos de trabajo y también de ocio", cuenta Elías Barticevic (50 años), quien ha sido jefe de la Base Profesor Julio Escudero del Instituto Antártico Chileno (INACH).

Lucas Kruger, biólogo de 35 años e investigador del INACH, ha pasado casi tres meses en carpa en medio de la desolada isla Nelson, separado por 3 horas de frío bajo cero y aguas congeladas de la base más cercana. Ahí, las tormentas heladas a veces lo han forzado a pasar semanas sin salir.

"Me focalizo en objetivos claros y realizables. Hay que ser realista a la hora de fijarlos y tienes que tener claro por qué quieres lograrlos. Que sean alcanzables, porque cuando los alcanzas es cuando te sientes productivo y feliz", cuenta.

Un estudio de la Universidad de Standford arrojó que el establecer objetivos muy abstractos, como "hacer a alguien feliz", generaban más sensaciones de ansiedad que de felicidad. Es mejor ponerse un objetivo más claro: hacer a alguien reír.

Alimentarse bien y desconectarse

En invierno, los investigadores del INACH dejan la Antártida. Sus bases son solo visitadas en esa época por personal de las Fuerzas Armadas. En la estación más fría del año, las temperaturas promedio del subcontinente caen hasta los -20° y las tormentas te pueden dejar meses encerrado. En esos meses hay días en los que jamás sale el sol.

Ese es el panorama que le espera a David Knoff, australiano líder de la estación Davis, que pasará este invierno en la Antártida.

Algunas de las recomendaciones de Knoff son las básicas, pero no por eso dejan de ser importantes. "No hay que descuidar la buena alimentación, porque está relacionada con el estado de ánimo. Considerar suplementos de vitaminas si no se puede exponer al sol. También hacer ejercicio", señala.

"Vemos películas y leemos. Eso ayuda a despejarte", añade el australiano. Todos los residentes antárticos leen libros, sobre todo novelas. Y algo de razón tienen. Un 68% de las personas que leían ficción más de 6 minutos al día reportaban sentirse menos estresadas, según investigadores de la Universidad de Sussex.

Otra recomendación, que quizá puede de sonar paradójica, es que el aislamiento puede ser una buena oportunidad para desconectarse.

"Estar en el campamento se siente como un alivio a veces, porque te desconectas completamente de las redes sociales. Es como una desintoxicación que hace muy bien", cuenta la bióloga brasilera Julia Finger (28), que desde 2012 viaja a la Antártida y ha pasado hasta dos meses en campamentos alejados de la civilización, donde toda la única comunicación por ondas al alcance son unos pocos minutos de telefonía satelital a la semana.

"Usar las redes sociales para sustituir conexiones reales con otras personas, como conversaciones de varios minutos, puede aumentar la sensación de soledad", dice un estudio del American Journal of Preventive Medicine.

Finger lleva ya varias semanas en cuarentena, esta vez no voluntaria y lejos de la Antártida, en su hogar. Eso sí, la investigadora es optimista sobre los periodos de encierro. Según ella, los meses en la Antártida te hacen valorar las cosas cuando vuelves al continente.

"Te enseña de gratitud. Uno da por sentado muchas cosas, una ducha caliente, una cama caliente, a la familia. Pero en la Antártida, en el aislamiento, no tienes nada de eso, y cuando vuelves te sientes definitivamente más feliz. Creo que algo similar nos sucederá cuando estos periodos de cuarentena acaban", cuenta la investigadora desde su casa en Brasil.

Y un último consejo: ¡No cuente los finales de las películas a sus compañeros de encierro!

2 **Sociedad** La Segunda jueves 16 abril 2020

El clima antártico puede dejar a los investigadores encerrados en una carpa por semanas.

"Estar en el campamento se siente como un alivio porque te desconectas".
Julia Finfer,
bióloga.

"Me focalizo en objetivos claros. Hay que ser realista a la hora de fijarlos".
Lucas Kruger,
Investigador del INACH.

Que tal fazer o isolamento no gelo da Antártica? **Jornal NH - Caderno ABC**, Novo Hamburgo, RS, p. 6 - 7, 11 jul. 2020.

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Que tal fazer o isolamento no gelo da Antártica?

Doutoranda em biologia pela Unisinos, a ivotiense Júlia Finger passa até 80 dias em acampamentos no continente gelado pesquisando aves marinhas

Gustavo Henemann

[illegible]

A pandemia do novo coronavírus trouxe ao mundo a experiência do isolamento domiciliar e, em muitos casos, é possível amenizar a falta de contato por meio da Internet, das redes sociais, da televisão, sem contar ainda na possibilidade do conforto do sofá da sala, da cama, de um bom banho, entre outras comodidades. Porém, quem já viveu na pele o isolamento real foi a ivotiense Júlia Finger, de 29 anos. A doutoranda em biologia pela Unisinos, a partir de um convênio com o Instituto Antártico Chileno (Inach), estuda ecologia de aves marinhas, e desde 2012 realizou vários trabalhos de campo, passando de 50 a 80 dias totalmente isolada com sua equipe em acampamentos e refúgios em ilhas da Antártica.

Se não bastasse o frio, o único contato com a família é feito por um telefone via satélite. Atualmente, Júlia enfrenta a quarentena na sua casa em Dois Irmãos, saindo apenas para tarefas essenciais, e à reportagem do ABC ela conta mais sobre suas vivências no continente gelado. "É uma questão de perfil, se vive de uma forma diferente. É um momento de prazer profissional, e uma forma de se desconectar, fazer um detox digital, porque não temos Internet. São 80 dias com apenas um telefone via satélite para usar de vez em quando para falar com a família e dizer: 'estamos vivos'", detalha Júlia, sem perder o bom humor.

Contraste

Ela comenta ainda sobre a diferença em relação a sua vida quando está no Vale do Sinos. "É um contraste com minha realidade no Brasil, tenho estrutura, acesso a muitas coisas boas, mas na Antártica você não consegue tomar um banho direito, não tem água encanada, não tem aquecedor, e dormimos em barracas. Sou feliz por ter esse contraste, e gratidão pelo que tenho aqui", reforça a ivotiense.

Psicológico

Para Júlia, que fez a última viagem à Antártica em novembro do ano passado, o fator psicológico precisa ser bem trabalhado, pois não é tarefa fácil ficar longe dos familiares e dividir espaço com outras pessoas que também possuem seus costumes e manias. "É importante ter a consciência do outro e tolerância com as coisas", enfatiza Júlia, que acredita ser importante o trabalho de união do grupo durante o isolamento na Antártica. Por conta da pandemia, a doutoranda não sabe agora quando será a próxima viagem para o continente gelado.

Equipe de pesquisa do Inach é composta por três a seis pessoas.

Júlia em viagem com Instituto Antártico Chileno

Júlia Finger, Lucas Krüger e Danyelle Corá na cidade portuária de Punta Arenas, no Chile

Aves marinhas são rastreadas por GPS

Júlia realiza o doutorado com orientação da Dra. Maria Virginia Petry no Laboratório de Ornitologia e Animais Marinhos, da Unisinos, por meio do projeto do Inach: "Desvendando as dinâmicas entre a pesca e espécies de aves marinhas em águas Antárticas: uma perspectiva de manejo". Ela possui uma bolsa de estudos fornecida pela Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes), que é uma fundação vinculada ao Ministério da Educação (MEC). A doutoranda detalha seu estudo na Antártica. "Minha pesquisa está centrada na interação entre a pesca na região antártica e patagônica e o petrel-gigante-do-sul, uma ave marinha predadora de topo, que reproduz na Antártica e tem hábitos alimentares oportunistas. Ou seja, ela come o que estiver disponível. Por isso, aproveita os descartes da pesca como fonte de alimento", explica Júlia. A pesquisadora fala, ainda, que para chegar aos estudos conclusivos, ela acoplou equipamentos GPS nas aves. "Para saber se as aves estão interagindo com barcos e comendo descartes, estou rastreando eles com GPS acoplados aos seus dorsos e analisando o DNA das fezes para detectar DNA de espécies-alvo e espécies descartadas pela pesca", afirma. Segundo Júlia, além do estudo sobre a espécie petrel-gigante, ela pesquisa os hábitos dos pinguins, com os trabalhos realizados nas Ilhas Shetland do Sul. Na Ilha Rei George, está situada a Estação Antártica Comandante Ferraz do Brasil.

Os acampamentos

Da cidade de Punta Arenas, ao Sul do Chile, Júlia sempre parte de avião ou navio para as expedições na Antártica. O trabalho no continente é realizado de duas formas, nos acampamentos ou mesmo nos navios, quando a equipe se desloca por várias ilhas. Júlia fala sobre como funcionam os acampamentos, onde passa de dois a três meses. "Acompanhamos a estação reprodutiva das aves (da espécie petrel-gigante), desde quando eles colocam os ovos, e saímos quando os filhotes estão nascendo", detalha. Ela conta que as dificuldades são enormes com as tempestades. "Em um dos acampamentos teve uma ventania que atingiu 120 km/h, quebrou a barraca, precisamos tirar todas as coisas, estava chovendo. Ficamos num refúgio antigo (cerca de 60 anos), acabamos dormindo em camas de campanha", recorda Júlia.

Viagem antes da tragédia

Na última viagem feita em novembro, Júlia lembra que o trajeto até o local do acampamento foi com o avião C130 Hercules da Força Aérea do Chile (FACh), o mesmo que viria a sofrer um acidente aéreo em 9 de dezembro com 38 pessoas a bordo a caminho da Antártica. Quando a aeronave desapareceu estava a 700 km de Punta Arenas (saída) e a 500 da Antártica. O avião levava apoio logístico rumo à Base Aérea Antártica Presidente Eduardo Frei Montalva, onde a equipe a bordo faria revisão de um oleoduto flutuante. Quando o acidente ocorreu, Júlia e os dois colegas de equipe estavam no acampamento. Por conta do acidente, eles precisaram voltar de carona em voo brasileiro. A ivotiense esteve acompanhada do biólogo leopoldense Lucas Krüger, que hoje é morador de Punta Arenas e pesquisador do Inach, e da bióloga de campo Denvelle Corá, de Chapecó (SC).

ARQUIVO PESSOAL

Refúgio dos pesquisadores em uma das ilhas da Antártica

ARQUIVO PESSOAL

Pesquisadora conta que sensação térmica já chegou a -15°C

LIANA CHESINI/DIVULGAÇÃO

Júlia acopla GPS nas aves da espécie petrel-gigante

TAMARA JUSTO/DIVULGAÇÃO

Os hábitos dos pinguins também são objetos de estudos

ARQUIVO PESSOAL

Na época de verão, essa é a vista do acampamento dos pesquisadores do Instituto Antártico Chileno (Inach), que à frente apresenta uma enorme geleira na Antártica