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VARIAÇÃO NO COMPORTAMENTO E PERFORMANCE DE PESCADORES ARTESANAIS QUE INTERAGEM COM BOTOS

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João Victor Silva do Valle Pereira

Variação no comportamento e performance de pescadores artesanais que interagem com botos

O presente trabalho em nível mestrado foi avaliado e aprovado por banca examinadora composta pelos seguintes membros:

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Este trabalho é dedicado aos pescadores de Laguna.

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"Gosto dos meus erros; não quero prescindir da liberdade deliciosa de me enganar."

Charles Chaplin

RESUMO

A pesca artesanal de pequena escala é uma atividade incerta e desafiadora. Além de eventuais flutuações na disponibilidade do recurso pesqueiro, a dinâmica da pesca artesanal também é influenciada pelas habilidades intrínsecas de forrageio e tomada de decisão dos pescadores. Os pescadores normalmente variam em seus objetivos, experiências e táticas, muitas vezes buscando aperfeiçoar sua performance de pesca. No entanto, pouco se sabe sobre a influência da variação comportamental no sucesso de captura de pescadores artesanais. Em Laguna, sul do Brasil, uma comunidade de pescadores artesanais interage com uma população de botos-da-tainha (*Tursiops truncatus* cf. *gephyreus*). Enquanto botos conduzem cardumes de presas (principalmente *Mugil liza*, a tainha) até uma linha de pescadores posicionada paralela à margem, estes aguardam um evento comportamental específico dos botos, que interpretam como 'sinal' para lançar suas tarrafas. Esta interação, tanto para botos como para pescadores, requer sincronismo e nuances comportamentais, e é um bom estudo de caso para avaliar performance e habilidades que possam maximizar o sucesso de captura. Além disso, este sistema contém pescadores amadores e profissionais, os quais têm diferentes percepções do sistema boto-pescador como resultado de suas experiências e ambientes sociais. Isso gera uma variação na percepção de reputação que os pescadores têm dos outros membros da comunidade pesqueira. Considerando tais diferenças comportamentais (e.g., como e onde lançam suas tarrafas) que podem afetar o sucesso na pesca com os botos e as diferentes percepções e relações sociais, minha dissertação tem dois objetivos principais. No primeiro capítulo, investigo como diferenças comportamentais e condições ambientais locais podem influenciar o sucesso de captura dos pescadores artesanais que interagem com botos. Ao combinar uma amostragem ambiental *in situ* com uma amostragem comportamental em escala fina por vídeos aéreos, demonstro maior capturabilidade de peixes entre os pescadores que estão mais bem posicionados na água e lançam suas tarrafas mais abertas e mais perto dos botos. Também descobri que as diferenças nas habilidades de lançamento de tarrafas afetam o sucesso dos pescadores artesanais sobre as condições ambientais relacionadas à disponibilidade de peixes. Isto sugere que estas variações de performance que maximizam o sucesso de captura não são respostas imediatas a variações na disponibilidade de recursos, mas sim resultante da experiência e conhecimento sobre o sistema, adquiridos pelos pescadores. Dessa forma, manter este conhecimento e habilidades adquiridas pode ser essencial para garantir os benefícios aos pescadores que interagem com botos. No segundo capítulo, investigo a relação entre a posição dos pescadores em sua rede social (centralidade) e a reputação dentro da comunidade pesqueira local. Busquei também avaliar a existência de preferências sociais em torno dessa reputação dos pescadores, isto é, se há uma preferência dos pescadores se associarem com outros pescadores de alta reputação. Além disso, avalio se essas relações sociais se mantêm quando os pescadores estão forrageando ou quando não estão forrageando, ou seja, em contextos comportamentais distintos. Para isso, registrei a localização dos pescadores por meio de pulseiras com GPS e acessei os índices de reputação dos pescadores artesanais, como por eles percebidos em entrevistas semiestruturadas de projetos paralelos. Em seguida, usei os dados de GPS para estabelecer grupos espaço-temporais de indivíduos nos diferentes contextos comportamentais e, finalmente, quantifiquei e testei se a centralidade se relaciona com a reputação e calculei os coeficientes de assortatividade em torno da reputação. Encontrei uma tendência de indivíduos de alta reputação serem mais socialmente centrais, especialmente no contexto de não forrageio, isto é, local onde os pescadores esperam os botos na praia e descansam, um ambiente socialmente mais favorável. Além disso, encontrei que os pescadores não tendem a se relacionar com pescadores de reputação similar em ambos os contextos (‘forrageio’ e ‘não-forrageio). Durante o forrageio, essa descoberta reforça a robustez das regras informais do sistema boto-pescador, as quais permitem que qualquer pescador possa usar qualquer um dos pontos de pesca (vagas), e pode sugerir que pescadores com baixa reputação tentam se aproximar dos pescadores de alta reputação, os quais são percebidos como os pescadores que têm maior sucesso de captura e que têm um entendimento melhor do sistema. No contexto de ‘não-forrageio’, onde interações sociais são mais pronunciadas, novamente os pescadores não tendem a se relacionar com similares em relação a reputação, o que sugere que as preferencias sociais de um pescador são independentes da reputação dos outros. Esses resultados também podem sugerir que pescadores com baixa reputação estão tentando criar relações com pescadores de alta reputação, a fim de adquirir conhecimento (por meio de troca de informação) e possíveis parcerias para cooperar na pesca com os botos. Concluo e reforço a importância da variação comportamental de pescadores em pescas artesanais de pequena escala, que pode, por exemplo, contribuir para uma melhor avaliação do uso do recurso pesqueiros. Além disso, é importante saber como os pescadores variam seu comportamento frente a flutuações ambientais e a disponibilidade de presas. Em pescas artesanais, essa variação não deve ser ignorada em estratégias de manejo pois, como demonstrado nesse estudo, variações comportamentais são relevantes para o sucesso dos pescadores, assim ajudando na persistência de pescas tradicionais centenárias.

Palavras-chave: pesca artesanal, manejo da pesca, relações sociais

ABSTRACT

Small-scale artisanal fishing is an uncertain and challenging activity. In addition to fluctuations in the availability of fishing resources, the dynamics of artisanal fishing is also influenced by the intrinsic foraging skills and decision-making processes of fishers. Fishers typically vary in their goals, experiences and tactics, often seeking to improve their fishing performance. However, little is known about the influence of behavioural variation on the catch success of artisanal fishers. In Laguna, southern Brazil, a community of artisanal fishers interacts with a population of Lahille's bottlenose dolphins (*Tursiops truncatus* cf. *gephyreus*). The dolphins lead fish schools (mainly *Mugil liza*, the mullet) to a line of fishers positioned parallel to the shore, the fishers await a specific behavioural event from the dolphins, which they interpret as a 'signal' to cast their cast nets. This interaction, for both dolphins and fishers, requires timing and behavioural nuances, and is a good study case for evaluating performance and skills that can maximize catching success. In addition, this system contains both amateur and professional fishers, who have different perceptions of the dolphin-fisher system as a result of their experiences and social environments. This creates a variation in the perception of peer reputation that fishers have with other members of the fishing community. Considering such behavioural differences (e.g., how and where they cast their nets) that can affect the success of fishing with the dolphins and the different perceptions and social relationships, my dissertation has two main objectives. In the first chapter, I investigate how behavioural differences and local environmental conditions can influence the catching success of artisanal fishers that interact with dolphins. By combining *in situ* environmental sampling with fine-scale behavioural sampling by aerial videos, I demonstrate greater fish catchability among fishers who are well positioned in the water and cast their nets wide open and closer to the dolphins. I have also found that differences in casting skills affect artisanal fishers' success over and above environmental conditions related to fish availability. This suggests that these performance variations that maximize capture success are not immediate responses to variations in resource availability, but rather result from experience and knowledge about the system acquired by fishers. Thus, maintaining this knowledge and acquired skills can be essential to ensure benefits to fishers who interact with dolphins. In the second chapter, I investigate the relationship between the position of the fisher in their social network (centrality) and reputation within the local fishing community. I also sought to assess the existence of social preferences around this the fisher reputation, that is, if there is a preference for fishers to associate with other highly reputable fishers. Furthermore, I assess whether these social relationships are maintained when fishers are foraging or when they are not foraging, that is, in different behavioral contexts. For this, I recorded the fishers' location using GPS wristbands and accessed the artisanal fishers' reputation indexes, as perceived by themselves in semi-structured interviews of parallel projects. Next, I use the GPS data to establish spatiotemporal groups in our different behavioural contexts, and finally I quantified and tested whether centrality is related to reputation and calculated the assortativity coefficients around reputation. I found a tendency of high reputation fishers to be more socially central, especially in the non-foraging context, that is, where fishers wait for the dolphins on the beach and rest, a more socially favorable environment. Furthermore, I found that fishers do not tend to associate to fishers of similar reputation in both contexts ('foraging' and 'non-foraging'). During foraging, this finding reinforces the robustness of the informal rules of the dolphin-fisher system, which allow any fisher to use any of the fishing spots and may suggest that low-reputed fishers try to approach high-reputation fishers, who they perceive as the fishers who have the greatest fishing success and who have a better understanding of the system. In the 'non-foraging' context, where social interactions are more pronounced, again fishers do not tend to relate to similar in terms of reputation, suggesting that a fishers' social preferences are independent of the reputation of others. These results may also suggest that fishers with low reputations are trying to build relationships with fishers of high reputation in order to gain knowledge (through information exchange) and possible partnerships to cooperate in fishing with the dolphins. I conclude and reinforce the importance of behavioural variation of fishers in small-scale artisanal fisheries, which can, for example, contribute to a better assessment of fish stocks. Furthermore, it is important to know how fishers vary their behaviour in the face of environmental fluctuations and prey availability. In artisanal fisheries, this variation should not be ignored in management strategies because, as shown in this study, behavioral variations are relevant to the fishers' success, thus helping the persistence of centuries-old traditional fisheries.

Keywords: artisanal fisheries, fisheries management, social relationships

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INTRODUÇÃO GERAL

O sistema socioecológico da pesca e seu desenvolvimento

O desenvolvimento da pesca em sociedades humanas é um processo contínuo. Com origens em tempos pré-históricos, atividades pesqueiras têm passado por inúmeros aperfeiçoamentos e divergido em uma vasta gama de técnicas e estratégias; hoje em dia, são marcadas pela monetarização das economias e pelos processos de industrialização (Kent 1986). O desenvolvimento de atividades pesqueiras é, em geral, pautado por empirismo e processos de aprendizado coletivo sobre sistemas adaptativos complexos (Berkes et al. 2000), e motivado pela busca constante na eficiência e sucesso de capturas em contexto de mudanças dinâmicas e incertezas (Dietz et al. 2003). A pesca artesanal, ou de pequena escala, encontra-se no meio deste caminho e pode ser, apressadamente, definida como pesca não-industrial. No entanto, é muito tênue a linha que separa as categorias industrial e não-industrial, devido às diversas variantes de pescarias com diferentes petrechos. Embora a definição de pescaria artesanal seja um debate persistente na literatura pesqueira (García-Flórez et al. 2014), há consenso suficiente para sugerir que uma pesca artesanal possa ter caráter de subsistência ou fins comerciais; em ambos, espera-se escala de produção limitada, geralmente utilizando pequenas embarcações, com diversidade de espécies-alvo e baixa biomassa de captura (Smith & Basurto 2019). Em contraste, a pesca industrial utiliza grandes embarcações para a captura de muita biomassa, de poucas espécies (Mansfield 2010).

Esta classificação dicotômica tentativa dos sistemas pesqueiros, no entanto, varia regionalmente (Rousseau et al. 2019), refletindo as dificuldades em classificar a diversidade de pescarias existentes, em especial as ditas artesanais. Além disso, esta dificuldade é potencializada pelo processo de desenvolvimento tecnológico que vêm aumentando o poder de pesca das pescarias de pequena escala (Damasio et al. 2020). Assim, a distinção entre uma prática artesanal e industrial já foi mais evidente em décadas passadas. Uma definição comumente utilizada para a costa brasileira considera o pescador artesanal como um profissional autônomo, em atividade familiar ou comunitária, com baixo poder de predação e pequena produção mercantil (Diegues 1995). Ou seja, a pesca artesanal é tida como uma atividade de muita mão-de-obra e pouco capital. Porém, com as pescarias artesanais globalmente se beneficiando da acessibilidade às inovações tecnológicas, definições mais amplas são necessárias. Na América Latina, as propostas da FAO (2000; 2021) distinguem ao menos três categorias de pesca artesanal: (a) a avançada ou semi-industrial, com embarcações medianas que competem com a pesca industrial tanto pelo pescado quanto pelo mercado; (b) a tradicional, com embarcações, petrechos e estratégias tradicionais e direcionadas para o mercado local ou regional; e (c) a artesanal de subsistência, de caráter ocasional e/ou complementar para uma comunidade. Independente da tipologia utilizada, estas divisões discretas representam um gradiente contínuo de um sistema dinâmico, de forma que pescadores artesanais também possam ser (ou foram) pescadores industriais e vice-versa (Haggan et al. 2007). Esta flexibilidade possibilita uma troca constante de saberes e práticas entre cada pescaria: a pesca artesanal pose ser influenciada pelas inovações tecnológicas da pesca industrial, que, por sua vez, reflete antigos métodos e ferramentas que inspiram a produção de novas tecnologias visando o aumento da capturabilidade, ganhos econômicos e redução da seletividade (Ruttan et al. 2000).

Neste entrelace entre as diferentes escalas, uma questão central difere a prática industrial da artesanal. Geralmente, a estatística pesqueira e os métodos de avaliação de estoque pesqueiro focam na dinâmica da pesca industrial, talvez pela alta produtividade e consequente risco de sobrepesca de tal pescaria em grande escala (Mansfield 2010). Para a pesca artesanal, em contraste, a ausência de estatística de pesca é uma rotina (Oliveira-Junior et al. 2016), embora tais pescarias possam praticar a sobrepesca mesmo em pequena escala (Bender et al. 2014; Gough et al. 2020). Por exemplo, os recursos da pesca produzidos por pescarias em pequena escala representam mais da metade de todas as capturas globais (Davy 2000). Mesmo assim, a ecologia pesqueira avalia os efeitos da pesca artesanal aos sistemas ecológicos de uma forma abrangente (Jackson et al. 2001), enfatizando questões relacionadas ao (i) co-manejo ou conservação de seus habitats (Gelcich et al 2019), (ii) ao risco que algumas práticas impõem ao ambiente natural e às espécies não-alvo (Shester & Misheli 2011), (iii) à utilidade do conhecimento tradicional para o manejo (Begossi 2008), e (iv) aos valores da diversidade cultural armazenada em muitas comunidades e tradições pesqueiras. Esses valores geram inovações e urgem por condições de serem produzidos e reproduzidos (Pellowe & Leslie 2021). Esta complexidade intrínseca à pesca artesanal se manifesta mediante as diversidades de espécies-alvo, habitats, práticas, técnicas e saberes — muitas vezes dependentes de processos culturais locais (Munro & Smith, 1984; Keppeler et al. 2020). Assim, encontrar padrões para pescarias artesanais é um desafio constante, e seu estudo deve considerar as realidades regionais e refinamentos.

Um refinamento recente na literatura pesqueira é o crescente interesse no pescador como um indivíduo e nas motivações de suas decisões sociais e de forrageio (Gaertner et al. 1999; Ruttan 2003; Keppeler et al. 2020). Este foco no indivíduo, o agente pesqueiro, tem se mostrado útil para entender padrões comportamentais coletivos em pescarias de grande escala (Salas & Gartner 2004). Porém, o foco no indivíduo é ainda pouco estudado em pescarias de pequena escala (Branch et al. 2006), o que é surpreendente dado que nestes sistemas cada indivíduo tem mais autonomia na tomada de decisão, a qual é influenciada por históricos individuais de experiências na prática de pesca (Fulton et al. 2011). Dessa forma, o entendimento dos processos que interferem nas habilidades intrínsecas e definem as escolhas de um pescador artesanal é essencial para entender o funcionamento de uma pescaria de pequena escala — isto é, como se organiza, como seus agentes interagem entre si, como seus conhecimento adquiridos e acumulados são transmitidos, como uma inovação surge e é selecionada —; bem como a flexibilidade e resiliência de tal pescaria — isto é, como se adapta às transformações dos ambientes físico e social, como se dá o equilíbrio entre estados de sustentabilidade e insustentabilidade, e o quão possível é manejar para garantir maior ganho coletivo em longo prazo (Salas & Gartner 2004; Huntington et al. 2017). Apesar da clara importância do efeito do comportamento dos pescadores nas atividades pesqueiras (Andrews et al. 2021), em especial para o manejo (Hilborn & Walters 1992; Charles 1995; Wilen et al. 2002), seu papel na dinâmica e no gerenciamento das pescarias, em especial das de pequena escala, permanece pouco estudado (Begossi 1998; Cabrera & Defeo 1997; Salas 2000).

O agente pescador

Um pescador pode ter múltiplas motivações e objetivos com uma pescaria. Muitos pescadores são profissionais e dependem economicamente desta atividade, visando lucro ou subsistência. Outros são amadores, não dependem da pesca como fonte de renda, mas a utilizam como atividade recreativa. Entre as pescarias artesanais há grande diversidade de táticas, que se refletem nos petrechos utilizados, nas espécies buscadas, nas condições financeiras e no estilo de vida das comunidades dos pescadores. Além da diversidade entre pescarias, também há muita diversidade entre os pescadores praticantes de uma pescaria específica ou membros de uma mesma comunidade. Em um sistema de pesca artesanal, cada pescador é representante direto de suas capturas, tem diferentes motivações e preferências quanto ao uso do recurso, e desenvolve e implementa suas estratégias e táticas de pesca em resposta aos contextos humanos, sociais, culturais, ambientais e econômicos em que se encontram (Hart & Pitcher 1998; Silvano

& Begossi 2001). Ainda, cada pescador tem sua própria trajetória individual de relação com uma prática de pesca, um recurso e um ambiente. Estes históricos de experiências individuais se entrelaçam no conhecimento coletivo acumulado ao longo do tempo, compondo desta forma o 'conhecimento ecológico local' (CEL) da comunidade pesqueira (Silvano & Valbo-Jorgensen 2008). Este conhecimento, embora comunitário, é diferente entre pescadores. Esta diferença deve ser considerada em abordagens de manejo, pois determina como cada indivíduo entende os processos biológicos e ecológicos, como usam o ambiente, e como exploram seus recursos (Begossi 2008). Pescadores individuais diferem quanto à percepção do meio e quanto à habilidade de apreender e inovar. Tais percepções influenciam as decisões individuais sobre como, onde e quando pescar, refletindo assim na performance de pesca e sucesso de captura (Keppeler et al. 2020). Estas diferenças individuais podem também levar a respostas distintas diante de regulamentações e proposições de manejo (Halwass et al. 2013).

Além desta contribuição de traços individuais relacionados a experiências históricas e habilidades em aprender e inovar, o comportamento individual também pode ser moldado pela busca em otimizar capturas, economizando esforços e recursos. Tal busca se manifesta desde o desenvolvimento constante de petrechos mais eficientes e materiais mais duradouros até o esmero de técnicas e comportamentos que podem dar uma pequena, porém notável, vantagem em relação a outros pescadores. Na literatura pesqueira, essa questão é amplamente discutida sobre a ótica da Teoria do Forrageio Ótimo, que inclui modelos clássicos de ecologia que abordam o comportamento de um organismo na busca e manuseio de recursos naturais (Stephens & Krebs 1987). Um caso especial de modelos de forrageio ótimo, a "teoria do forrageio no local central" (Orians & Pearson 1979), é bem aplicado para sistemas pesqueiros de pequena escala, uma vez que os pescadores retornam a um "local central" com suas capturas. Essa tendência à otimização se manifesta não só nas escolhas individuais de como, onde e quando pescar, mas também nas interações sociais dos pescadores que compõe uma comunidade pesqueira. Relações sociais entre pescadores permitem o rápido compartilhamento de informações, facilitando decisões de pesca (Gezelius 2007), aumentando as chances de sucesso ao reduzir as incertezas relacionadas a imprevisibilidade de recursos, a distribuição no espaço e no tempo e aos riscos financeiros que se seguem (Gatewood 1984, Hilborn & Walters 2013, Salas & Gartner 2004). Assim, a troca de conhecimento socialmente pode ter muitas motivações em termos de otimização; por exemplo, o rápido acesso à informação de localização do recurso alvo tende a aumentar a eficiência da pesca reduzindo o tempo de busca (Lyle & Smith 2014, von Rueden 2020).

Em geral, pescadores que buscam constantemente melhorias e oportunidades de aprendizagem se conectam socialmente com pescadores mais experientes e que podem fornecer boas informações sobre o sistema pesqueiro (Henrich & Broesch 2011). Em uma comunidade pesqueira, então, estes indivíduos percebidos como repositórios de conhecimento apresentam maior reputação, são seguidos pelos demais e tendem a apresentar um maior número de relações sociais, ou seja, são mais centrais dentro da rede social dessa comunidade (Crona & Bodin 2006, Carlsson & Sandström 2008). Mas quais seriam as vantagens para tais pescadores experientes em compartilhar seus saberes para a exploração de um recurso que é compartilhado com os demais pescadores? Repassar pontos de pesca, ensinar técnicas e compartilhar conhecimentos biológicos inevitavelmente aumenta o potencial de captura de outros pescadores, aumentando riscos de competição entre pescadores e de sobrepesca do recurso. A modesta literatura pesqueira que explora o papel dessas relações sociais entre pescadores (Bebbington 1999; Grant & Berkes 2006) sugere que, em um cenário de escassez de recursos explorado por uma comunidade com menor propensão à colaboração, aqueles pescadores detentores de conhecimento tendem a reter informações para si ou a compartilhá-las com pescadores que também têm outras informações a oferecer ou apenas com seus parentes (Begossi 1998). Em contraste, em uma comunidade com propensão à comportamentos cooperativos, pescadores experientes podem estar propensos a compartilhar informações com qualquer outro pescador interessado (Palmer 1991)

Além de considerar a importância das variações individuais entre pescadores quanto ao entendimento do sistema que estão inseridos e quanto as técnicas e táticas que usam, abordagens de manejo devem também olhar para essa dinâmica social e suas interações entre indivíduos que determinam o fluxo de informação em uma comunidade, sua estrutura, organização e natureza. Em resumo, considerar esses aspectos individuais e coletivos é fundamental para predizer como um coletivo de pescadores vai se comportar em cenários de mudanças ambientais e/ou variações de recurso; e para antecipar estratégias de manejo que possam acomodar conflitos e otimizar pescarias (Halwass et al. 2013). No entanto, são pouco estudados os sistemas pesqueiros que permitem tal refinamento de um olhar em nível individual. Enquanto em pescarias de larga escala o papel do indivíduo é indireto, em pescarias de pequena escala ele é direto; no entanto, em tal pequena escala, a dinâmica de pesca é mais complexa e diversa, impondo assim desafios à ecologia pesqueira tradicional. Torna-se fundamental, portanto, identificar e estudar sistemas pesqueiros em pequena escala simplificados que permitam o aprofundamento da análise da dinâmica pesqueira em nível individual e subsequentes generalizações para sistemas similares. Desta forma, é possível testar as seguintes hipóteses: (i) variações comportamentais possivelmente relacionadas à experiência maximizam sucesso de captura; (ii) variações individuais relacionadas a reputação afetam padrões sociais; (iii) pescadores buscam se relacionar com pescadores que possuem alta reputação dentro da comunidade pesqueira. Esta dissertação investiga um sistema pesqueiro de pequena escala único buscando testar tais hipóteses.

O modelo de estudo

Em Laguna, Santa Catarina, sul do Brasil, há uma comunidade de pescadores artesanais que pescam com auxílio de botos-da-tainha (*Tursiops truncatus gephyreus* ou *T. gephyreus*[1]) em pontos específicos (Figura 1A). A praia da Tesoura (Figura 1) é o principal deles, tanto pela frequência de uso por pescadores e botos, quanto pela acessibilidade a turistas e, consequentemente, com mais potencial mercantil. Nessa interação, os botos conduzem cardumes de peixe (principalmente tainha, *Mugil liza*) em direção à costa, onde pescadores com tarrafas ficam dispostos em fila em cima de um banco de areia. Os pescadores esperam um comportamento estereotipado dos botos, o qual é interpretado como o momento e local corretos para lançar suas tarrafas (Simões-Lopes et al. 1998). Sabe-se que os pescadores que participam dessa interação conseguem pegar mais e maiores peixes quando botos estão presentes (Simões-Lopes et al. 1998). A interação é um símbolo da cidade de Laguna; sua importância não é exclusiva aos pescadores, mas caracteriza a cultura e movimenta o turismo local — ambos importantes para a identidade e economia da cidade.

Essa comunidade pesqueira de Laguna é autorregulada por uma gama de regras informais que prospera há anos (Peterson et al. 2008), promovendo o compartilhamento de recursos e minimizando efeitos e conflitos que podem ser causados por 'estranhos' à comunidade. Estes 'estranhos', pescadores ocasionais, muitas vezes não possuem um conhecimento das instituições locais e muito menos de como interpretar o comportamento do boto, podendo ameaçar o cumprimento das regras implementadas pela comunidade e o funcionamento do

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[1] Existe um debate taxonômico se esta é uma espécie (e.g., Wickert et al. 2016) ou subespécie (e.g., Wang et al. 2020).

sistema boto-pescador como um todo (Peterson et al. 2008). Apesar da importância da interpretação do comportamento e identidade dos botos durante a pesca, não há consenso, mesmo entre os pescadores frequentes, quanto a estes pontos; por exemplo, existe um grau de incerteza entre pescadores quando tentam identificar os botos pela forma de suas nadadeiras dorsais (da Rosa et al 2020). Os pescadores dessa comunidade têm diferentes percepções de como funciona e quais os benefícios atrelados ao sistema boto-pescador. O benefício mais claro, o financeiro, é percebido e almejado pelos pescadores dessa comunidade, porém outros benefícios como lazer, bem-estar, valores intrínsecos e relações sociais também fazem parte do que esse sistema representa para esses pescadores (Machado et al. 2019). Essas diferentes percepções entre os pescadores é reflexo das suas diferentes histórias de vida, experiência na pesca com o boto e o ambiente social em que vivem (Machado et al. 2019). Em relação a atividade pesqueira, além da experiência, os pescadores variam na frequência e na dependência econômica da interação, sendo possível observar tanto pescadores profissionais como amadores (Peterson et al. 2008, Catão & Barbosa 2018, Machado et al. 2019, da Rosa et al. 2020). Esta pescaria exige dos pescadores uma rica compreensão empírica das condições ambientais locais (e.g., vento e maré; Silvano et al. 2006; Herbst & Hanazaki 2014;) e um conhecimento refinado do repertório comportamental dos botos (Peterson et al. 2008, da Rosa et al. 2020).

Objetivos

Esta dissertação se baseia na coleta de dados durante dois anos subsequentes e com marcantes diferenças na disponibilidade de recurso local, a tainha. Como a comunidade pesqueira de Laguna é diversa em vários aspectos pessoais, como experiência, reputação dentro da comunidade, relacionamentos sociais, dependência financeira e, em última análise, o conhecimento dos pescadores sobre sistema de pesca boto-pescador, mostra-se um excelente sistema de estudo para investigar variações em fina escala como diferenças comportamentais e as relações sociais dos pescadores que pescam com auxílio dos botos. Unindo essa variedade de fatores que podem influenciar nos comportamentos dos pescadores e, consequentemente, no seu sucesso de captura, com a notável diferença na disponibilidade de tainhas entre anos e as diferentes escolhas pessoais com quem se relacionar dentro da comunidade pesqueira, essa dissertação possui dois principais objetivos: (i) quantificar a variação no desempenho de pescadores artesanais de Laguna que pescam com auxílio do boto-da-tainha e avaliar a contribuição de variações comportamentais no seu sucesso da captura, controlando para variáveis ambientais relacionadas à disponibilidade de recurso; e (ii) investigar as relações sociais desses pescadores para avaliar se existe uma preferência em se associar a pescadores com maior reputação dentro da comunidade pesqueira.

Mais especificamente, testei no primeiro capítulo se a posição (i.e., a partir das medidas da distância da tarrafa ao boto e ao pescador), o tempo de reação dos pescadores em relação ao comportamento de forrageio dos botos e a capacidade dos pescadores de lançar as tarrafas de maneira adequada (i.e., a área da tarrafa e o ângulo da tarrafa em relação ao boto) são as principais fontes de variação para seu sucesso na pesca, ou se variáveis ambientais (i.e., temperatura da água, velocidade e direção do vento, e condição da maré) são mais importantes para o sucesso dos pescadores. No segundo capítulo, investiguei como a reputação individual dentro da comunidade pesqueira se relaciona com a centralidade na rede social dos pescadores de Laguna. Além disso, investiguei se os pescadores seguem o princípio da homofilia — a tendência de indivíduos se associarem com seus semelhantes (Mcpherson & Smith-Lovin 2001) — testando se pescadores com reputação mais alta se associam com mais frequência entre si, em diferentes contextos comportamentais, quando pescando com botos ou esperando na praia.

Aspectos metodológicos

A coleta de dados para os dois objetivos foi realizada no principal sítio de interação boto-pescador, a praia da Tesoura (ver Peterson et al. 2008). Essa praia é localizada no Complexo Lagunar Santo Antônio dos Anjos, Imaruí e Mirim (300 Km²; Daura-Jorge et al. 2012) adjacente à cidade de Laguna, SC, no sul do Brasil (28°20'S e 48°50'O) (Figura 1A). Os dados foram coletados durante 18 dias do ano de 2018 (capítulo 1) e 26 dias no ano de 2019 (capítulos 1 e 2) e o esforço amostral foi concentrado na época da tainha (entre os meses de maio e junho), período em que a interação boto-pescador é mais expressada (Simões-Lopes et al. 1998). A coleta de dados se dividiu em 3 principais frentes. A primeira frente consistiu na coleta de variáveis ambientais *in situ.* Foram coletadas variáveis chave, relacionadas com a disponibilidade regional (Vieira & Scalabrin 1991; Herbst & Hanazaki 2014, Lemos et al. 2014) e local (Machado et al. 2021) da tainha, principal espécie alvo de ambos os agentes da interação boto-pescador. A segunda frente foi a coleta de dados referente as variações comportamentais dos pescadores, que *a posteriori* foram utilizadas para descrever a performance destes. Essa coleta se deu a partir de filmagens áreas por um drone, que posteriormente foram processadas num software de vídeo de onde foram retiradas as variáveis comportamentais. Por último usei pulseiras esportivas (apenas durante o ano de 2019) para rastrear a posição geográfica de cada pescador ao longo do tempo, onde múltiplas pulseiras eram colocadas ao mesmo tempo, o que nos permite observar e inferir pela proximidade geográfica associações entre pescadores. Além disso, utilizei dados de entrevistas semiestruturadas oriundas de projetos paralelos que ocorreram no mesmo período, de onde retirei os dados de reputação utilizados no capítulo 2 (ver Santos-Silva 2021). Todas as frentes de coleta foram realizadas simultaneamente entre as 9:00 às 17:00. Detalhes da coleta, processamento e análises subsequentes são apresentados nos capítulos que seguem.

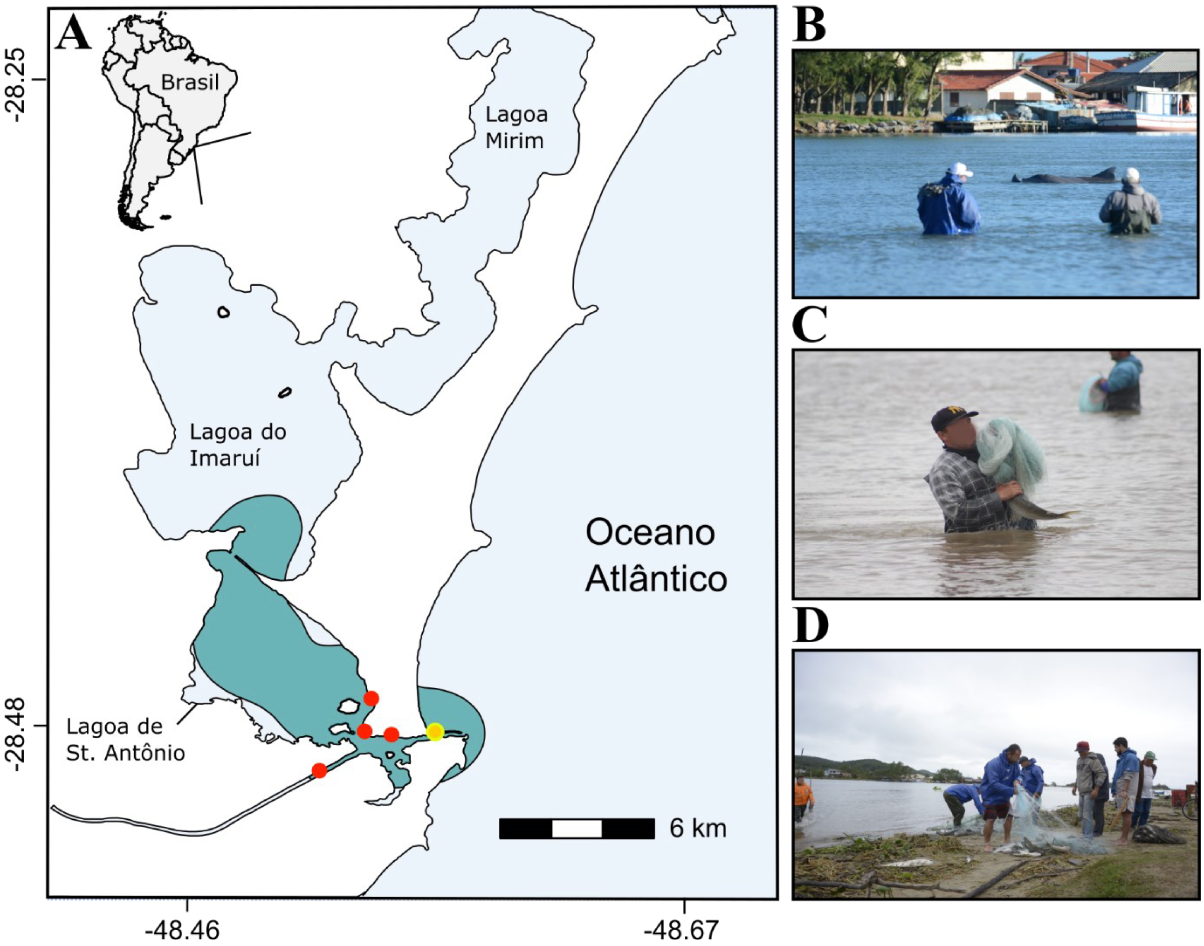

Figura 1. Área de estudo. (A) Complexo lagunar de Santo Antônio dos Anjos, Imaruí e Mirim, adjacente a cidade de Laguna, sul do Brasil. Círculo amarelo indica a localização da praia da Tesoura, principal sítio de interação boto-pescador. Círculos vermelhos indicam 4 outros sítios onde a interação de forrageio entre boto e pescador também ocorre. Área em verde representa a área de vida dos botos. (B) Pescadores na linha de pesca esperando o comportamento estereotipado dos botos. (C) Pescador saindo da linha de pesca com uma tainha em sua tarrafa, proveniente da interação com o boto. (D) Pescadores na areia da praia,

descarregando suas tarrafas após pescar com auxílio dos botos. Todas as fotos foram tiradas na praia da Tesoura (círculo amarelo em A).

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THE ROLE OF BEHAVIOURAL VARIATION IN THE SUCCESS OF ARTISANAL FISHERS WHO INTERACT WITH DOLPHINS

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ABSTRACT

Understanding the dynamics of small-scale fisheries requires considering the diversity of behaviours and skills of fishers. Fishers may have different abilities and tactics that can translate into different fishing outcomes. Here we investigate how variation in fishing behaviours among net-casting fishers can interact with environmental conditions and influence their fishing success during a traditional fishery assisted by wild dolphins. By combining *in situ* environmental sampling with fine-scale behavioural sampling from overhead videos, we found a higher probability of catching fish among fishers well-positioned in the water and that cast their nets wide-open and closer to dolphins. These differences in net-casting performance affect their chance of catching any fish over and above environmental conditions related to fish availability. This finding suggests that fishers' success may not be simply an outcome of variations in resource availability, but also result from subtle variations in fishing behaviours. We discuss how such behavioural variations can represent skills acquired over the years, and how such skills can be crucial for fishers to benefit and keep interacting with dolphins. Our study demonstrates the role of behavioural variation in the dynamics of a century-old fishery and highlights the need to consider fishers' behaviours in co-management of small-scale fisheries.

Key words: artisanal fisheries, fisher behaviour, foraging, fisheries management

INTRODUCTION

Artisanal fishing is a challenging activity for individuals foraging for limited, uncertain resources. In the marine environment, where resource distribution is mostly unpredictable in space and time, artisanal fishers continuously seek to increase their chances of catching fish. With an appropriate understanding of the environment in which a fishery takes place, fishers can predict where and when to find the target resource, optimizing fishing efforts by increasing catch and reducing costs and risks (Hilborn & Walters 2013, Salas & Gartner 2004). At the fishing community level, multiple technological and environmental factors can drive variations in fishing success in terms of increased catching chances and rates (Hilborn 1985, Seijo et al. 1998). However, the success of individual fishers is also affected by their intrinsic and learnt skills, which influence their ability to make good decisions about where and when to fish (Gaertner et al. 1999, Ruttan 2003). Despite growing interest in incorporating fisher behaviour in fisheries management (Salas & Gartner 2004, Branch et al. 2006, Van Oostenbrugge et al. 2008, Fulton et al. 2011, Andrews et al. 2021), the role of variation in skills, fishing behaviour and decision making in the efficiency of small-scale fisheries is rarely quantified.

In small-scale fisheries, individual fishers can optimize their catching rates by adjusting their short-term tactics (e.g. gear, target species) to the current environmental conditions (e.g. Laloë & Samba 1991), by defining long-term strategies (e.g. planning fishing in time and space), and by honing fishing skills with accumulating experience and training (Salas & Charles 2007). Given that these tactics and strategies can translate into different catching rates, quantifying the required behaviours and skills is essential to understand the role of individual variation on the collective dynamics of small-scale artisanal fisheries (Hallwass et al. 2013). The traditional fishery in which artisanal net-casting fishers are assisted by wild bottlenose dolphins in southern Brazil is a conducive system for assessing how variation in the performance of fishing behaviour influences catching rates, thereby modulating the dynamics of a small-scale fishery. This is because fishers vary widely in their understanding of, and experience in, this traditional fishery (Machado et al. 2019a, da Rosa et al. 2020), which takes place at fixed and accessible locations where the behaviour of fishers can be tracked individually.

This century-old fishery requires the artisanal net-casting fishers to have a rich empirical understanding of the local environmental conditions (Herbst & Hanazaki 2014), and refined knowledge of the dolphins' behavioural repertoire (Peterson et al. 2008, da Rosa et al. 2020). These net-casting fishers stand in the shallow and murky waters waiting for dolphins foraging on fish schools (mainly mullet, *Mugil liza*, Mugilidae) to approach the shore and perform a behavioural cue that indicates when and where fishers should cast their nets. Previous studies show that individual fishers vary in their social environment, frequency and economic dependence on fishing with dolphins, which is likely linked with variations in their local ecological knowledge and abilities in interacting with dolphins (Peterson et al. 2008, Catão & Barbosa 2018, Machado et al. 2019a, da Rosa et al. 2020). These factors can affect how fishers perceive the best conditions for fishing and how they perform the required fishing behaviours to succeed in this traditional fishery. There have been many advances in our understanding of the ecology of dolphins (Romeu et al. 2017, Bezamat et al. 2019; Cantor et al. 2018, Machado et al. 2019b) and how fishers interact with them (e.g. Peterson et al. 2008, Catão & Barbosa 2018, Machado et al. 2019a, da Rosa et al. 2020), but very little attention has been given to how behavioural variation can influence the dynamics of this fishery. For instance, while previous studies show that interacting with dolphins is beneficial for fishers—they catch more and larger fish when dolphins are present (Simões-Lopes et al. 1998, Land dos Santos et al. 2018)—the extent to which this success depends on the environmental conditions for fish availability and on the variation in how fishers interact with dolphins remains unknown.

Here, we quantify the fine-scale behaviour of artisanal net-casting fishers who interact with dolphins to evaluate the contributions of behavioural variation on fishing success, controlling for environmental conditions that influences resource availability. By combining behavioural observations with overhead video sampling of individual fishers and *in situ* environmental sampling, we quantified how fishers vary in their fishing performance—in terms of their position and reaction time relative to dolphins, and ability to cast nets properly—during two years with marked differences in environmental conditions that determine availability of mullets. We show that where, when and how fishers cast their nets in response to dolphins affect their fishing success—defined in terms of the chance of catching any fish—over and above the variation in local mullet availability. Our findings suggest that subtle variation in how fishers perform fishing behaviours, which reflects variation in their accumulated skills, can be an important axis of the dynamics of small-scale fisheries systems.

MATERIAL AND METHODS

Study system

We studied the behaviour of the traditional net-casting fishers who interact with wild bottlenose dolphins and are part of the artisanal fishing community of Laguna, southern Brazil (28°20' S, 48°50' W). We focused our sampling effort on the net-casting fishers that use the main interaction site, the Tesoura beach (Peterson et al. 2008), during the mullet season (May–June) when this traditional fishery is more pronounced (Simões-Lopes et al. 1998). During 18 days in 2018 and 26 days in 2019, we recorded the fishing behaviour of fishers during the interaction with dolphins and the environmental conditions related to mullet availability.

This fishing system is self-regulated by informal rules that define a rotation in the use of the spots along the fishers' line when they wait for dolphins: when a fishers catch two or more mullets, he has to leave the spot, which is then taken by the next fisher waiting in line (Peterson et al. 2008). These rules organize the fishery in a way that promotes resource sharing and minimizes the presence of outsiders—even though opportunistic and amateur fishers can use the same fishing sites as the professional fishers (Machado et al. 2019a).

Sampling environmental conditions

We collected *in situ* environmental data to investigate whether the net-casting behaviour of fishers and their chances of catching fish are related to the local conditions that influence the presence of mullets at the interaction site. We focused on key environmental variables—such as temperature, wind, and tide—known to be related to high mullet suitability at both regional and local scales (Machado et al. 2021). For instance, the reproductive migration of mullets towards the waters of southern and south-eastern Brazil is associated with the decrease of seawater temperature (optimal condition ~19-21oC; Lemos et al. 2016) and frequent southern winds (Herbst & Hanazaki 2014; Lemos et al. 2014). Locally, fishers report that northeast wind and flood tide can facilitate mullets' schools to enter the connecting canal where the dolphin-fisher interaction takes places (Herbst & Hanazaki 2014). Based on our empirical observations of the local environmental dynamics, we defined 1 hour as a suitable period for collecting environmental conditions. Every hour, we recorded the speed and direction of the wind using an anemometer (AD-250, precision: ≤ 20 m/s: ± 3% of the full scale > 20 m/s: ± 4% of the full scale), water temperature with a handheld thermometer (Knup KP-8007, precision: 1% or 1°C), and the tide state (visual observations). We later retrieved the hourly measurements of tide height from the nearest operating weather station (28°37'S 49°01'W; Santa Catarina Agricultural Research and Rural Extension Company, EPAGRI).

Sampling fishing behaviour of fishers

To describe the net-casting behaviour and success of fishers, we used all-occurrence sampling (Altmann 1974), between 9:00 and 17:00 of each sampling day, combining direct observations with overhead videos. Our sampling unit was each net cast by each individual fisher during an interaction event with dolphins. We defined an independent dolphin-fisher interaction event as when one or more foraging dolphins approached the coast and made a stereotypical behavioural cue (either a sudden deeper dive, a head slap, or a tail slap) to which one or several fishers react by casting their individual nets (see Simões-Lopes et al. 1998). During our direct observations, we quantified, for each interaction event, the number of dolphins, the number of fishers in the water, the total nets cast, and whether fishers were successful in catching any fish or not. For each successful net-casting, we counted the number of fish caught in each net. Whenever the weather permitted, we also recorded dolphin-fisher interactions from unmanned aerial vehicles to quantify the fishers' behaviour (see below). To restrict our sample to dolphin-fisher interaction events, we disregarded all nets cast when there were no dolphins at the interaction site, or when the present dolphins were foraging by themselves. The same individual fishers were recorded in both sampling years, as the number and composition of fishers in the interaction site only fluctuate with the presence of occasional visitors.

Quantifying fishers' net-casting performance and fishing success

We used unmanned aerial vehicles (drones) to record and quantify how the net-casting behaviour of fishers when interacting with dolphins can influence their chance of catching any fish. We recorded overhead videos using DJI Phantom 3 and Mavic Pro drones hovering at least

60 meters above the water (high enough to cover the entire interaction area and to minimize disturbance to the dolphins; see Christiansen et al. 2016) and 25 meters from the edge of the canal (a safe horizontal distance from the fishers). We initiated the drone recordings whenever there were one or more dolphins at the interaction site, only in good weather conditions for flying (no rain, wind speed $\lessapprox$ 15 m/s), observing all safety flight guidelines (e.g. Fiori et al. 2017). We kept the drone stationary when recording videos, with the high-resolution camera mounted on a gimbal and pointing straight down to provide direct overhead footage. Each flight session lasted a maximum of 20 minutes (the duration of the drone battery).

We recorded a total of 118h of drone videos, from which we analysed 243 interaction events. Using our all-occurrence observation data, we identified the moment of the dolphin's cue and used it to crop three minutes of videos around each dolphin-fisher interaction. We manually processed each of the resulting six-minute drone video clips in the software ImageJ (Rasband 2012). We set a visible scale (a straight object of known size) in each video frame to convert all the measures taken from the videos from pixels to metric units. We measured the following six variables to describe how fishers cast their nets (Figure 1): (a) the area of the net at the moment it hits the water; the (b) distance and (c) angle of the centroid of the net to the place where the dolphin performed the cue; the (d) casting distance as the distance from each fisher to the centroid of the net they cast; (e) the distances between the centroid of the first net cast to all nets cast subsequently in the same interaction event; and the (f) fishers' reaction time to the dolphin cue. We assumed that these net-casting variables are good representations of fishing skills, as they can be influenced by the fishers' experience and practice over time. Fishers who are well-trained in net handling tend to use larger and heavier nets and are capable of casting them wide-open and at long distances; fishers with a good understanding of dolphins' behaviour tend to be quicker in their net-casting reactions, and cast at an adequate distance and angle to the dolphin position; and experienced fishers who comprehend the behaviour of other fishers tend to cast nets closer to the first fisher who reacted to the dolphin.

From the drone footage, we also recorded the success of each net-casting, defined as the catch of any fish. After a successful cast, when a fisher catches any fish, fishers leave the water immediately, trailing the net behind them, to remove the fish from the net and store it. Thus, after each cast by each fisher, we carefully investigated their nets and displacement in the videos to record whether their casts were successful or not in catching any fish, cross-referencing with our all-occurrence observations.

Data analyses

After following traditional data exploration protocols (Zuur et al. 2010), we built generalized linear mixed models (GLMMs) with a binomial error structure and logit link function (Bolker et al. 2009, Zuur et al. 2009) to test if and how fishing behaviour (net-casting variables) and fishing conditions (environmental variables) influenced fishing success (whether fishers caught any fish or not in a given interaction event). We opted for a binomial response variable (fish caught vs. no fish caught) to avoid any imprecision when linking the cast variables measured in the video clips with the number of fish caught by each individual fisher across both years. As predictors, we fit the six variables that describe how fishers cast their nets (Figure 1) at the level of each fisher in each interaction event; and the environmental variables at the level of each interaction event. We included day as a random effect to account for an unexplained variance from large-scale factors (e.g., recent rainfall, which reduces mullet availability, wind variations, which can affect the casting, and day-to-day variation in mullet migration) or from changes in the number of fishers between days. We included the year as a covariate since the catch rates of mullet fish at the interaction site were, for reasons not understood so far, clearly higher in 2018 than in 2019 (see Results). Our initial model with all explanatory variables, before the selection procedures, can be represented by:

$$\begin{aligned}
\text{Fishing success}_i &\sim \text{Binomial}(n = 1, \text{prob}_{\text{fishing success}=1} = \hat{P}) \\
\log\left[\frac{\hat{P}}{1-\hat{P}}\right] &= \alpha_{j[i]} + \beta_1(\text{wind direction}_\text{S}) + \beta_2(\text{wind speed}) + \beta_3(\text{water temperature}) + \\
&\quad \beta_4(\text{tide height}) + \beta_5(\text{tide direction}_\text{flood}) + \beta_6(\text{reaction time}) + \beta_7(\text{net area}) + \\
&\quad \beta_8(\text{net angle}) + \beta_9(\text{net distance to the dolphin}) + \beta_{10}(\text{casting distance}) + \beta_{11}(\text{distance between nets}) \\
\alpha_j &\sim N\left(\gamma_0^\alpha + \gamma_1^\alpha(\text{year}_{2019}), \sigma_{\alpha_j}^2\right), \text{ for day j = 1, ... ,J}
\end{aligned}$$

We then selected variables using stepwise backward elimination. We only considered additive and isolated relationships between response (fish caught vs. no fish caught) and explanatory variables (all net-casting and environmental variables), not including interaction terms to avoid overparameterization. We used Akaike's information criterion corrected for small samples (AICc) and AICc weight to rank and identify the most parsimonious candidate model (using R package 'MuMIn'; Barton 2019), the one with the lowest AICc and highest weight. We validated and checked model assumptions by following the DHARMa protocol (Hartig 2018), simulating 1,000 datasets from the fitted model to test if the distribution of the scaled residuals deviates from the expected distribution. Finally, we calculated the part R^2 for the fixed effects to estimate the variance explained by each explanatory variable of the most parsimonious model and quantified its uncertainty using parametric bootstrapping. We carried out all the analyses in the R environment (R Core Team, 2020). We used the R package 'glmmTMB' (Magnusson et al. 2017) to fit the models, and 'lme4' (Bates et al. 2014) and partR2 (Stoffel et al. 2021) to quantify the part R^2.

RESULTS

We observed a total of 1,285 fishing interaction events, 243 recorded in the drone videos, characterized by a solitary or a small group of dolphins (median=1.0, mean=1.33 ± 0.66 SD, range=1–5) foraging with net-casting fishers (median=14.00, mean=15.29 ± 7.63, range=1–38) during two mullet seasons (2018: 128.5h and 2019: 138.8h of direct observation). During these interaction events, we observed a total of 4,771 net casts (median=3.00, mean=3.78 ± 3.01, range = 1–20) with which the fishers captured a total of 4,205 mullets. Mullet catches were remarkably higher in the 2018 season: 80% of the mullets were captured in 2018 and, on average, each interaction event resulted in >5 times more fish (mullet caught per interaction event=6.32 ± 23.60 SD, n=593 events) than the events of the 2019 season (1.21 ± 5.35 SD, n = 692 events).

Out of the 243 interaction events recorded in the drone videos, we unmistakably identified fishers' mullet catch attempts (successful and unsuccessful) in 119 events with a total of 654 individual net casts (234 from 2018 and 420 from 2019). The net-casting variables varied across casts, and some varied between successful and unsuccessful casts (Figure 1). The net area varied considerably across casts (median=36.73 m2, mean=39.98 m2±16.24 SD, range=12.70–96.89 m2), and the unsuccessful casts tended to be more skewed toward lower values than the successful casts (Figure 1a). The angle between the net and the dolphin heading also varied considerably across casts (median=49.95°, mean=60.37° ± 45.72 SD, range=2.43–179.67°), with greater variation in successful casts (Figure 1b). The distances from the centroid of the net to the dolphin (median=14.95 m, mean=16.53 m ± 7.72 SD, range=2.43–61.43 m) and to the fisher (median=7.20 m, mean=7.37 m ± 1.96 SD, range=2.93–15.0 m) were similar in both unsuccessful and successful casts (Figure 1c; d). The distances between the first net cast and the subsequent casts in the same interaction event were typically small (median=7.48 m, mean=9.22 m ± 9.04 SD, range=0–57.05 m; Figure 1e), suggesting that multiple fishers nearby tend to react collectively to the dolphins' behavioural cues. Indeed, the fisher reaction time typically ranged between 0 and 10 seconds (median=6.00 s, mean= 6.81 s ± 3.58 SD, range=3–38.00 s; Figure 1f).

Out of the 654 net casts recorded in the video, we had all the environmental variables available for 395 casts (226 from 2018, 169 from 2019). From these 395 casts, 296 were cast with the wind blowing to the north and 99 to the south; 292 casts during the flood tide and 103 during the ebb tide. The tide height varied considerably across cast events (median=115.00 cm, mean= 112.80 cm ± 16.01 SD, range= 79.00–137.83 cm) while water temperature (median=20.15 °C, mean= 20.24 ºC ± 1.00 SD, range= 17.00–22.00 cm) and wind speed (median=6 m/s, mean= 7.74 m/s ± 4.88 SD, range= 0–16.00 m/s) were less variable.

We fitted our linear models by using the 395 net casts with all predicted variables (net-casting and environmental variables) and found that the most parsimonious model (lowest AIC) predicted the probability of catching any fish to be a function of the area of the cast net, the casting distance, and the distance between the net and the dolphin (Table 1; Table S1). This selected model did not include any environmental variables, suggesting that environmental conditions do not affect the fishers' probability of catching fish in a single cast, while how the fishers cast their nets does. Fixed effects represented 20.3% of the variance (theoretical marginal R2) and 25.9% when combined with random effects (theoretical conditional R2). Residuals of this model were visually adequate (Figure S1). The net distance to the dolphin cue (β=-0.11, Std. Error=0.02, z=-3.93, P<0.001; Figure 2a) and the casting distance (β=-0.20, Std. Error=0.09, z=-2.09, P=0.037, Figure 2c) were both negatively correlated to the probability of catching any fish, while the net area (β=0.03, Std. Error=0.01, z=3.00, P=0.003, Figure 2b) was positively correlated. The net distance to the dolphin cue explained most of the variation in the probability of catching any fish (semi-partial R^2=0.088, 95%CI=0.027–0.215, Figure S2), followed by net area (semi-partial R^2=0.026, 95%CI=0–0.157, Figure S2) and casting distance to the fisher (semi-partial R^2=0.021, 95%CI=0–0.153, Figure S2).

Table 1. Most parsimonious generalized linear mixed model describing the fishing outcomes (whether fishers caught fish or not) as a function of three variables of fishers' performance. We present the odds ratios, standard errors, standardized beta-coefficients, Z statistic and p values for each variable.

		Selected model: Fishing outcome ~ net distance from dolphin + net area + net casting distance + (1|day)				
Predictors		*Odds Ratios*	*std. Error*	*std. Beta*	*Z value*	*P value*
(Intercept)		1.50	1.18	0.19	0.51	0.609
Net distance to the dolphin (distance between the centroid of the cast net and where the dolphin cued)		0.90	0.02	0.44	3.93	**<0.001**
Net area (area of the cast net when it hit the water)		1.03	0.01	1.59	3.00	**0.003**
Casting distance (distance between the centroid of the net and the fisher who cast it)		0.82	0.09	0.68	2.09	**0.037**
N_{day}	22					
Observations	395 net casts					
Theoretical Marginal R^2 / Conditional R^2	0.203 / 0.259					
Delta Marginal R^2 / Conditional R^2	0.121 / 0.155					

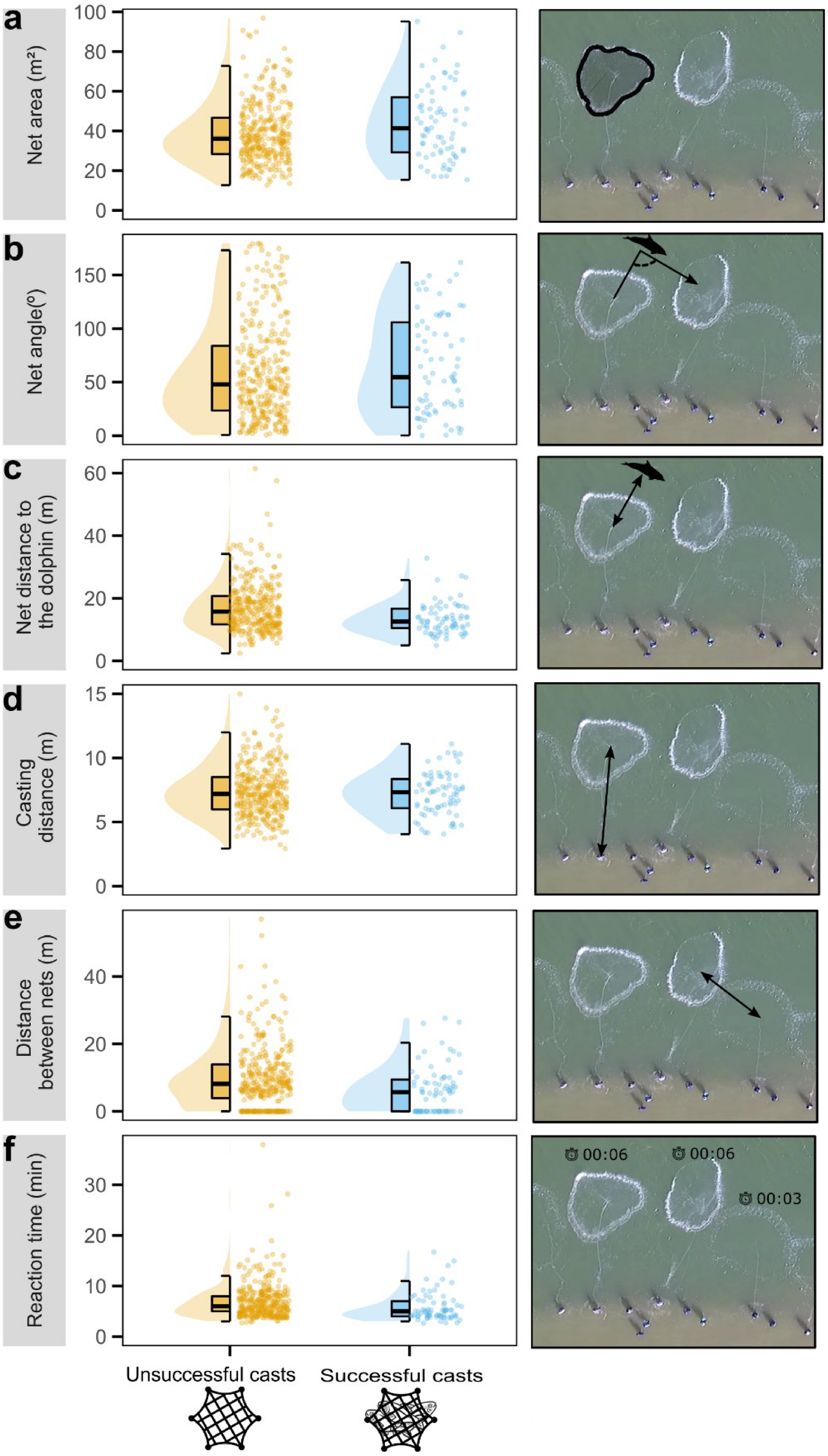

Figure 1. Distribution of the net-casting descriptors of foraging performance of artisanal fishers who forage with wild dolphins. (a) Net area: area (m^2) of the cast net when it hit the water. (b) Net angle: angle (º) between the centroid of the cast net and the dolphin heading when cueing. (c) Net distance to the dolphin: distance (m) between the centroid of the

cast net and where the dolphin cued. (d) Casting distance: distance (m) between the centroid of the net and the fisher who cast it. (e) Distance between nets: distance (m) from the first net cast to each of the subsequent nets. (f) Reaction time: time (min) taken for the fisher to react and cast net in response to the dolphin cue. Orange graphics represent the unsuccessful casts (no fish caught); blue graphics represent the successful casts (one or more mullet caught). The second panel illustrates each net-casting descriptor with annotated drone images.

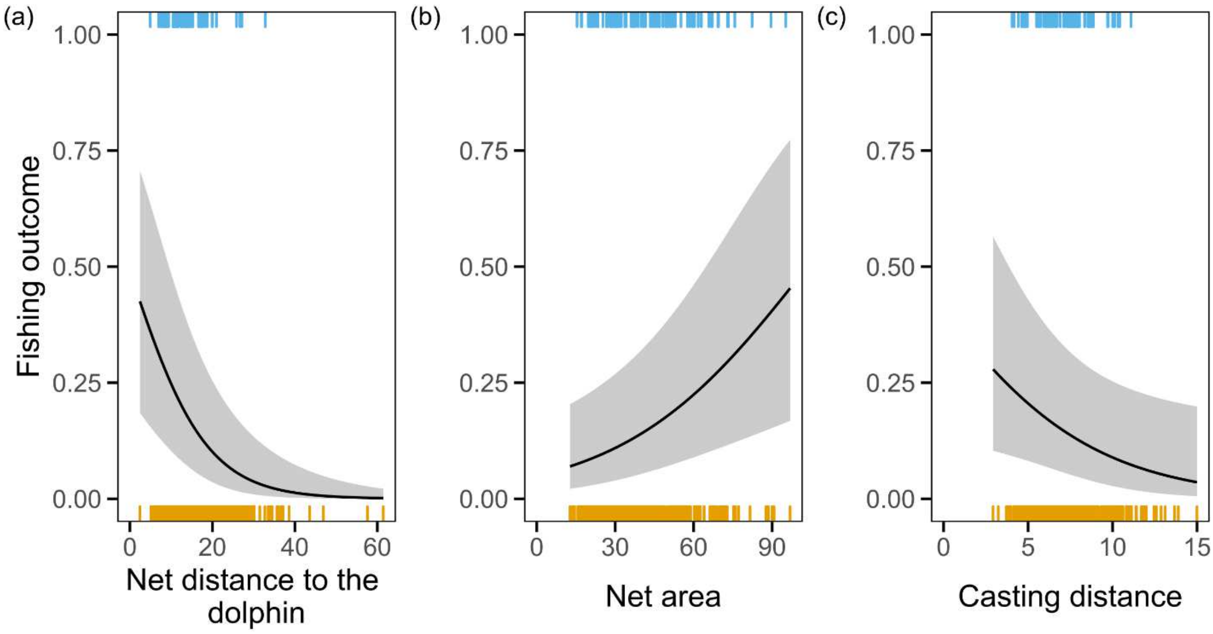

Figure 2. Artisanal fishers' net casting performance and fishing outcome. (a) The net distance to the dolphin (between the centroid of the net and where the dolphin cued), and (c) the casting distance (between the centroid of the net and the fisher who cast it) were both negatively related to the fishers' catch probability. The closer the net was to the fisher and the dolphin, the higher the chance that fishers caught fish. (b) The area of the net showed a positive relationship: larger nets tended to have a higher catch probability. The lines are the predicted values of net catch probability, with 95% confidence intervals calculated from the coefficients of the most parsimonious fitted model. Blue rugs indicate successful casts and orange rugs indicate unsuccessful casts.

DISCUSSION

We found that variation in how artisanal fishers cast nets when fishing with dolphins modulates their chance of catching fish, regardless fishing conditions. The fishers' success in terms of catching any fish is more directly related to their ability to execute fishing behaviours than it is to the environmental conditions that influence the local abundance of fish. These abilities could reflect a role of individual fishing experience and knowledge of this traditional fishery related to the behaviour of dolphins, mullets and other fishers. In what follows, we discuss how such differences in how fishers perform the fishing behaviour is influenced by their accumulated skills and can be important for the long-term persistence of this rare human-dolphin fishery and should, therefore, be considered in the management of small-scale artisanal fisheries.

Among the behavioural and environmental factors, we found that three out of the six measures of net-casting performance affected the chances of catching any fish when interacting with dolphins. Fishers who are better positioned in the water and cast nets closer to the dolphins significantly increase their probability of catching mullets. The latter finding aligns with the evidence that fishers benefit from interacting with dolphins (Simões-Lopes et al. 1998), presumably because approaching dolphins aggregate mullet schools close to shore (Simões-Lopes et al. 2016). We posit that understanding where one should be along the fisher line, the experience of anticipating the dolphin behaviour and position are important skills for a fisher to succeed in this fishery. The area of the net and the casting distance also play—yet a minor—role in the fishing success. Fishers who cast larger or more widely open nets and not too far away tend to have higher chances of catching fish. The skills required to cast a larger (and heavier) net in the right place, cast a net wide open, and choose the right position in the fishers' line likely also stem from practice and experience. Finally, given that large-scale variation in environmental conditions can influence the regional availability of mullets (Machado et al. 2021) and fine-scale environmental conditions can affect the behaviour of fish schools (Portner & Peck, 2010), we expected the environmental variables to influence the fishers' success. However, our data indicate that the influence of environmental conditions on the fishers' catch is minor, thereby strongly supporting the notion that fine-scale variations in how fishers perform the fishing behaviour can be a key source of variation for the chance of success of catching fish, at least in this traditional fishery with dolphins.

The importance of how individuals perform the fishing behaviours and the link of this performance with specific fishing skills is further illustrated by other fisheries, where such variation in behaviour and skills also determine the catch success of individual fishers when fishing (see Fulton et al. 2011, Andrews et al. 2021). For instance, in Yucatán, Mexico, catches of small-scale fisheries vary among and within communities, some fishers are more efficient than others—a subset of them do not tend to maximize their catch—and different factors, such as fishers' experience, skills, gears and boats size seem to play a role in the fishing behaviours and success (Salas & Charles 2007). In Lamu County, Kenya, younger and more educated fishers use the more modern gear acquired from traders and catch more fish than older and less educated fishers who rely on traditional equipment (Mwamuye et al. 2013). Variation among fishers can also stem from more nuanced factors, such as different fishing goals (e.g. for recreation, food, or income), the fishers' social and economic contexts (Salas & Gartner 2004; Machado et al. 2019a), specialization in a target species (e.g. Smith & McKelvey 1986, Miller 1995), heterogeneity in deciding when and where to fish (e.g., Frawley et al. 2021), and cooperative work among fishers (e.g. Salas 2000, Hilborn et al. 2001). Our findings showing that variations in fishers' casting performance—likely a product of skills honed with practice over time—affect catching probabilities reinforce that individual variation can be a key determinant of the fishing success and should be considered more often in fisheries science.

Fisheries management initiatives tend to overlook fishers' behaviour, abilities and decision-making processes. Our findings add to the increasing evidence that such factors are also important in the dynamics of fishing activities, especially in small-scale fisheries (Salas & Gartner, 2004). Our findings on fine-scale variation in fishers' behaviour modulating their chances of catching fish could be transferrable to other small-scale fisheries in which fishers adjust gear, effort, timing and movement to increase fishing success (see Marchal 2007). However, behaviour variation is often neglected in management, as fisheries science typically relies on aggregated data, which masks individual differences in behaviour, skills and performance (Bockstael & Opaluch 1983). Overlooking such differences can bias the definition of production functions and stock assessment (Ruttan & Tyedmers 2007), which can be particularly skewed in small-scale artisanal fisheries. For instance, to define fisheries management actions, it is particularly important to identify factors that potentially can modify fishers' tactics and strategies to then calibrate nominal effort measures and catch profiles when calculating the catch-per-unit effort (CPUE), improving empirical modelling of fisheries systems. Otherwise, changes in catches probabilities will be interpreted only as changes in the abundance of fishing resources (Hilborn & Ledbetter 1985; Gaertner et al. 1998), disregarding that changes in catch probability also stem from the influence of heterogeneity among fishers' skills and knowledge.

Evaluating fishers' behaviour and their long-term strategies to pursue their livelihoods can also aid the assessment of changes in the ecosystem and the effectiveness of management actions (Daw et al. 2012). Individual fishers can accumulate local ecological knowledge, develop novel strategies and modulate their behaviours in face of changes to guarantee their income. Such knowledge, strategies and behaviours can be a critical component to improve not only management of target stocks but rebuild marine environmental conditions in ecosystem-based approaches, such as delineating and managing marine protected areas (Johannes et al. 2008). For instance, fishers from Mamirauá in the Amazon basin detain deep knowledge and a valuable skill set in identifying subtle cues from surfacing fishes, which can be used to reliably count fishes—a crucial piece of information to guide the decision-making of fisheries managers (Castello et al. 2009). Moreover, identifying fishers' behaviours that optimize fishing success can help to understand the nature of the relationships among local fishers, and between fishers and other agents in the local community, and how these relationships, collectively, can influence stock depletion (Andrews et al. 2021, Branch et al. 2006, Kiyama &Yamazaki 2018). Understanding how the human component of a fishery system operates can devise management rules that reduce fishing effort without affecting fishing yield (Keppeler et al. 2020) and resource users (Salas & Gaertner 2004), facilitating co-management strategies and integrative governance policies (Salas & Gaertner 2004).

Our study reinforces the importance of fine-scale human behaviour variation in small-scale fisheries, but there are two important caveats. First, we were unable to capture the behavioural variations among specific individual fishers, as we could not precisely link each cast event measured from the overheard videos to each individual fisher observed at the beach. Therefore, we were also unable to consider the precise biomass caught by each fisher and instead adopted a coarser proxy of fishing success (nets with or without fish). Second, as we did not identify fishers, we could not link the observed behavioural variations to individual traits related to, for example, acquired skills and experiences— a challenge that remains for future studies. Third, and most importantly, our current analyses do not consider the multileveled (e.g., individuals and communities) and multiscaled (e.g., ecosystem-based approaches to fisheries management) implications of fishers' behaviour, which is an increasing concern in fisheries science (Andrews et al. 2021).

Concluding remarks

Our study sheds further light on the role of fishers' behavioural variation in fisheries dynamics, which is important for monitoring traditional small-scale fisheries, and can be useful for local management. Locally, we posit that the magnitude of variation in fishers' behaviour can influence the persistence of this human-dolphins system in the face of environmental changes, as we found that differences in net-casting performance affect the success of artisanal fishers over and above the local environmental conditions. Through different learning routes, practicing levels, and degrees of accumulated empirical knowledge about the system over time, fishers can vary widely in their behaviour and adaptability to fluctuations in environmental conditions and prey availability. This variation should be accounted for in management actions targeting the conservation of traditional knowledge related to increasing the yield of the fishery, discouraging the emergence of new behaviours that may disproportionally increase the fishing effort that can change the informal rules that self-regulate this fishery. For example, in recent years, some fishers who interacted with dolphins have innovated by using a platform that allowed them to be above water, at a height that significantly facilitated casting nets as well as detecting fish schools. As the chances of catching fish greatly increased, this new behaviour generated conflicts among fishers and disrupted their informal rules (see Peterson et al. 2008). In response, the local management agent worked in agreement with fishers to ban this behavioral innovation. Such action was key to reduce conflicts, maintaining the local dynamic and rules, and serves as a good example of how monitoring changes and innovations of fishers' behaviours, in a co-management perspective. Incorporating the fishers' participation in management decisions is particularly relevant for the persistence of century-old traditional fisheries, such as the one studied here, which has long-term benefits for both the fishing community (Machado et al. 2019a) and the dolphin population with which they interact (Bezamat et al. 2019, 2020).

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SOCIAL PREFERENCES AND PEER REPUTATION AMONG ARTISANAL FISHERS WHO FISH WITH DOLPHINS

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ABSTRACT

Social relationships among fishers can promote sharing ecological and technical knowledge about a fishery, thereby influencing individual fishing success. Despite growing interest, the influence of social behaviour on the outcomes of artisanal fishing communities remains understudied. Here, we evaluate whether peer reputation plays a role in shaping the social interactions among artisanal net-casting fishers who fish with the assistance of wild Lahille's bottlenose dolphins. We quantified individual fishers' social interactions with GPS tracking devices and used semi-structured interviews to quantify their local reputation as perceived by their peers. We found a positive relationship between reputation and position in their social network, suggesting that individuals perceived as more successful in this traditional fishery are available to associate with other fishers. We further found that the peer reputation does not play a role in whom fishers choose to associate with at the fishing site. Fishers are not assorted by reputation, neither while active fishing nor during resting time, suggesting that part of this community is a cohesive group and that the ecological and technical knowledge about this century-old fishery can flow across fishers of different skill levels. Our findings support the growing evidence that sociality among fishers affects fishing dynamics and can be beneficial for both individuals and their community.

Key words: artisanal fisheries, fisher behaviour, information exchange, social network analysis

INTRODUCTION

Artisanal fishers face numerous challenges to improve their success in catching fish. One way to overcome these challenges is by engaging in social relationships with more experienced fishers from whom they can learn how, when and where to fish (Gezelius 2007). Such knowledge exchange is an important asset among fishers, takes place during social interactions, and can be facilitated by maintaining strong social relationships (Crona & Bodin 2006). The information about a fishery acquired socially can increase fishers' chance of success by reducing uncertainties related to resource distribution in space and time (Gatewood 1984, Hilborn & Walters 2013, Salas & Gartner 2004). Despite their important role to fishery dynamics, social interactions (Bebbington 1999) and information exchange among artisanal fishers (Grant & Berkes 2007) remain understudied in small-scale fisheries.

Social relationships among fishers can be shaped by many factors, including individual personality traits and trait similarity with others; but in the fishing context, such relationships may be primarily motivated by the access to information about the target resource that can increase fishing efficiency (e.g., reducing search time) (Forman 1967, Andersen 1972, Stiles 1972, Gatewood 1984, Rudd 2003, Lyle & Smith 2014, von Rueden 2020). In general, fishers who constantly seek learning opportunities for personal improvement aim to connect socially with fishers perceived as more experienced (Henrich & Broesch 2011). Experienced fishers tend to perform better and can be repositories of reliable information about the fishing system (Henrich & Broesch 2011); thus they generally have a high reputation within their communities. However, how individual reputation defines social preferences—ultimately shaping information sharing—remains unclear in artisanal fisheries. If inexperienced fishers seek to connect with such high-reputation fishers (Henrich & Gil-White 2001, von Rueden 2020) then the latter could have more social connections within the community (Crona & Bodin 2006, Carlsson & Sandström 2008). While in a cooperative community high-reputation fishers may be prone to share information with any interested fisher, in a competitive environment, however, high-reputation fishers may withhold information or prefer to share it with other knowledgeable high-reputation fishers who can provide good information in return.

The century-old southern Brazilian fishery where net-casting fishers are assisted by wild Lahille's bottlenose dolphins (*Tursiops truncatus gephyreus*) is a good model for assessing the potential links between social preferences and peer reputation among the fishing community. Individual fishers vary in frequency, experience and economic dependence on this traditional fishery (Peterson et al. 2008, Catão & Barbosa 2018, Machado et al. 2019, da Rosa et al. 2020), and organize themselves in distinct cooperative groups (Peterson et al. 2008, Santos-Silva 2021). Consequently, fishers have a diverse perception of how the dolphin-fisher system works, reflecting their different historical engagement in this interaction and social environment (Catão & Barbosa, 2018, da Rosa et al., 2020). These net-casting fishers stand in the shallow, murky water waiting for a cue from the dolphins foraging on fish schools (mainly mullet, *Mugil liza*, Mugilidae), which they interpret as the ideal time and place to cast their nets (Simões-Lopes et al. 1998, Peterson et al. 2008). To succeed, therefore, net-casting fishers need a refined knowledge about the dolphins' identity and behavioural repertoire (Peterson et al. 2008, da Rosa et al. 2020), as well as a rich empirical understanding of the local environmental conditions (Herbst & Hanazaki 2014).

Here, we investigate whether peer reputation within the fishing community—a surrogate for how skilled and knowledgeable fishers are—influences the social interactions among these artisanal net-casting fishers when fishing with dolphins. We first evaluate how the individual reputation relates to the fisher centrality in the social interaction network. We hypothesize that the higher the reputation, the higher the social centrality, suggesting that fishers who possess high-quality information about the system tend to be sought after by other individuals. Then, we investigate if fishers assort by their reputation, that is, whether high-reputation fishers associate more often among themselves, suggesting that individuals might compete by information sharing them only with those who possess high-quality information to share. Finally, we tested if these associations patterns are maintained across different contexts, i.e., when fishing with the dolphins or waiting at the beach. We hypothesize that the associations are maintained during both contexts, both when fishing and socializing fishers tend to associate with similar fishers in terms of reputation, reinforcing our previous hypothesis.

MATERIAL AND METHODS

Study system

We studied the social behaviour of the net-casting fishers who interact with wild Lahille's bottlenose dolphins and are part of the artisanal fishing community of Laguna, southern Brazil (28°20' S, 48°50' W). We focused our sampling effort during 26 days of the mullet season (May-June) of 2019 and on the net-casting fishers that use the main interaction site, the *Tesoura* beach (see Peterson et al. 2008), where this traditional fishery is more pronounced (Simões-Lopes et al. 1998). First, we (i) recorded GPS location data and (ii) accessed reputation indices of the artisanal fishers by interviews. Then (iii) we used the GPS data to establish spatial-temporal groups of individuals in different behavioural contexts and finally (iv) quantified individual centrality (and its relation to reputation) in the social network and assortativity coefficients around reputation.

Sampling GPS positions of fishers

We used fitness wristbands (Huawei band Pro-2) to track the geographical position of each fisher over time. We recorded the location and movement of 34 fishers who agreed to participate in the research. These fishers worn a wristband from the beginning of the sampling period (between 8-9 AM) for as long as the battery lasted (average±SD= 167.75± 136.51 min). By using a high recording rate of 12 Hz to ensure high resolution of the data, the batteries needed to be recharged at midday. All bands were retrieved from the fishers at the end of the sampling period (around 5 PM).

Fishers' peer reputation

We assessed the reputation of individuals as skilled and knowledgeable fishers as perceived by their peers. Artisanal fishers were interviewed (Santos-Silva 2021) based on a semi-structured questionnaire (see Bernard 2006) during May and June 2019 at the same time as the GPS sampling. One of the questions aimed to identify which fishers in the community were perceived as the most skilled fishers when interacting with dolphins. Interviewees reported skilled individuals as those with consistently high success in catching mullets, having reliable knowledge about the behaviour of the dolphins and the fish, and the best time and place to fish. We used the total number of citations each individual fisher received as a quantitative score of their peer reputation. The interviews were performed with a subset of 22 fishers who were substantially more active in interacting with dolphins and agreed to wear the GPS wristbands.

Social associations in different contexts

We defined two contexts to account for behavioural-specific preferred associations (Gero et al. 2005). The 'Foraging' context represented the moment fishers were aligned in the water, waiting for the dolphins to herd fish schools towards them (Simões-Lopes et al. 1998). The 'Non-foraging' context represented the moment fishers were at the beach and included other behavioural states, such as socializing, resting and observing.

To quantify pairwise associations, we used the GPS data and the gambit-of-the-group (Whitehead & Dufault 1999), which considers all individuals seen together in a group as potentially interacting with one another. We first defined a 5-minute time window and a spatial threshold between fishers to define a group. We then used both time and position thresholds to generate a group-by-individual matrix for each behavioural context. We defined different spatial thresholds between contexts because the associations work differently when fishers are foraging in the water and when they are not foraging at the beach. For the 'Foraging' context, we used 10 meters as the distance threshold as it covers most of the neighbours' distance from fisher to fisher in the fishing line without exceeding two spots, meaning that the associations in this context were defined to who is positioned side to side in the fishing line. For the 'Non-foraging' context, we defined two meters as the distance between points that define a group, representing active social engagements by the fishers. Then, we calculated the association strength of each group using the half-weight index (Cairns & Schwäger, 1987), which estimates the proportion of time that two individuals were seen in the same group (0 = never, 1 = always), as so defined above.

Areas used in different behavioural contexts

We estimated the areas used by fishers with different peer reputations between the two behavioural contexts with kernel density methods. From the distribution of reputation scores (see Results), we heuristically defined the mean score (reputation score = 7) as a threshold to classify fishers into two categories: 'low reputation fishers' and 'high reputation fishers'. We then used a two-dimensional kernel density estimation with an axis-aligned bivariate normal kernel (Venables & Ripley 2002) to estimate the area used by all low and all high reputation fishers in the water and at the beach. The bandwidth was automatically chosen by a rule-of-thumb of a Gaussian kernel density estimator (Venables & Ripley 2002).

Fishers' position in the social network

We assessed the fishers' position in the social network by calculating the eigenvector centrality of each fisher, that is, the first eigenvector of the graph adjacency matrix (Bonacich 1987, Wasserman & Faust 1994). The centrality of each fisher is proportional to the sum of the centralities of those fishers to whom he is connected. In our study system, high eigenvector centrality indicates that a fisher has direct connections to many other fishers, which are themselves connected to many others (Scott 2000).

To investigate whether fishers' centrality relates to fishers' reputation, both when individuals were fishing or not, we built a multi-membership Generalized Linear Mixed Model (GLMM) with Gaussian error distribution using a Markov chain Monte Carlo (MCMC), approach under a Bayesian statistical framework (Hadfield, 2010). The chain length was set as 300000 and we used a burn-in of 100000 and sampled the chain every 2000 iterations. We specified the default uninformative priors for the fixed and random structure of the model. As the response variable in the fixed part of the model, we used the eigenvector centrality difference between nodes in a dyad, and as the predictors, we used the differences in reputation (quantified during the interviews with fishers) between nodes in a dyad with the behavioural context (foraging, non-foraging) as an interaction term. We accepted that a fixed effect was significant when the credible intervals of the posterior distribution did not overlap with zero. A positive relationship between reputation and centrality differences would suggest that individuals with high reputations may also have high centrality, while a negative relationship would suggest the opposite. MCMC GLMMs can deal with part of the inherent and complex non-independence of the social network data. We then used this approach here to control for node dependence by including individual fishers' identities as multilevel random effects (Hart et al. 2021).

Assortativity of the social network

To test if social interactions among fishers are coupled to individual reputation, we estimated the assortativity coefficients in each behavioural context by calculating a continuous assortativity index (r_c^w). This index ranges from -1 (fully disassorted) to 1 (fully assorted), suggesting, respectively, that high reputation fishers are always found with low reputation fishers, or high reputation fishers are always found with high reputation fishers and low reputation fishers with low reputation fishers (Farine 2014).

We used Monte Carlos simulations (Manly, 1995) to test whether the assortativity values were higher or lower than expected by chance. We performed 1,000 permutations in the group by individual matrix for each context, which were then used to generate 1,000 new associations matrices and corresponding assortativity indices. From the theoretical distribution of assortativity indices, we calculated 95% confidence interval (CI) and considered the empirical values as significant when outside of the 95%CI. We carried out all the analyses in the R environment (R Core Team, 2020). We used the R package 'spatsoc' (Robitaille et al. 2019) to define the spatial-temporal groups, the package 'igraph' to calculate the eigenvector centrality (Csardi & Nepusz 2006), the package 'asnipe' (Farine 2013) to calculate the association indices and the 'assortnet' (Farine 2014) package to calculate the assortativity coefficients.

RESULTS

The 22 interviewed individuals varied considerably in their reputation as skilled and knowledgeable artisanal fishers, as perceived by their peers (median=0.50, mean=7.10 ± 12.22, range = 0–40). Low- and high-reputation fishers highly overlapped their used areas in both behavioural contexts (Figure 1). There was a slight difference in the use of the foraging area between low- and high-reputation fishers. In the 'Foraging' context, high reputation fishers tended to concentrate in the first spots of the fishing line, perceived as the best places to fish (see Peterson et al. 2008), while low-reputation fishers tend to be more spread through the fishing line. In the 'Non-foraging' context, both low- and high-reputation fishers use the same social/rest area (tent mounted at the beach, Figure 1), which can promote social associations between different skilled, experienced and successful fishers. The social interactions were similarly distributed across the behavioural contexts: during 'Foraging', the social network was composed of 88 vertices (mean HWI = 0.07±0.11 SD), while during the 'Non-foraging' fishers were connected by 86 vertices (mean HWI = 0.06±0.11 SD).

The eigenvector centrality of individual fishers varied between the behavioural contexts. In both the ‘Foraging’ (median=0.39, mean= 0.45± 0.30, range = 0.04–1.00) and the ‘Non-foraging’ context (median=0.27, mean=0.45± 0.40, range = 0.01–1.00) we observed central and peripherical individuals, but most of the values were median. We found a positive relationship between nodes centrality and reputation differences across behavioural contexts (posterior mean = 0.007625, 95% credible interval = 0.003644– 0.011557, pMCMC < .001; Figure 2). This positive relationship was more pronounced in the 'Non-foraging' context, where centrality differences increased with reputation differences and were up to 0.012 higher than centrality differences in the 'Foraging' context (posterior mean = 0.012108, 95% credible interval = 0.008070– 0.016088, p < .001; Figure 2).

We observed a slight disassortative pattern in both behavioural contexts. Assortativity indices were higher in the ‘Non-foraging’ (r_c^w= -0.178, 95% IC = -0.180;-0.072) than in the ‘Foraging’ context (r_c^w= -0.218, 95% IC = -0.217;-0.064) but in both contexts the empirical assortativity was lower than expected by chance. We rejected the null hypothesis that fishers associate randomly; instead, fishers tended to associate with others with different reputation scores.

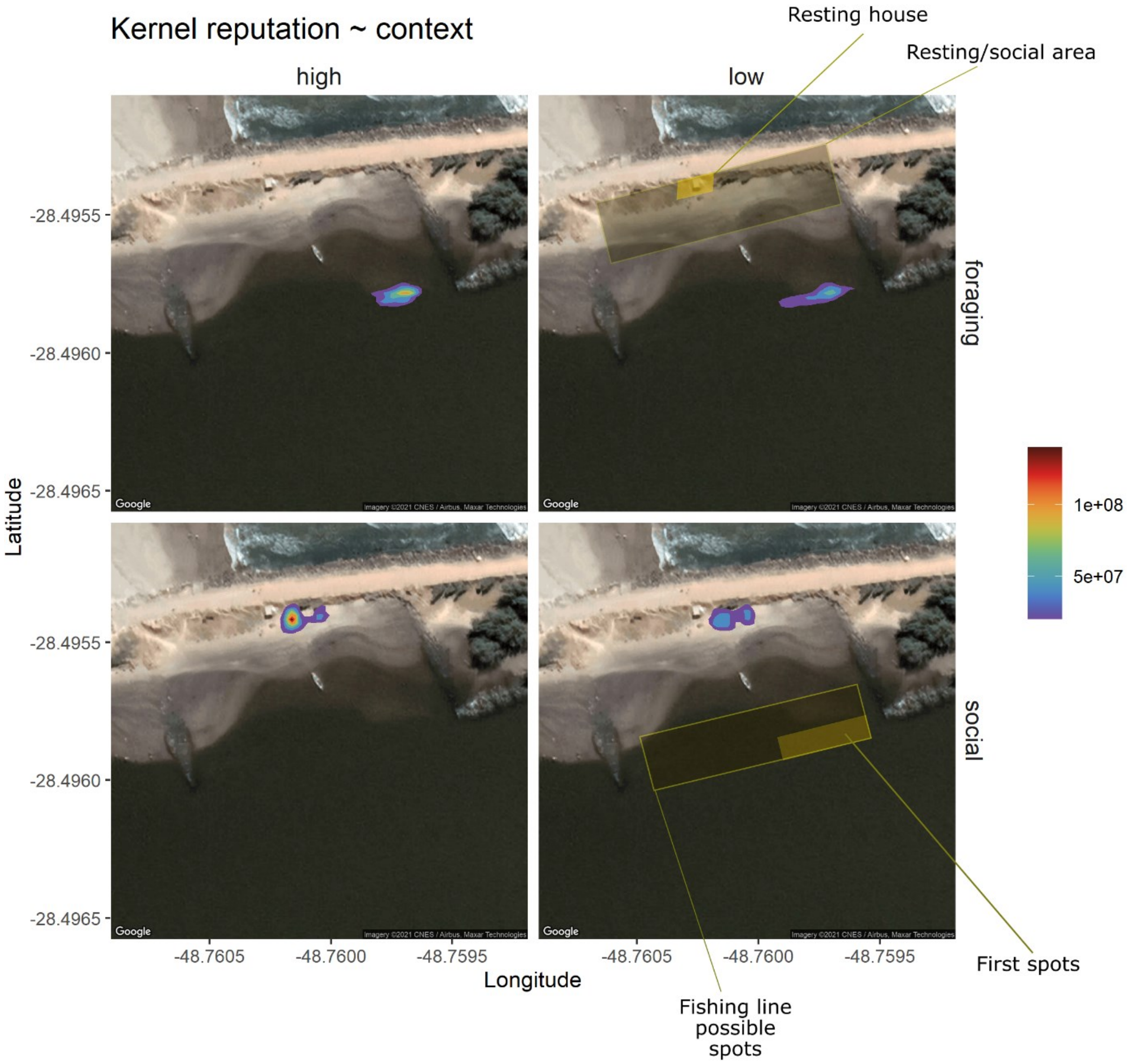

Figure. 1. Fishers' Kernel estimation by context. Kernel density estimation indicate the area used by fishers of low and high reputation when foraging in the water, and when resting or socializing at the beach (*Tesoura* beach). Hotter colours represent more frequent usage of the area and colder colours represent less frequent accessed areas.

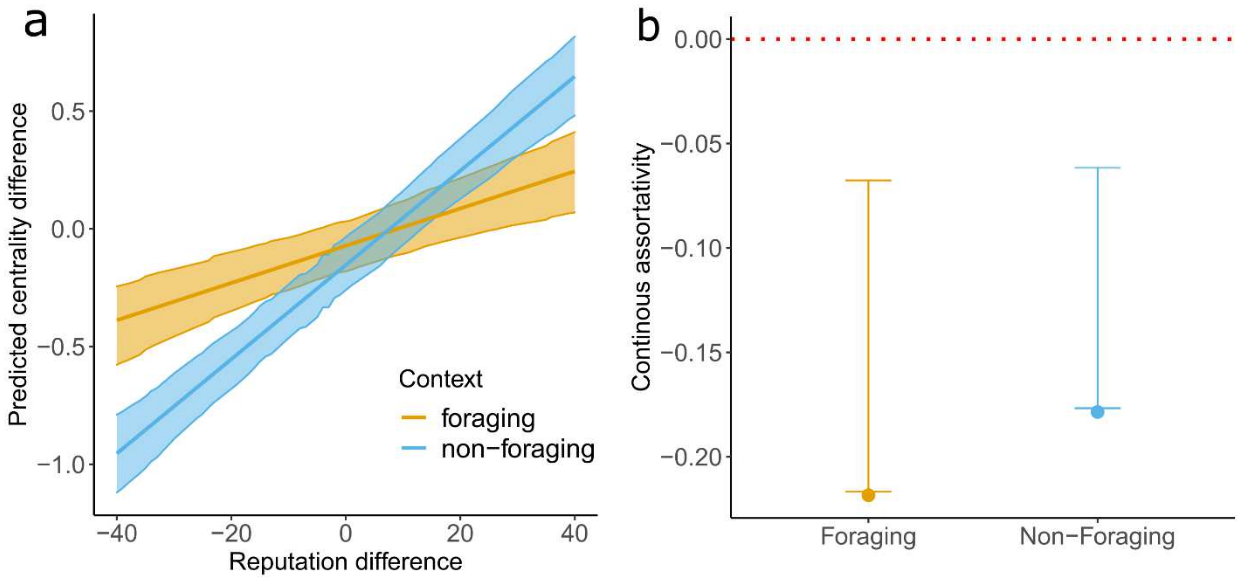

Figure. 2. Predicted social centrality, peer reputation and assortativity. (a) Individual centrality difference (and consequently the individual centrality) showed a positive relationship with reputation difference in both behavioural contexts. This positive relationship is more pronounced in the 'Non-foraging' context, where social associations are more likely to take place. The lines are the predicted values of the centrality differences, with 95% confidence intervals calculated from the coefficients of the fitted model. (b) Continuous assortativity (dots) indices around reputation were lower than expected by chance in the social network of both behavioural contexts. Whiskers indicate the 95% confidence interval generated by a null model. Results are colour-coded by behavioural context.

DISCUSSION

We found a positive relationship between fishers' peer reputation and their social centrality, suggesting that high-reputation fishers in this fishery system are available to associate with other fishers. We also found a small disassortative effect of reputation on the social network when individuals are either fishing with dolphins or waiting at the beach. These findings suggest that while fishers choose with whom they associate regardless of reputation, the high-reputation fishers may play a key role in maintaining the social cohesion and the information flow within this subset of this fishing community.

Among the interviewed net-casting fishers who fish with dolphins, we found a tendency for high-reputation individuals—the more experienced and successful in fishing with dolphins (Santos-Silva 2021)—to be more socially connected, especially in the more socially conducive context comprised by the time waiting for dolphins at the beach. Similar to other fishing communities (Gezelius 2007) in which the experienced fishers are followed by the others (Van Ginkel 2001), inexperienced fishers may seek to associate with high-reputation net-casting fishers in the traditional fishery with dolphins. Fishing with dolphins is a complex tactic that requires a deep understanding of the dolphins' and the fish's behaviour; to acquire these skills, unexperienced or new fishers (who occasionally come from neighbouring communities) may copy the more experienced local fishers by following their decisions on when and where to cast their nets. It thus seems beneficial for inexperienced fishers to associate with the experienced fishers—as seen, for instance, in the fisheries of Loreto, Mexico, where experience mediates fishers' social associations and less experienced fishers seek advice from the more experienced ones (Ramirez-Sanchez 2011).

Benefits can be less clear for experienced fishers. Experienced fishers are more likely to associate with others when (1) the resource is abundant and so competition is low (Palmer 1991, Salas & Gaertner 2004); (2) associating with unexperienced fishers can increase access to novel tactics (Bodin & Crona 2009); or (3), individuals perceive to benefit more by fishing collectively, rather than individually (Hilborn et al. 2001; Dreyfus-Léon & Gaertner 2002). The more social connections fishers have, independently if with less or more successful fishers, the broader their fishing knowledge tends to be. Consequently, the success of well-connected fishers will likely be higher than fishers with fewer connections (Crona & Bodin 2006, Carlsson & Sandström 2008). Therefore, fishers can be central in social networks because of their experience and success, being followed by others, or being successful because of their position in the network (Turner et al. 2014). Both success and network position are likely to be an interactive process (Bodin & Crona 2011). For example, in Lake Michigan, United States, captains of fleets are key components of their community social networks, often sharing information with other fishers, including less successful ones, who also appear to share information with the captains (Mueller et al. 2008).

We found a small disassortative effect around peer reputation in the fishing community of Laguna across two different behavioural contexts. Social disassortativity when foraging suggests that that any fisher in this area could potentially fish along this line, following the informal local rules (see Peterson et al. 2008). In this context, when higher-reputation fishers concentrate their efforts in the spot they perceive to be most productive, the disassortativity suggests that other fishers can access these areas too. This disassortative effect could also reinforce that lower reputation fishers are either seeking improvement and learning from the fishers whom they perceive as more successful (Henrich & Broesch 2011) or, alternatively, suggesting a simple aggregation effect as the higher reputation fishers mostly fish in the same good spots, which are also of interest to other fishers. When not foraging, fishers tend to aggregate in the resting area, and we also found a small disassortative effect of reputation on the social interactions. Thus, this fishing community seems homogeneous in terms of social associations, suggesting that high-reputation fishers may not competitively exclude other fishers by their knowledge, spots, or resource; therefore, the information can potentially flow through different levels of skills.

The absence of assortativity around reputation may be beneficial to the community as a whole, reducing inequalities and the chance of antagonist "us *versus* them" thinking (Borgatti & Foster 2003), and then social fragmentation that can compromise the sense of community and collective action (Granovetter 1973). In the fishing community of Laguna, assortativity around reputation could lead to misinterpretation of the dolphins' behaviour by the lower reputation fishers, compromising the fishing efficiency of the whole system. Disassortativity favouring information flow can increase similarly among the knowledge held by the fishers in the community (Bodin & Crona 2009). Lower reputation fishers are also able to share information with whom they perceive to be successful (Turner et al. 2014). High reputation fishers, at the same time, are not just able to receive new information from others, which is an important social asset (e.g., Gatewood 1984, Gezelius 2007, Mueller et al. 2008), but may also be able to perceive better the new benefits related to it and how to apply such new knowledge.

A socially homogenous fishing community across reputation levels may also present some disadvantages. Knowledge homogeneity can facilitate the invasion of new but not adaptive behaviours (Bodin & Norberg 2005), especially among those with better perception of the system, changing their behaviours and potentially reducing their efficiency in using the resource (Little & McDonald 2007). In addition, fishers sharing a common knowledge may take the same decisions, fishing in the same places and time, overcrowding fishing spots, overfishing the same stock, and ultimately, reducing their fishing success (Gatewood 1984). The informal rules developed by fishers in Laguna define that they must wait in a queue until the one in the water catches two or more fish to use the same spot (Peterson et al. 2008). Then, sharing information on the best fishing spot in the fishing line may overcrowd them, increasing fishers' waiting time. Still, if an inexperienced fisher does not know how to identify and interpret the dolphins' behaviour properly and pass this information on, this can lead to a detrimental fishing success of other fishers (da Rosa et al. 2021).

Our study sheds further light on the notion that having social connections is an important social asset for artisanal fishers within their fishing community. We found a well-mixed association pattern in our studied fishing community, without social barriers limiting the transmission of the knowledge on how to fish with dolphins from the more experienced fishers to all others. This open system can increase system resilience by constantly recruiting new fishers to acquire the basic skills and become experienced. On the other hand, being the system open to new fishers, it can also be vulnerable to the introduction of new, non-adaptive behaviour. Understanding the social interaction patterns among fishers can contribute to the discussion of how the transmission of traditional knowledge may underpin the resilience of artisanal fisheries. Our study adds to the growing literature concerned with decision-making processes and social behaviour within small-scale fisheries.

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CONSIDERAÇÕES FINAIS E CONCLUSÕES

Em minha dissertação, investiguei características comportamentais e relações sociais de pescadores artesanais que pescam com auxílio do boto-da-tainha no sul do Brasil. Demonstrei, a partir de sistema socioecológico único, a importância de variações em fina-escala para pescadores e pescarias artesanais, e ressaltei a relevância de como estudos em pequena escala, que nos ajudam a entender dinâmicas pesqueiras em nível individual, podem contribuir no entendimento de sistemas pesqueiros como um todo e, eventualmente, no seu manejo. Divido meus achados sob a ótica de dois principais agentes — o pescador, e a comunidade pesqueira —, cujas contribuições para o desenvolvimento científico e manejo de pescas de pequena escala enfatizo no que segue.

O pescador (i) deve ser tratado como um componente ativo dentro de um sistema pesqueiro, que age e interage com seu ambiente a partir de inúmeros fatores (sociais, culturais e econômicos), fatores estes que influenciam suas decisões e seus comportamentos no cotidiano e frente a adversidades. Apesar de não ter feito uma análise de caráter individual, demonstrei que existem comportamentos específicos que podem aumentar o sucesso de captura dos pescadores de Laguna que pescam com botos. Esses comportamentos devem ser considerados em uma estratégia de manejo dessa atividade pesqueira. De forma mais ampla, esse achado ilustra que não podemos ignorar essas nuances comportamentais e mascará-las em esforços de manejo simplificados que não levam em consideração o principal agente do sistema pesqueiro de pequena escala (o pescador). Além disso, também estaríamos sujeitos a propor regulatórias ineficazes, que não representam aquele sistema fidedignamente. Assim, sugiro que analisar como e sob quais condições os pescadores variam seu comportamento frente a pesca será útil para corrigir estatísticas pesqueiras e parâmetros utilizados em avaliações de estoques pesqueiros e na elaboração de indicadores e regulamentações.

A comunidade pesqueira (ii) pode ser um ambiente amigável ou hostil, seleto ou cooperativo. É na comunidade pesqueira que o pescador pode ter a oportunidade de melhorar suas estratégias de pesca, adquirir conhecimentos sobre o sistema pesqueiro e criar relações sociais com outros pescadores. Demonstrei também que a comunidade pesqueira de Laguna é potencialmente uma comunidade aberta e socialmente homogênea, com padrões de associação misturados. Isto é, essa comunidade está aberta para pescadores novos e já fazendo parte da comunidade não existe uma exclusão de pescadores menos experientes ou de menor reputação.

A troca de informação entre os variados níveis de experiência pode ocorrer livremente, aumentando a resiliência e persistência do conhecimento ecológico tradicional na comunidade e, consequentemente, a persistência da centenária pesca com os botos. Por isso, sugiro que a avaliação de parâmetros sociais dentro de uma comunidade pesqueira é de suma importância para identificar fatores que podem deteriorar ou preservar a persistência de uma pescaria de pequena escala.

APÊNDICE A – Material suplementar do manuscrito: Behavioural traits influence foraging success of artisanal net-casting fishers who interact with wild dolphins

Supplementary Material for the article: Behavioural traits influence foraging success of artisanal net-casting fishers who interact with wild dolphins

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1 MODEL SELECTION

Table S1: Generalized linear mixed models were fitted with a binomial error structure and logit link function to assess the influence of environmental conditions and fishers' performance on the fishing outcomes. Candidate models are ranked by the Akaike Information Criteria corrected for small samples (AICc). The *Δ*AICc is calculated to each model relative to the model with the smallest AIC, considered to be most parsimonious model. AICc weight shows the probability of the model to fit the data given all candidate models. Values were rounded to three digits.

Model	Intercept	Reaction time	Net angle	Net area	Net distance to the dolphin	Distance between nets	Casting distance	Tide direction	Tide height	Water temperature	Wind direction	Wind speed	Year	df	log-likelihood	AICc	Delta AICc	weight
M10	0.404			0.029	-0.107		-0.195							5	-174.968	360.090	0.000	0.472
M9	0.532	-0.046		0.026	-0.102		-0.171							6	-174.679	361.575	1.485	0.225
M11	-0.814			0.022	-0.103									4	-177.433	362.969	2.879	0.112
M8	0.316	-0.059	0.003	0.026	-0.096		-0.161							7	-174.419	363.127	3.036	0.103
M7	0.545	-0.062	0.003	0.025	-0.097		-0.175				+			8	-174.238	364.849	4.759	0.044
M6	-0.697	-0.061	0.003	0.027	-0.097		-0.167		0.010		+			9	-174.012	366.492	6.402	0.019
M12	0.076				-0.098									3	-180.618	367.298	7.208	0.013
M5	-1.065	-0.063	0.003	0.027	-0.099		-0.173		0.013		+	0.025		10	-173.824	368.220	8.130	0.008
M4	-3.119	-0.063	0.003	0.028	-0.101		-0.176		0.014	0.090	+	0.030		11	-173.737	370.163	10.073	0.003
M3	-2.953	-0.066	0.003	0.029	-0.099		-0.173		0.014	0.086	+	0.030	+	12	-173.705	372.227	12.137	0.001
M2	-2.923	-0.062	0.003	0.029	-0.097	-0.004	-0.171		0.013	0.084	+	0.030	+	13	-173.693	374.342	14.252	0.000
M1	-2.921	-0.062	0.003	0.029	-0.097	-0.004	-0.171	+	0.013	0.084	+	0.030	+	14	-173.693	376.492	16.402	0.000
M0	-1.438													2	-189.960	383.952	23.861	0.000

2 MODEL ASSUMPTIONS

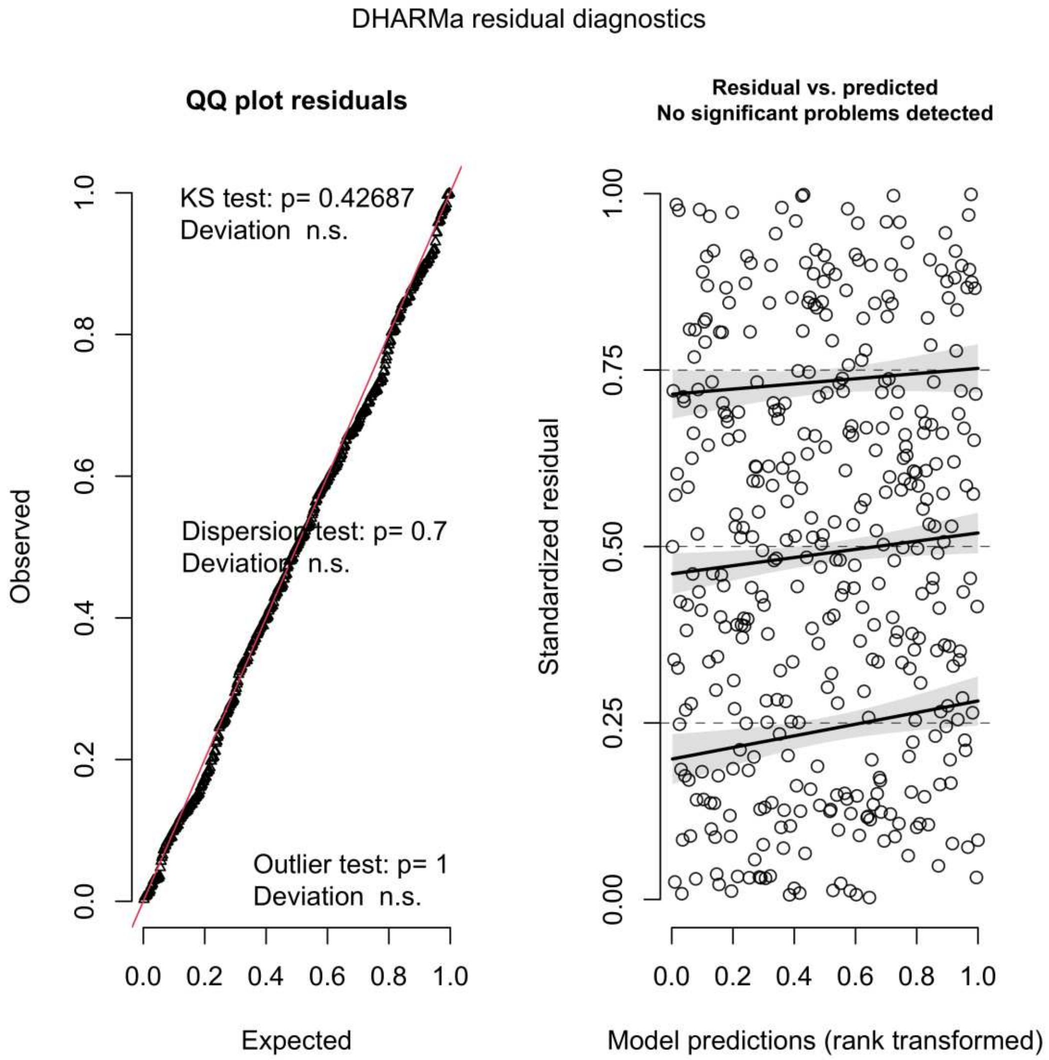

Figure S1: Scaled residuals from 1000 simulations from the fitted model were used to validate the model assumptions. A Kolmogorov-Smirnov test was used to test if the observed and expected residual distributions deviate significantly.

3 PARTITIONING R2

We estimated the relative contribution of the net area, net distance to the dolphin and casting distance by decomposing the marginal R2 of the selected model into the variation explained uniquely by each predictors using semi-partial R^2 (Stoffel *et al.*, 2021). We calculated a 95% confidence interval using parametric bootstrapping. We selected model M10, considering it to be the most parsimonious model (see Table S1). Then, we refitted our selected model with lme4::glmer() (Bates *et al.*, 2015) only to calculate semi-partial R^2 for the fixed effects. This step was necessary since partR2::partR2() only supports models fitted with lme4.

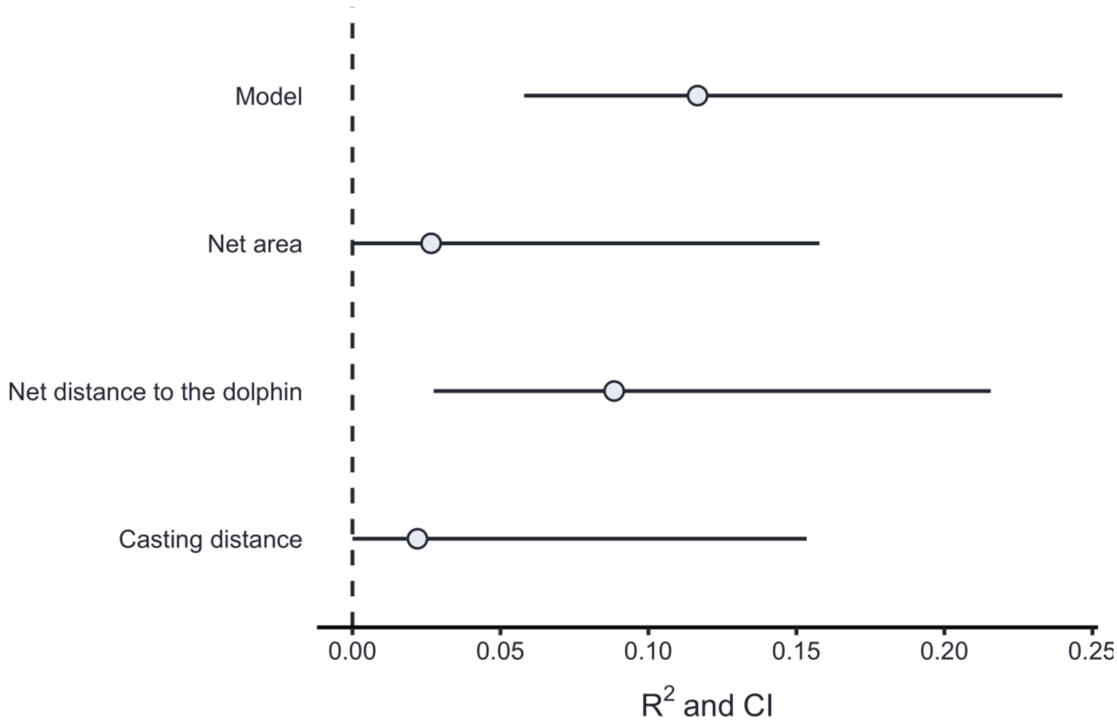

Figure S2: Forest plots for the most parsimonious model (semi-partial R^2 = 0.117, 95% CI = 0.0580–0.240) decomposing the contribution of net area (semi-partial R^2 = 0.0266, 95% CI = 0–0.158), net distance to the dolphin (semi-partial R^2 = 0.0884, 95% CI = 0.0274–0.216) and casting distance (semi-partial R^2 = 0.0219, 95% CI = 0–0.153) in fishing outcomes.

4 SESSION INFORMATION

R version 4.0.3 (2020-10-10) Platform: x86_64-apple-darwin17.0 (64-bit) Running under: macOS Big Sur 10.16

Matrix products: default BLAS: /Library/Frameworks/R.framework/Versions/4.0/Resources/lib/libRblas.dylib LAPACK: /Library/Frameworks/R.framework/Versions/4.0/Resources/lib/libRlapack.dylib

Random number generation: RNG: Mersenne-Twister Normal: Inversion Sample: Rejection

attached base packages: [1] stats graphics grDevices utils datasets methods base

other attached packages: [1] bookdown_0.21 cowplot_1.1.1 jtools_2.1.3
[4] sjPlot_2.8.6 reshape2_1.4.4 colorblindr_0.1.0
[7] colorspace_2.0-0 gghalves_0.1.1.9000 patchwork_1.1.0.9000 [10] lme4_1.1-25 Matrix_1.2-18 future_1.20.1
[13] partR2_0.9.1 performance_0.7.1 MuMIn_1.43.17
[16] MASS_7.3-53 DHARMa_0.3.3.0 glmmTMB_1.0.2.1
[19] car_3.0-10 carData_3.0-4 forcats_0.5.0
[22] stringr_1.4.0 dplyr_1.0.2 purrr_0.3.4
[25] readr_1.4.0 tidyr_1.1.2 tibble_3.1.0
[28] ggplot2_3.3.3 tidyverse_1.3.0 flextable_0.6.6
[31] captioner_2.2.3

loaded via a namespace (and not attached): [1] readxl_1.3.1 uuid_0.1-4 backports_1.2.0
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[7] splines_4.0.3 listenv_0.8.0 digest_0.6.27
[10] foreach_1.5.1 htmltools_0.5.1.1 fansi_0.4.2
[13] magrittr_2.0.1 doParallel_1.0.16 openxlsx_4.2.3
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[19] rvest_0.3.6 haven_2.3.1 xfun_0.21
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[25] glue_1.4.2 gtable_0.3.0 emmeans_1.5.2-1
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[106] shiny_1.6.0 lubridate_1.7.9.2 base64enc_0.1-3

5 REFERENCES

Bates, D., Mächler, M., Bolker, B. M., and Walker, S. C. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67. https://arxiv.org/abs/1406.5823.

Stoffel, M. A., Nakagawa, S., and Schielzeth, H. 2021. partR2 : partitioning R 2 in generalized linear mixed models. PeerJ, 9: e11414. https://peerj.com/articles/11414