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DINÂMICA POPULACIONAL DE DUAS ESPÉCIES DE PEIXE-AGULHA, *Hyporhamphus unifasciatus* E *Hemiramphus brasiliensis*: UMA ABORDAGEM ETNOECOLÓGICA

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Tese apresentada ao Programa de Pós-Graduação de Etnobiologia e Conservação da Natureza da Universidade Federal Rural de Pernambuco (UFRPE, UEPB, URCA e UFP), como parte dos requisitos para a obtenção do título de doutor.

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SUMÁRIO

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RESUMO

O declínio da disponibilidade de peixes, como consequência de mudanças ambientais antrópicas, tais como mudanças climáticas, e sobrepesca, pode afetar a renda econômica de pescadores artesanais. Devido às mudanças climáticas, os organismos são forçados a migrar ou se adaptar a novos climas e, se não o fizerem, correm o risco de declinar e extinguir-se. Sabe-se que as populações pesqueiras locais, por utilizarem e conhecerem os recursos do ambiente, acumulam conhecimentos sobre as mudanças e processos ambientais e podem perceber a diminuição da abundância de recursos e auxiliar na detecção das possíveis alterações da disponibilidade das espécies. Neste contexto, esta tese objetivou investigar dois aspectos complementares a respeito de duas espécies de agulhinhas, *Hyporhamphus unifasciatus* (agulhinha branca) e *Hemiramphus brasiliensis* (agulhinha preta), dois pequenos pelágicos de relativo interesse pesqueiro e de alta relevância na cadeia trófica. O primeiro destes aspectos investigou como as alterações ambientais ocasionadas por ações antrópicas nas águas costeiras afetarão a distribuição e oferta das espécies de agulhinhas nas Américas nos próximos 30 e 70 anos? O segundo aspecto investigou se é possível fazer um resgate histórico da oferta destes recursos a partir da percepção dos pescadores locais. Utilizando Modelos Bayesianos de Distribuição de Espécies (B-SDMs), identificamos que ambas as espécies são mais provavelmente encontradas em águas rasas, quentes e salgadas. A previsão do modelo sugere que as duas espécies provavelmente se beneficiarão das mudanças climáticas, com potencial aumento em sua área de ocorrência nas regiões costeiras das Américas, especialmente devido ao aumento da temperatura e aumento da salinidade, desde que encontrem habitat favorável para tal. Para o segundo questionamento, realizamos 18 entrevistas semiestruturadas com pescadores especialistas selecionados com a técnica bola de neve em três localidades no litoral para obter informações sobre possíveis mudanças na abundância das populações com o passar dos anos. Compilamos ainda dados de reconstrução das capturas das duas espécies de 1950 a 2010. Para verificar se a curva de variação na captura oficial correspondia a curva de variação, de acordo com a percepção dos especialistas nesta pesca, selecionamos os anos citados por eles como sendo os melhores. Na percepção dos pescadores, foi identificada variação na disponibilidade das espécies e redução na quantidade capturada, embora as análises indicaram não haver diferença na percepção sobre a disponibilidade e que não houve mudança na quantidade disponível dessa espécie em suas zonas de pesca.

Palavras Chave: *Hemiramphus brasiliensis*; *Hyporhamphus unifasciatus*; Mudanças climáticas; pescadores artesanais; conhecimento ecológico local.

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ABSTRACT:

The decline in the availability of fish, as a consequence of anthropic environmental changes, such as climate change, and overfishing, can affect the economic income of artisanal fishermen. Due to climate change, organisms are forced to migrate or adapt to new climates and, if they do not, they risk to decline and become extinct. It is known that local fishing populations, by using and knowing the resources of the environment, accumulate knowledge about changes and environmental processes and can perceive the decrease in the abundance of resources and assist in the detection of possible changes in the availability of species. In this context, this thesis aimed to investigate two complementary aspects regarding two species of needles, Hyporhamphus unifasciatus (white needles) and Hemiramphus brasiliensis (black needles), two small pelagics of relative fishing interest and of high relevance in the trophic chain. The first of these aspects investigated how the environmental changes caused by anthropic actions in coastal waters will affect the distribution and supply of needle species in the Americas over the next 30 and 70 years? The second aspect investigated whether it is possible to make a historical rescue of the supply of these resources from the perception of local fishermen. Using Bayesian Species Distribution Models (B-SDMs), we identified that both species are more likely to be found in shallow, warm and salty waters. The model's prediction suggests that both species are likely to benefit from climate change, with a potential increase in their area of occurrence in the coastal regions of the Americas, especially due to the increase in temperature and the increase in salinity, provided they find favorable habitat for this. For the second question, we conducted 18 semi-structured interviews with specialist fishermen selected with the snowball technique in three locations on the coast to obtain information about possible changes in the abundance of populations over the years. We also compiled data on the reconstruction of the catches of the two species from 1950 to 2010. To check whether the variation curve in the official catch corresponded to the variation curve, according to the perception of experts in this fishery, we selected the years cited by them as being the best. In the perception of fishermen, variation in the availability of species and reduction in the quantity caught was identified, although the analyzes indicated that there was no difference in the perception of availability and that there was no change in the available quantity of this species in their fishing zones.

Keywords: *Hemiramphus brasiliensis*; *Hyporhamphus unifasciatus*; climate changes; artisanal fishers; fishers' ecological knowledge**.**

1. INTRODUÇÃO GERAL

1.1 Objetivos e Questionamentos

Em conversas acadêmicas no Departamento de Pesca da UFRPE, descobri que as duas espécies de agulhinhas, *Hyporhamphus unifasciatus*, branca e *Hemiramphus brasiliensis*, preta, vinham desaparecendo das águas costeiras do estado de Pernambuco. As agulhinhas, como são popularmente conhecidas, são peixes de grande relevância cultural e gastronômica no estado, sendo largamente comercializados há décadas.

O interesse no assunto me fez buscar na literatura informações sobre a ecologia e etnobiologia dessas espécies em escala global, obtendo dados e informações sobre a dinâmica populacional, reprodução, alimentação e alterações morfológicas, todos moldados pelas alterações ambientais ocasionadas por ação antrópica. Segundo os estudos analisados, foi possível perceber que a alteração das características da água (temperatura, turbidez, pH, salinidade) e presença de poluentes dissolvidos, além da pressão de pesca, são os fatores chave na dinâmica dessas espécies (ALVES, 2000; LAEGDSGAARD; JOHNSON, 2001; ADAMS; EBERSOLE, 2002; MAGALHÃES; ALVES, 2002; PEREIRA et al., 2010).

Nenhuma publicação compilou as informações da distribuição das espécies e como os fatores ambientais alterados por ações antrópicas podem influenciar sua distribuição. Da mesma forma, não estão compiladas informações sobre alteração da oferta desse recurso em locais em que as espécies apresentam importância na alimentação da população humana local, através da pesca artesanal como ocorre em Pernambuco.

Contudo, há evidências de que a pressão de pesca das agulhinhas resultou em declínio significativo destas populações no estado de Pernambuco. Somente entre 2003 e 2005, estima-se que a produção pesqueira de agulhinhas sofreu uma queda de 50%, embora a produção pesqueira total do estado tenha duplicado (MONTEIRO, 2003; FUNDAÇÃO PROZEE, 2006). Estes peixes têm seu ciclo de vida fortemente relacionado a fanerógamas marinhas, conhecidas popularmente por capim-agulha (*Halodule wrightii*). Segundo Magalhães (2002), grandes quantidades dessas fanerógamas marinhas foram retiradas de Itamaracá para a alimentação de peixes-boi do Centro de Mamíferos Aquáticos do IBAMA durante vários anos, sem nenhum controle. As consequências desta extração descontrolada de fanerógamas nos estoques de agulhinhas já eram notadas pelos pescadores da região (ALVES, 2000).

O declínio da disponibilidade de peixes, por quaisquer razões, pode afetar a renda econômica de pescadores artesanais (BAFFOUR-AWUAH, 2014). As populações locais, ao utilizarem e conhecerem os recursos do ambiente em que vivem ao longo de sua história, acumulam conhecimentos sobre as mudanças e processos ambientais (BELL, 2001; SILVANO; BEGOSSI, 2009). Sendo assim, os pescadores artesanais podem perceber a diminuição da abundância de recursos (DAW et al., 2011) e auxiliar na detecção das possíveis alterações da disponibilidade das espécies no meio ambiente (COLEY et al., 1999; BALÉE, 2006; BEGOSSI et al., 2011).

A partir dessas informações e inquietações esta tese pretende alcançar os seguintes objetivos: 1. Considerando as alterações ambientais ocasionadas nas águas costeiras por ações antrópicas, saber como se dará a distribuição e oferta das espécies de agulhinhas preta e branca nas Américas; 2. Detectar possíveis alterações na disponibilidade de espécies costeiras através do conhecimento ecológico local; 3. Fazer uma reconstrução histórica da oferta das agulhinhas a partir da percepção dos pescadores locais.

Espero apresentar os cenários futuros da distribuição de *H. unifasciatus* e *H. brasiliensis* na costa das Américas considerando os dados do Painel Intergovernamental sobre Mudanças Climáticas (IPCC). Com isto, espero atualizar os conhecimentos sobre a dinâmica das populações dessas duas espécies de zonas costeiras sob intensa pressão pesqueira e influência antrópica, possibilitando compreender a ação da pesca ao longo do tempo e sua potencial distribuição. Além disso, pretendo trazer informações de especialistas na pesca de *H. unifasciatus* e *H. brasiliensis* sobre a disponibilidade local e possíveis mudanças temporais na abundância, com base em suas percepções.

Estes dados podem sustentar a proposta de ações que possam ser utilizadas na recuperação das capturas obtidas na zona costeira, através da participação da população pesqueira, especialista na captura destas espécies, como provedora de informações biológicas e ecológicas do local do estudo. Essas ações estarão voltadas para o desenvolvimento local e a gestão participativa dos recursos naturais, uma vez que a redução da produção pesqueira de *H. unifasciatus* e *H. brasiliensis* é um problema para a conservação da biodiversidade, as atividades econômicas das populações humanas que vivem da pesca, e a manutenção do consumo dessas espécies.

Assim, os resultados desta tese podem fornecer subsídios para o manejo e direcionar a gestão pesqueira destes recursos, dos quais o ser humano é tanto dependente quanto agente importante nesse processo. Sem dúvida, é um grande desafio aliar a conservação de espécies sob alguma ameaça com os interesses econômicos e outras demandas de uso por parte de populações locais.

1.2. Estratégias de Pesquisa

No segundo capítulo buscamos investigar as mudanças na distribuição das espécies frente aos cenários futuros de mudanças climáticas nos anos de 2050 e 2100, em cenários otimista e pessimista de emissão de carbono. Também avaliamos as respostas das espécies quanto ao tamanho de sua área de distribuição, evidenciando expansão ou retração também para os anos de 2050 e 2100. Para isso aplicamos Modelos de Distribuição de Espécies (SDMs) para avaliar os impactos sobre a biodiversidade ou serviços ecossistêmicos e as prováveis respostas de espécies às mudanças climáticas (CHEUNG et al., 2010). Os Modelos de Distribuição de Espécies (SDMs) são amplamente utilizados em ambientes terrestres, e aquáticos para identificar as relações espécie-ambiente e prever a ocorrência e/ou densidade de espécies em locais não amostrados (FONSECA et al., 2017).

Para prever a distribuição atual e futura de *H. brasiliensis* e *H. unifasciatus* ao longo da costa das Américas (local ao qual a maior parte das espécies estudadas se restringe) utilizamos dados de duas fontes: 1) levantamento bibliográfico e 2) bancos de dados online (Aquamaps, Gbif e Species Link) que possuem informações sobre presença das espécies. Realizamos uma revisão bibliográfica exaustiva de pesquisas anteriores sobre ocorrências de *H. brasiliensis* e *H. unifasciatus* georreferenciadas em todas as águas das Américas. Os estudos que identificamos foram, em sua maioria, amostragens científicas que registraram a presença das espécies em um determinado local, por meio de métodos como os transectos, em que o pesquisador amostrou várias áreas próximas umas das outras. Para esses casos, elencamos aleatoriamente um dos locais amostrados e atribuímos a presença (ou ausência) das espécies a ele. Para garantir que estaríamos incluindo todas as informações disponíveis, extraímos dados de presença de bancos de dados online (KASCHNER et al., 2013) e excluímos observações duplicadas.

Consideramos quatro variáveis abióticas como potenciais preditoras da distribuição de *H. brasiliensis* e *H. unifasciatus*: temperatura da superfície do mar (SST em °C), salinidade da superfície do mar (SSS em PSU), profundidade (em metros) e rugosidade do fundo do mar; e uma variável biótica: produtividade primária líquida (NPP em mg Cm−2 d− 1).

Tomamos cuidado para assegurar que a resolução espacial (1° x 1°) fosse a mesma para cada preditor ambiental, uma vez que foram extraídos de diferentes fontes. Todas as variáveis ambientais foram padronizadas para reduzir a correlação entre os coeficientes do modelo e para permitir a comparação dos pesos relativos entre as variáveis (KINAS e ANDRADE, 2014).

Além disso, utilizamos modelos espaciais para verificar cenários futuros para os anos de

2050 e 2100, através de diferentes predições extraídas do Painel Intergovernamental sobre Mudanças Climáticas a partir do banco de dados BioOracle (http: //www.biooracle.org) com resolução espacial de 1° x 1°.

Utilizando o modelo bayesiano de iCAR estimamos a probabilidade de ocorrência de *H. brasiliensis* e *H. unifasciatus*, o qual leva em consideração uma possível autocorrelação espacial nos dados (LATIMER et al., 2006) e diferentes fontes de incertezas. Utilizamos um modelo autorregressivo condicional intrínseco de Gauss (iCAR) (BESAG, 1974) para autocorrelação espacial entre observações, pressupondo que a probabilidade de presença de espécies em um local depende da probabilidade de presença das espécies em locais vizinhos.

Para cada previsão, validamos o melhor modelo selecionado usando uma validação cruzada interna de 10 vezes baseada em conjuntos de dados de treinamento e teste selecionados aleatoriamente (criados por uma seleção aleatória de 75% e 25% dos dados respectivamente) (FIELDING e BELL, 1997), com o pacote “PresenceAbsence” em R (FREEMAN e MOISEN, 2008).

Desta forma, acreditamos ter encontrado um método facilmente replicável para avaliar se mudanças climáticas podem ter efeito positivo ou negativo na distribuição de espécies no futuro.

No segundo artigo buscamos investigar se na percepção dos pescadores especialistas na captura de *H. brasiliensis* e *H. unifasciatus* houve variação temporal na disponibilidade dessas espécies e se o tempo de experiência do pescador na atividade poderia afetar essa percepção. Além disso, a percepção quanto à variação na oferta das duas espécies deste estudo foram comparadas com a variação dos dados oficiais. Para isso, apenas os pescadores especialistas na pesca de *H. brasiliensis* e *H. unifasciatus* em três trechos do litoral de Pernambuco foram convidados a participarem. Estes especialistas responderam questões sobre idade, tempo de experiência na pesca, se essa correspondia a sua única atividade com rendimento financeiro, se houve mudanças na estratégia da pesca ao longo do tempo, se houve mudança de local de pesca, se percebeu mudança na quantidade de peixes pescados dessas espécies ou no tamanho dos que são capturados, os anos de melhores e piores capturas, entre outras. A seleção dos especialistas e destas perguntas nos permitiram fazer um diagnóstico sobre a situação da pesca das agulhinhas percebida pelos pescadores e alguns aspectos da resiliência do sistema socioecológico (HIND, 2014), além de considerar um possível efeito relacionado à mudança na linha de base (SÁENZ–ARROYO et al., 2005).

Já os dados oficiais de captura foram extraídos do banco de dados disponibilizados na plataforma *Sea around us*. Os dados para o Brasil foram reconstruídos a partir de dados oficiais da captura oficial de *H. brasiliensis* e *H. unifasciatus* para o período entre 1950 a

2010 em alguns estados do Brasil (FREIRE et al., 2014). Fizemos o recorte dos dados para Pernambuco e para verificar se a curva de variação na captura oficial correspondia à curva de variação, de acordo com a percepção dos especialistas nesta pesca, selecionamos os anos citados por eles como sendo os melhores. Para este mesmo ano citado como melhor, foi perguntada também a quantidade capturada de agulhinha estimada por saída de barco. Enquanto os dados da reconstrução pesqueira trazem capturas em toneladas por ano, as informações fornecidas pelos pescadores correspondem a apenas uma saída de barco para captura e é estimada em kg. Desta forma, os dados foram comparados apenas em tendências de comportamento.

1.3. Estrutura da Tese

A presente tese está apresentada e organizada em três capítulos para responder as questões da pesquisa, sendo um de revisão literária narrativa, no formato de artigo de opinião (*opinion piece*), e dois artigos científicos. Destes, um deles já foi publicado recentemente pela revista “Fisheries Research” com o título: “Damage or benefit? How future scenarios of climate change may affect the distribution of small pelagic fishes in the coastal seas of the Americas”. O texto deste capítulo específico foi organizado utilizando o método IMRAD, acrônico para Introdução, Métodos, Resultados e Discussão. O desenvolvimento do trabalho dentro de cada seção do IMRAD respondeu, sequencialmente, às perguntas principais do trabalho: (i) identificar quais características bióticas ou abióticas têm maior influência na distribuição das duas espécies de agulhinhas; e (ii) investigar mudanças distributivas, incluindo eventual expansão ou retração, dessas espécies diante de cenários futuros de mudanças climáticas (2050 e 2100, cenários otimistas e pessimistas de emissão de carbono).

O terceiro capítulo, intitulado “Conhecimento ecológico local e a importância do resgate histórico: um estudo de caso da percepção de pescadores artesanais sobre variações na disponibilidade de peixes-agulha no nordeste brasileiro” foi enviado para publicação no “Human Ecology”, ISSN 0300-7839 (print); 1572-9915 (web). Também foi utilizado o método IMRAD para o desenvolvimento do texto para Introdução, Métodos, Resultados e Discussão. O desenvolvimento do trabalho dentro de cada seção do IMRAD respondeu sequencialmente às perguntas principais do trabalho: (i) na percepção dos pescadores, houve variação significativa na disponibilidade temporal da oferta de agulhinhas (brancas e pretas)?; (ii) existe variação significativa na percepção sobre a disponibilidade temporal em função do tempo de experiência do pescador?; e (iii) existe alguma relação entre a variação na disponibilidade temporal de agulhinhas (brancas e pretas), com base nos dados oficiais de captura e com base na estimativa de captura dos pescadores?

2. Capítulo I – Fundamentação Teórica – *Opinion Piece*

Let’s not forget about small fish: a call for halfbeaks

Marine ecosystems are permanently regulated by a range of biotic and abiotic factors. Among several regulators, there are small pelagic fish, which due to their significant biomass at intermediate levels of the food chain (Palomera et al. 2007; Fauchald et al. 2011), play an important role in connecting the lower and upper trophic levels (Cury et al. 2000; Taylor et al. 2008; Brochier et al. 2011). According to the Food and Agriculture Organization (FAO), these fish represent 25% of the world landings (in tonnes), of which anchovies, sardinella, sardines, mackerel and herring are the most commonly caught due to their commercial importance as food and animal feed (FAO 2018). However, some other small pelagic fish may go accounted for in the main fishing statistics throughout the world (Takasuka 2018), mostly due to their low economic value. This is often the case of halfbeaks.

Halfbeaks are small pelagic fish of the family Hemiramphidae caught in coastal waters of several countries in the Atlantic, Indian and Pacific (Hughes and Stewart 2006). They measure between 15-30 cm (standard length: from tip of upper jaw to base of caudal fin) and are usually found close to the surface, forming small schools (Sokolovsky and Sokolovskaya 1999; Trnski et al. 2000; Monteiro et al. 2004). Like most small pelagic fish, halfbeaks have a fast initial growth, reaching their maximum size in a short period of time, being considered species of low to medium longevity (McBride and Thurman 2003; Stewart and Hughes 2007).

Despite their low commercial value, these species play an important role in human nutrition, contributing to the food security of coastal communities, especially fishing communities, which tend to be socioeconomically more vulnerable (Lessa and Nóbrega 2000; Pereira et al. 2010; Fernandes 2011). The fishing of these species is mainly artisanal and, although most of the fish caught will be consumed by the fishers' families themselves, some communities trade part of their halfbeak catches locally, especially where these fish are part of the local gastronomic tradition (Fernandes 2011).

Halfbeaks are also an important ecological link in the oceanic pelagic food chain, serving as important prey to large marine predators of high commercial value, such as tunas and sailfish (Pires 1997). Halfbeaks are also used as bait in the commercial and sport fisheries of tuna and tuna-like species (Nelson 2006).

Growing anthropogenic impacts in tropical coastal zones, which are often subjected to high demographic density, unplanned tourism and intense fishing exploitation (Ouyang et al. 2018; Bolívar et al. 2019), have compromised the dynamics of halfbeak populations. For example, significant changes have already been observed in their reproductive success (McBride and Thurman 2003; Hughes and Stewart 2006; Oliveira and Chellappa 2014), in their feeding behavior (Collette 2002; Vasconcelos Filho et al. 2009) and in their mortality rate (Oliveira and Chellappa 2014). Coastal land-use changes for real estate speculation and aquaculture, for example, lead to habitat change (Ouyang et al. 2018; Bolívar et al. 2019) and loss of seagrass prairies (*Halodule wrightii*) used by halfbeaks as food and shelter (Berkeley and Houde 1978; Sokolovsky and Sokolovskaya 1999; Noell 2003). Seagrass can also be harmed by some fishing practices (Cullen-Unsworth et al. 2018).

Halfbeaks are also subjected to global anthropogenic impacts caused by climate change. According to the Intergovernmental Panel on Climate Change (IPCC), global warming is expected to exceed 2° C by 2100 (IPCC 2018), with various impacts, mostly negative, expected to affect life on Earth, including that in the oceans. It is assumed that pelagic fish will undergo significant changes in their distribution because the superficial layers of the ocean are already suffering higher rates of change (Cheung et al. 2012). For halfbeaks these changes are not necessarily bleak nor are they simple. A study carried out with two species of halfbeaks, *Hemiramphus brasiliensis* and *Hyporhamphus unifasciatus*, suggests that these fish could actually increase their distribution in the Americas by the year 2100, even under the most pessimistic scenarios (RCP 2.6 and RCP 8.5). This could happen due to the high tolerance these species have to warmer temperatures and, consequently, increased salinity (Guerra et al. 2021). However, an increased distribution would only be possible if the species that are key for halfbeaks life histories, as the ones forming the prairies where they feed, court and shelter (e.g., *Halodule wrightii*) also expand. The future distribution of these prairie-forming species has not been modeled to date, but their expansion seems unlikely due to their high sensitivity to coastal changes (Waycott et al. 2009; Sunny 2017).

Although halfbeaks are key both in the food webs of highly sought fish species and in the food security of several traditional and often impoverished communities worldwide, they do not get enough scientific attention. The vast majority of studies on halfbeaks concern their co-occurrence in specific habitats with other small pelagics, their reproductive characteristics and feeding, with few or no studies attempting to better understand their ecological functional (Villéger et al. 2017), socioeconomic (Thiault et al. 2017; Alheit and Peck 2019) and even cultural role (Freitas et al. 2020). In the absence of baseline knowledge, their proper management is compromised. In fact, the management of less economically relevant fish species is a global problem (Pikitch et al. 2014), which include many small pelagic (FAO 2020). Instead of adopting a precautionary management approach, which is recommended for when knowledge is far from complete (Lopes et al. 2018), governments and management bodies overlook halfbeaks. In an emblematic case in the Brazilian northeastern coast, fishermen reported that the halfbeak *H. brasiliensis* practically disappeared in the 1980s and 1990s. According to the fishermen, this happened when the prairies of seagrass started being intensively harvested to feed a local manatee (*Trichechus manatus*) as part of a conservation project (Projeto Peixe Boi – Manatee Project). Such an unintended negative consequence due to an otherwise highly justifiable goal (the protection of the endangered *T. manatus*) is telling. It shows, for example, the shortcomings of adopting a species management approach instead of an ecosystem approach (Skern-Mauritzen et al. 2016). Perhaps more importantly, it shows how halfbeaks, possibly with other less important small pelagic species, come last in the conception of any sort of management: halfbeaks can be treated as irrelevant species whose presence can be compromised for the greater good of more emblematic ones.

Gathering ecological and socioecological knowledge on halfbeaks and on other small pelagic species of lesser economic relevance is urgently needed for their own sake, for the sake of food webs, including those of direct interest to humans, and for the sake of vulnerable human coastal communities. While more and better knowledge is not available, precautionary ecosystem management approaches should bear in mind the relevance of the small fish.

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3. Capítulo II. Damage or benefit? How future scenarios of climate change may affect the distribution of small pelagic fishes in the coastal seas of the Americas.

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4. Capítulo III. Local ecological knowledge and the importance of historical rescue: a case study of artisanal fishers's perception of variations in the availability of halfbeak in northeastern Brazil

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Action	Manuscript Number	Title	Initial Date Submitted	Status Date	Current Status
Action Links	HUEC-D-22-00032	Local ecological knowledge and the importance of historical rescue: a case study of artisanal fishers's perception of variations in the availability of halfbeak in northeastern Brazil	31 Jan 2022	31 Jan 2022	New Submission

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Local ecological knowledge and the importance of historical rescue: a case study of artisanal fishers's perception of variations in the availability of halfbeak in northeastern Brazil

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Abstract

We investigated the ecological parameters of populations of halfbeak *Hyporhamphus unifasciatus* and *Hemirampus brasiliensis* through the experience of artisanal fishers's off the coast of Northeastern Brazil in association with historical catch data. Data from the official catch of *H. brasiliensis* and *H. unifasciatus* from 1950 to 2010 allowed us to verify if the variation curve in the official catch corresponded to the variation curve, according to the perception of the specialists in this fishery. Fishers perceive an especially negative variation in species availability. Although 82% of the informants reported that the availability of ballyhoo halfbeak has decreased, there is no difference in the perception of availability. Among the fishermen who catch the common halfbeak, only 33.3% reported a reduction in the amount caught. The majority (61%) indicate that there has been no change in the amount of this species available in their fishing zones. Is no significant difference in the availability of captured common halfbeak. The shorter the experience, the greater the perception of variation in the temporal availability of the ballyhoo halfbeak, which is not repeated in relation to the common halfbeak.

Keywords: artisanal fishers; fishers' ecological knowledge; historical rescue; halfbeak.

Introduction

The intense exploitation of fisheries resources around the world has significant negative consequences for marine ecosystems (Pauly et al., 2013; Valin et al., 2014), generating severe problems related to food security (Pauly et al., 2005), that intensely affects local populations due to their direct dependence on these resources. Avoiding, reversing, and mitigating the overexploitation of fisheries resources requires public policies and decision-making for sustainable fisheries management (FAO, 2011).

However, the proper management implementation faces the lack of data on fisheries and fish stocks (Costello et al., 2012). Monitoring trends in stock abundance usually requires long-term data collection programs, which are not always carried out due to adverse environmental conditions, insufficient planning, and especially the lack of economic resources (Chambers et al., 2014; Johannes, 1998).

In the absence of long-term monitoring, the possibility of having statistical baselines that allow temporal comparisons is lost (Eddy et al., 2018.), which are essential to define good goals for the management and restoration of fish stocks (Jackson et al., 2001; Lotze & Worm, 2009; Roberts, 2003). In this context, secondary historical data, such as newspapers, and less usual sources, ranging from paintings to restaurant menus (McDowell, 2013), can help fill in knowledge gaps. One of these alternative sources shows promising results for the reconstruction of short-term statistical data, such as information provided by fishers from their memories (Pinnegar & Engelhard, 2008; Sáenz-Arroyo et al., 2006).

Still, when using the information provided by fishers, it is important to be aware of the information bias brought about by the shifting baseline syndrome (shifting baseline syndrome). In the absence of historical information or experiences, a generation takes as a reference (e.g., the moment when the resource is in its best condition) the beginning of its experience, noting as a decline or change in species composition only what happened after this one moment (Pauly, 1995). In this case, recent generational information may differ from that stored by older generations (Bruno et al., 2014);

Thus, while fostering alternative methods for data collection is essential to inform decision-making in fisheries in general and in small-scale fisheries in particular (Ruano-Chamorro et al., 2017), they must be used carefully. On the other hand and despite these limitations, there is undoubtedly enormous potential to use information from local memory to obtain knowledge about environmental changes and processes (Bell, 2001; Silvano & Begossi, 2009; Hind, 2014). For example, artisanal fishers may notice a decrease in resource abundance (Daw et al., 2011, Hallwass et al., 2013), in fish size (Sáenz-Arroyo et al., 2005a), changes in the landscape (Pitcher, 2001), the arrival of invasive species and species replacement (Johannes et al., 2000).

In most of the studies carried out to date, there has been a significant effort to seek information about fish stocks of high commercial interest, even for small-scale fishing, such as groupers, for example (Sáenz-Arroyo et al., 2005). Species used for local consumption and of lower economic value receive less attention, as is the case of small pelagics, although there are abundant examples of the collapse of these stocks due to overfishing (Lessa et al., 2004; Fréon et al., 2005; Pikitch et al., 2018).

In Brazil, the capture of small pelagics is carried out mostly by artisanal fisheries. Although not always of high economic value, many of these small pelagics contribute to the food security of coastal communities, especially fisheries, which tend to be socioeconomically more vulnerable (Lessa & Nóbrega, 2000; Pereira et al., 2010). In addition, small pelagics, in general, play a significant role in the marine food chain, as they are important foods for high-demand species such as tuna and sailfish (Pires, 1997). Among these pelagics of socioeconomic and environmental relevance, the little halfbeak (Hemirhamphidae) stand out. These fish are coastal species that occur in shallow and meadow environments, areas extremely subject to local impacts (Oliveira & Chellappa, 2014) in several Atlantic, Indian and Pacific countries (Hughes & Stewart, 2006). *Hyporhamphus unifasciatus* (ballyhoo halfbeak) and *Hemiramphus brasiliensis* (common halfbeak) are the two species of halfbeak most commonly found in Brazil and commercially exploited however, there are few studies on the economic or ecological importance of these species.

Based on these questions, we will test the hypothesis that fishers specializing in the capture of halfbeak in the Northeast of Brazil are affected by the baseline syndrome. This phenomenon promotes non-consensual information among informants of different age groups and time of life experience and between informants and official data on the variation in the capture of these species.

Methods

Sampling location

The coastal fishing area evaluated is located in the northeastern region of Brazil, in the State of Pernambuco, which is 187 km long (07° 15' 45" S and 09° 28' 18" S), along which there are 34 communities fisheries (IBAMA, 2001). According to the Koeppen classification system, this coastal region has a tropical climate of type Am'. The temperature of the region oscillates between 20ºC and 34ºC (Andrade & Lins, 1971), with two climatic seasons, usually quite distinct: a dry season, between September and January, with an average rainfall of less than 60 mm, followed by the rainy season between February and August, which has an average rainfall of over 60 mm (Nimer, 1979; Medeiros & Kjerfve, 1993).

Data collection was restricted to artisanal fishing since only this group captures the halfbeaks. Artisanal fishing provides the most significant part of the fishing production in the State of Pernambuco, and it is characterized by family and community work, using traditional techniques and technologies, either on foot or with the use of boats, such as: rafts, canoes, baiteras and small motorized boats size (Lira, 2010). Interviews were carried out in three locations on the coast of Pernambuco: Itamaracá, Ponta de Pedras and Jaboatão dos Guararapes, as they are places where the concentration of halfbeak is known (Lessa et al., 2006) (Figure 1). Itamaracá Island (7° 44′ 52″ S, 34° 49′ 33″ W) has a population of 21,884, which depends especially on the service sector and tourism. Ponta de Pedras (7º 33' 38" S, 35º 00' 09" W) is a district of the municipality of Goiana, with 8,008 inhabitants, formed by a small commercial area and a hotel chain, in addition to several restaurants that guarantee the economy of the city region. Jaboatão dos Guararapes (8º 06' 46" S, 35º 00' 53" W) is a municipality in the metropolitan region of Recife, with 702, 298 inhabitants, in which the service sector is also the most representative in the economy.

Figure 1. Fishing communities sampled, Ponta de Pedras, Itamaracá and Jaboatão dos Guararapes in the State of Pernambuco, Northeast region of Brazil.

Data collect

Data were collected through semi-structured interviews between May and September 2018. The questionnaire was designed to obtain information on possible changes in the abundance of populations of *Hyporhamphus unifasciatus* and *Hemiramphus brasiliensis* over the years, based on the perceptions of expert fishers in the communities studied. An attempt was made to access fishers specializing in the fishing of halfbeak through the colonies of each locality however, the colonies did not have information on which and how many fishers practiced fishing for the halfbeak. Specifically, in Itamaracá, there is practically no more fishing for halfbeak, where most of the interviewees were already retired. Due to the difficulty of finding only the experts, the interviewees were selected using the snowball technique, "snowball" (Berg, 2006), which relies on references from initial subjects to generate additional topics.

The interviews followed the technical recommendations of CNS nº 466/12, of the National Health Council, which meet the ethical aspects of research involving human beings, in which the informants were introduced to the research objectives and the Free and Informed Consent Term (FICT). The research was approved by the Research Ethics Committee of the University of Pernambuco (CAAE: 73680817.0.0000.5207). Then they were invited to sign it, authorizing their participation in the present study. All interviews were carried out individually, whenever possible in the afternoon, right after the fishers had completed their working day and gathered on the beach to socialize, in the case of active fishers. In the case of retirees, the interviews took place in their respective homes.

In all, 18 specialist fishers were interviewed in the fishing of halfbeak. Four were retired (they left fishing between eight and 20 years ago). Of the others, two alternate fishing with commercial activity, one no longer practices fishing, exercising another economic activity, and eleven still exercise fishing as their only source of income. All fishers are men aged between 33 and 75 years.

Official catch data were extracted from the Sea around Us platform, exclusively for Brazil, based on a national effort to reconstruct fisheries catches for 1950-2010 (Freire et al., 2014). We cut the data for Pernambuco, and to verify if the variation curve in the official catch corresponded to the variation curve, according to the perception of the specialists in this fishery, we selected the years cited by them as being the best. For these years, the fishers also estimated the amount per boat trip. Reconstruction data are presented as catches in ton per species per year, while fisheries data are presented as catches in kilograms per species per boat trip. Thus, as they are different units, only variations in trends between official capture data and informants' perception data were observed and described.

Results

Temporary availability of needle supply

Of the 18 fishers interviewed, five fished only ballyhoo halfbeak, three fished only common halfbeak and 10 fished both species.

In the fishers's perception, variation was identified in the availability of the species *H. unifasciatus* (ballyhoo halfbeak) and *H. brasiliensis* (common halfbeak) on the coast of the

State of Pernambuco. Among the informants who fish for ballyhoo halfbeak, about 82% reported that their availability has decreased over time. Even so, in the case of *H. unifasciatus*, this reduction is not statistically significant (Z (U) = 1.7836; p = 0.0745) (Figure 2).

The analysis showed that there is no significant difference in the availability of captured common halfbeak (Z (U) = 0.8718; p=0.3833) (Figure 2). Among the fishers who catch the common halfbeak, only 33.3% reported a reduction in the amount caught. The majority, 61%, indicate that there has been no change in the amount of this species available in their fishing zones.

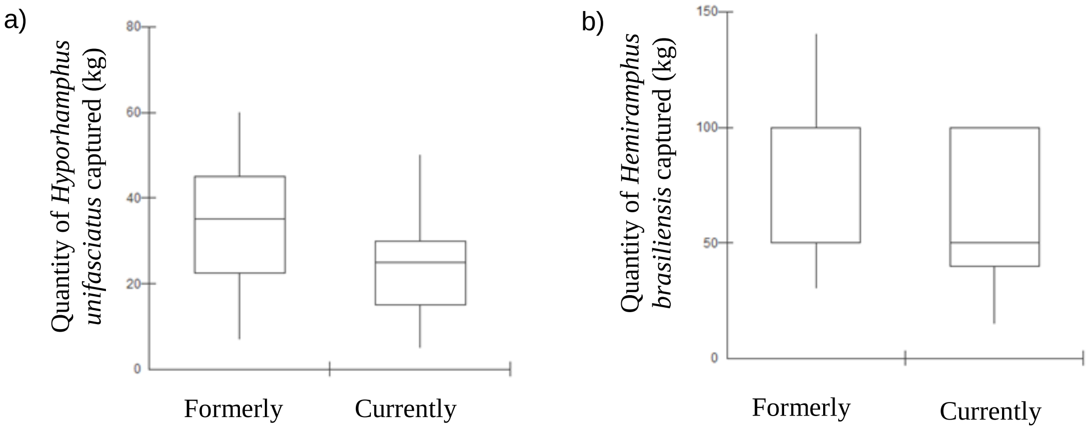

Figure 2. Estimated average catch by fishers of *Hyporhamphus unifasciatus* (ballyhoo halfbeak) (a) and *Hemiramphus brasiliensis* (common halfbeak) (b) for each boat trip in the past (considering the individual memory of older years, in fishing activity) and currently (considering the individual memory of the most recent years, in the fishing activity).

Variation in time availability and experience time

Considering the experience of fishers, in general, this time ranged between 18 and 45 years. The experience time was evenly distributed throughout the sample. However, regression analysis showed that the shorter the experience, the greater the perception of variation in the temporal availability of the white needle (R2 = 32%; p = 0.015) (Figure 3a). On the other hand, the experience time was not related to the variation in the perception of time available in the case of the black needle (R2 = 2.57%; p = 0.5744) (Figure 3b).

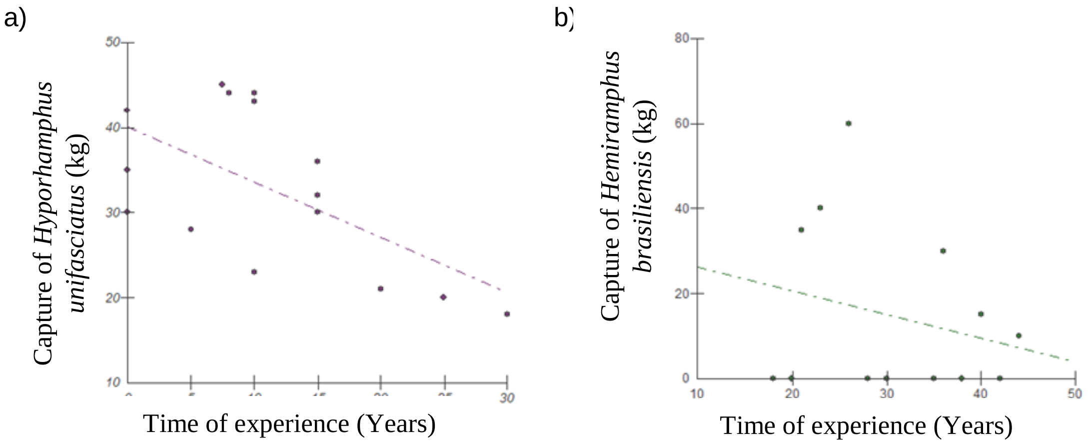

Figure 3. Variation in fishers's perception of Hyporhamphus unifasciatus (ballyhoo halfbeak) (a) and Hemiramphus brasiliensis (common halfbeak) (b) on the time available for sailing as a function of the fisherman's experience time.

Needle capture versus official data

In the historical series between the years 1950 and 2010, two major peaks were identified in the amount of H. unifasciatus (ballyhoo halfbeak) and H. brasiliensis (common halfbeak) in the late 70's to mid 80's. However, in the fishers's report, the best years of capture were from 1995 onwards for both species. Crossing official catch data from 1995 onwards with estimated data on the amount caught by fishers on each trip, it is noted that the moving average on the perception of species availability followed the official data (Figure 4).

The official data of the historical series indicate that the common halfbeak was captured more than the ballyhoo halfbeak, which is in agreement with the fishers's estimate. There was significant variation in the estimated amount of white needle caught among fishers in their best years (p = 0.0093), ranging from 45 to 80 kg per boat trip in 2000 and 1998, respectively. All the fishers who reported this period as being the best are part of the fishing colony of Ilha de Itamaracá. The period reported by all fishermen in the Ponta de Pedras colony as being the best in quantitative terms for white needle fishing was concentrated between the years 2013 and 2018, with estimates that varied significantly ($p < 0.0001$).

There was also significant variation in the estimated amount of common halfbeak caught among fishers in their best years ($p < 0.0001$), ranging from 150 to 520 kg per boat trip in 1999 and 2000, respectively. This period was reported only among fishers from the colony of Ilha de Itamaracá, suggesting that perhaps some spatial factor may have interfered with more abundant catches in more recent years, as fishers from the colonies located in Jaboatão and Ponta de Pedras estimated that the best years occurred from the year 2000 onwards. The estimated amount of common halfbeak caught between them was 90 and 320 kg per boat trip. It is possible that the techniques adopted between the colonies or the change of technique of the same colony over time, may explain the temporally different results between them.

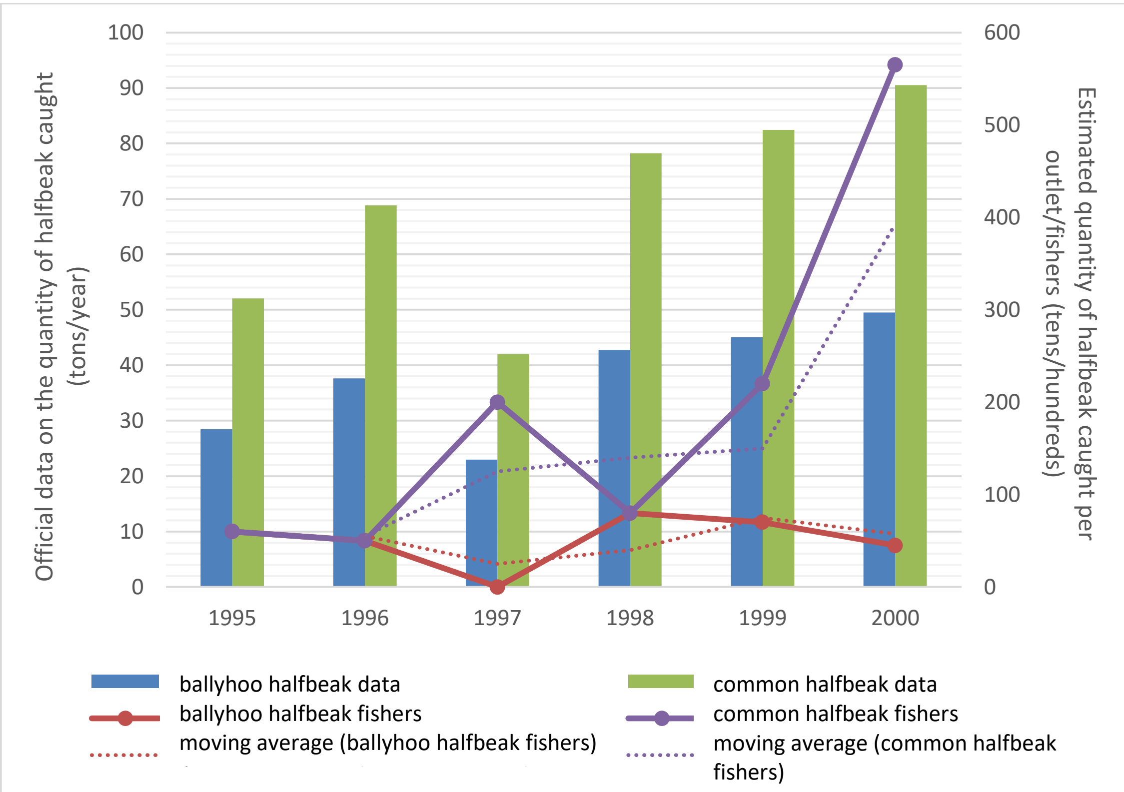

Figure 4. Crossing official catch data (in tons/year) with the perception data of the year of greatest catch (in kg per trip) reported by the fishers of *Hyporhamphus unifasciatus* (ballyhoo

halfbeak) and *Hemiramphus brasiliensis* (common halfbeak). Graph with secondary axis and a moving average trend line applied to the fishers perception record.

Discussion

Based on the results, the hypothesis that fishers specializing in the capture of halfbeak in Northeast Brazil are affected by the baseline syndrome was refuted, as the information provided by fishers of different age groups was consensual. In the case of *H. unifasciatus* (ballyhoo halfbeak), the majority reported a reduction in availability. Still, when we analyze the answers given by the informants from a quantitative point of view, there is no significance in this reduction. That is, the expression of this decrease in the amount of ballyhoo halfbeak is not detected statistically. It is important to point out that the other informants did not notice a change in the quantity of ballyhoo halfbeak. Knowing that fishers of different age groups had the same perception regarding the variation in the availability of ballyhoo halfbeak available for fishing, we can infer that the baseline syndrome does not affect this parameter in fishing. This result may indicate that the transmission of knowledge and experience from fishers occurs to new generations. This dynamic is important to avoid "generational amnesia": for example, as more experienced fishermen leave the system, the population's perception about normality refers to current conditions and past conditions are forgotten (Papworth et al., 2009). When a socioecological system is affected by the baseline shift syndrome, there is a reduction in the usefulness of local ecological knowledge in reconstructing trends in exploited populations (Sáenz-Arroyo et al., 2005). However, the results of this work point to the idea that, in general, fishers have a vast knowledge of the resources and the dynamics of the environment in which they work, although decision-makers rarely consider this knowledge for more integrated management of the resource (Hind, 2015).

Fishers's local ecological knowledge (LEK) helps to build trends regarding variations in the size of fish populations (Colloca et al., 2020). With this, it is possible to foresee changes or adjustments in practices that involve the capture of certain species at specific times of the year or particular locations. In the Mediterranean Sea, Colloca et al. (2020) identified particular localities as points of high fishing records. This points to the importance of information transmitted by fishers, possibly indicating that certain areas need special attention in the management of fisheries resources. In addition, this information can consist of consultation bases when a species may have its survival threatened, characterized by a decline in capture (Colloca et al., 2020). Using the Local Ecological Knowledge of fishers as a reference, it is possible to reconstruct trend lines and abundance of fisheries resource populations in different places in aquatic ecosystems (Hallwass et al., 2019; Peñaherrera et al., 2018; Aminpour et al., 2020;). In the Straits of Sicily, for example, 95% of fishers reported the decline of commercially important species and species that had become locally extinct (Colloca et al., 2020). This shows that local ecological knowledge of fishers can be beneficial in reconstructing long-term population trends of exploited species when traditional standard data on catch fisheries or relative abundance of species from surveys is limited or only available for recent periods (Beaudreau & Levin, 2014). At this point, Local Ecological Knowledge also becomes important for taking conservation measures and takes place in the construction of management plans (Hanazaki, 2002; Córdula & Nascimento, 2020).

The Red Book of Brazilian Fauna Threatened with Extinction recorded that *Hyporhamphus unifasciatus* (ballyhoo halfbeak), at risk of extinction, is a near-threatened species, that is, it is not classified as critically endangered or vulnerable, but is in the quantitative thresholds of the criteria and is likely to fall into a threat category soon. On the other hand, *Hemiramphus brasiliensis* (common halfbeak) was considered as a species of least concern, since no significant threats were identified regarding its geographic distribution and abundance (ICMBio/MMA, 2018). The present study showed that in *H. brasiliensis* (common halfbeak), there is a perception on the part of most fishers of stability in terms of availability in the environment. However, official catch data points to a variation in abundance on a short time scale. Thus, the hypothesis that there is no consensus between the official and perception data regarding the variation in the temporal availability of the species was confirmed in *H. brasiliensis*. In addition, in their information, they agree with the official data of capture recorded in a sequence of years, showing differences in the supply of the two species, with the common halfbeak being the most abundant. This helps to explain the fact that it is more commercially exploited.

This current scenario indicates the importance of considering local ecological knowledge in the elaboration of a management plan that helps to maintain the sizes of commercially exploited populations in order to guarantee the maintenance of the resource in the medium and long term. Some research indicates that fishing increases the variability in the abundance of exploited species. Chih-hao Hsieh et al. (2006) isolated the effects of environmental variables and the effects caused by fishing on target species and those that are not used in fishing and identified evidence that in the marine environment, exploited species exhibit greater temporal variability in abundance than unexploited species. Following this line, we can infer that the exploited populations of common halfbeak may suffer from variation in temporal supply, including a reduction in its abundance. Despite not knowing for sure, what is directly linked to this greater risk of variability, it is already known that the increase in temporal variability in the population does not arise from variable exploitation, it arises from an increased instability in dynamics. Populations whose development is interrupted by fishing have increasingly unstable population dynamics due to changes in demographic parameters, such as intrinsic growth rates (Anderson et al., 2008).

The results indicated that the shorter the experience, the greater the perception of variation in the temporal availability of the ballyhoo halfbeak.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The author declares that he has no conflict of interest.

Informed Consent

Participation in the study was voluntary and anonymous. Informed consent was obtained from all individual participants included in the study. The data and personal information collected through this study were treated confidentially.

Ethics Approval

The research was approved by the Research Ethics Committee of the University of Pernambuco (CAAE: 73680817.0.0000.5207).

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5. Orçamento

Este estudo foi financiado pela Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) por meio de Bolsa de Doutorado para o discente Thiago Pereira Guerra e com auxílio pesquisa (Item 0), em um depósito o valor de R$800,00 (2018), outro no valor de R$800,00 (2019) e outro no valor de R$1.000,00 (2020). Não houve despesas para material de campo. Os custos de transporte (Item 1) referem-se ao gasto com combustível nos 4 trajetos: 2x trajeto para entrevistas em Ponta de Pedras; 2x trajeto para entrevistas em Itamaracá, com uma média de R$ 80,00/trajeto. A alimentação (Item 2) refere-se a dias de permanência nos locais de entrevistas, que duraram 10 dias e totalizam uma média de R$30,00/dia. A estada (Item 3) refere-se a hospedagem nos locais de entrevistas, que nos 10 dias totalizaram uma média de R$60,00/dia. A tradução do manuscrito para a língua inglesa (Item 4), refere-se a requisitos de submissão da revista “Fisheries Research”, sendo selecionada a melhor proposta de orçamento entre tradutores com qualificação e qualidade profissional comprovada. A tradução do manuscrito para a língua inglesa (Item 5), refere-se a requisitos de submissão da revista “Human Ecology”, sendo selecionada a melhor proposta de orçamento entre tradutores com qualificação e qualidade profissional comprovada.

Ao total foram investidos R$2.860,00 durante 8 semestres (2017.1-2020.2) de atividades pré-experimento, experimento e pós experimento, com um gasto médio de R$357,50/semestre. O resultado orçamentário do projeto foi negativo no valor de (-) R$240,00, que foi liquidado por reservas internas da banca de orientação.

Tabela 1. Itens de despesa com respectivo valor gasto durante o desenvolvimento do projeto de pesquisa entre os meses de março/2017 a novembro/2020.

ITEM DE RECEITA	**VALOR**	
0. Auxílio pesquisa (Fonte PPGETNO)	R$	2.600,00
ITEM DE DESPESA	**VALOR**	
1. Transporte	R$	320,00
2. Alimentação	R$	300,00

3. Estada	R$	600,00
4. Tradução para o inglês 1° artigo	R$	820,00
5. Tradução para o inglês 2° artigo	R$	800,00
Total de despesas	R$	2.860,00
Total de despesas (-) Receita	-R$	240,00

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Damage or benefit? How future scenarios of climate change may affect the distribution of small pelagic fishes in the coastal seas of the Americas

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ABSTRACT

Species occurrence and distribution have already been directly affected by climate change, a scenario that is likely to be accentuated as the temperature rise is expected to exceed 2 °C by 2100. Owing to climate change, organisms are forced to migrate or adapt to new climatic conditions, and if they fail to do so, they are at risk of declining and becoming extinct. However, some species are adapted to overcome and even benefit from these new conditions, increasing their occurrence area or even their abundance. Using Bayesian Species Distribution Models (B-SDMs), we evaluated the current distribution of two halfbeak fishes, *Hyporhamphus unifasciatus* and *Hemiramphus brasiliensis*, and the effect of climate changes predicted for 2050 and 2100 on the distribution of these populations in coastal waters of the Americas. We used species occurrence data from bibliographical sources and online databases. One biotic (net primary production - NPP) and four abiotic variables (sea surface temperature - SST), sea surface salinity - SSS), depth, and sea bottom rugosity) were used as potential predictors of species distribution. Results indicated that both species are more likely found in shallower, warmer, and saltier waters. Model prediction suggests that they will probably benefit from climate change, with potential increase in their occurrence area in coastal regions of the Americas, especially due to temperature rise and increased salinity.

1. Introduction

Due to the influence of climate change, we have been witnessing a major redistribution of species worldwide. According to the Intergovernmental Panel on Climate Change (IPCC), human activities have been contributing with global temperature rise since the 1st Industrial Revolution, and by 2100 global warming is likely to exceed 2 °C (IPCC, 2018). Several impacts that are majorly negative are expected to affect most organisms on Earth, including marine ones. In fact, this can already be observed in coral bleaching events (Hoegh-Guldberg, 2005), seafood contamination (Kibria et al., 2013, 2016b), changes in several fish physiological aspects, such as impaired growth, reproduction, and survival (Perry, 2011; Kibria et al., 2016a), decline in fish diversity (Fischlin et al., 2007; Bates et al., 2008), and movement of fish towards deeper (Dulvy et al., 2008; Nye et al., 2009) and cooler waters (Last et al., 2011; Wernberg et al., 2011; Cheung et al., 2013; Barange et al., 2014).

Rapid climate change most likely reduce the chances of several species adjusting to new environmental conditions, since the response to changes tends to be insufficient to keep up with their speed and magnitude (Sinervo et al., 2010). Local adaptation and/or vertical and geographical fish migration, for instance, with consequent shift in their original distribution, is particularly affected by changes in temperature, salinity, and even depth due to sea level rise. Species that do no adapt or migrate are at risk of extinction (Berg et al., 2010; Feary et al., 2014). Pelagic fishes are expected to have the highest distributional shifts; aside from having higher mobility, sea surface layers is expected to suffer changes in their conditions at a higher rate (Cheung et al., 2012).

Although most studies report that some tropical and subtropical species are moving to warming temperate regions, while evading the tropics (Barange et al., 2014; Cheung et al., 2013, 2009; Last et al., 2011; Rijnsdorp et al. 2009), some species might be able to simply expand their original occurrence area (Barange et al., 2014; Cheung et al. 2013) or their abundance (Doubleday et al. 2016). The distribution of these

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species may increase due to their physiological characteristics or to changes in the trophic web because of the intolerance of their predators to higher temperatures, for instance (Wernberg et al., 2011; Tian et al., 2012). Thus, it seems likely that any shifts in diversity resulting from species redistribution shall have consequences on the ecosystems, including changes in the original food web (Online et al., 2017). For example, the arrival of new organisms can lead to increased mortality of some prey species either by predation or by competition with other predatory species in the area (Harley, 2011).

Depending on the sensitivity of species and ecological processes, the effects of climate change may be synergistic or even antagonistic (Fulton, 2011; Seabra et al., 2015). Additionally, the interaction of the effects of climate changes with other human stressors is likely to increase the impacts on marine species at regional and local scales (Halpern et al., 2008). One example of these stressors is human development and growth in coastal areas, which lead to the degradation of these environments, both by higher demand for fish as food and by habitat change due to construction and pollution (Bolívar et al., 2019; Ouyang et al., 2018). These actions reduce or negatively affect marine and coastal habitats that are important for species feeding, reproduction, and nursing, e.g. mangroves, reefs, and meadows formed by seagrass (Hughes and Stewart, 2006; De Oliveira and Chellappa, 2014; de Vasconcelos Filho et al., 2009). Consequently, fish abundance and marine life tend to decrease, posing a risk not only to ecosystems, but also to entire coastal socio-ecological systems, especially those marked by high human dependence on marine resources (de Barros et al., 2013; Haupt et al., 2017; Lopes et al., 2015; de Macedo et al., 2000).

Impacts on biodiversity or ecosystem services caused by climate change that result in species redistribution can be analyzed through Species Distribution Models (SDMs) (Cheung et al., 2010). SDMs are largely used in terrestrial and aquatic environments to identify species-environment relationships and predict species occurrence and/or abundance at unsampled sites (Elith and Leathwick, 2009). To date, many of these models have been used to predict the occurrence or abundance of species with high commercial value or with clear interest for conservation, and they often exclude smaller species that may occasionally play an important role in the trophic web or in human food security. Some halfbeak fish species fit these latter aspects, since they do not have great commercial importance but are used as source of food and income by fishing communities in several coastal regions around the globe (Fernandes, 2011; Lessa and Nóbrega, 2000; Mcbride et al., 1996; Pereira et al., 2010; Suzuki 1983). They are also used as bait for sport fishing (Nelson, 2006) and are part of the trophic web of large fish of economic value, such as tunas and billfish (Pires, 1997). Additionally, halfbeak fish are coastal species that occur in shallow and meadow environments, areas which are extremely vulnerable to local impacts (De Oliveira and Chellappa, 2014).

Therefore, the aim of this study was to predict the occurrence and the future effect of climate change on the distribution of two halfbeak species in the Atlantic and Pacific oceans that wash the shores of the Americas, *Hemiramphus brasiliensis* (Linnaeus, 1758), common halfbeak, and *Hyporhamphus unifasciatus* (Ranzani, 1841), ballyhoo halfbeak. Specifically, we used SDMs to (i) identify which biotic or abiotic characteristics have stronger influences on the distribution of these species; and (ii) investigate distributional shifts, including any eventual expansion or retraction, of these species in face of future scenarios of climate changes (2050 and 2100, optimistic and pessimistic scenarios of carbon emission).

2. Material and methods

2.1. Study area and database

The data used to predict current and future distribution of *Hemiramphus brasiliensis* and *Hyporhamphus unifasciatus* along the American coasts (primordial site of occurrence of the study species) derive from two sources: 1) bibliographical review and 2) online databases (Aquamaps, Gbif, and Species Link), which provide data on the presence of species (all sources, including geographical location of species occurrence events reported, are in Supplementary Material S1). For the bibliographical review, we thoroughly identified previous studies on the occurrence of *H. brasiliensis* and *H. unifasciatus* georeferenced in the Americas. The studies selected were mostly scientific samplings reporting the presence of these species in a given location, often using methods such as transects. In transects, the researcher may sample multiple areas close to each other (by a few meters, for example). For these cases where more than one georeferenced location was presented for the same general area, we randomly took one of the locations and assigned the species presence to it. Reports with ambiguous or dubious information and no geographical coordinates were excluded. In order to ensure that we included all information available, we extracted all the presence data from online databases, and then, excluded duplicated observations. After that, we combined both data sources (online databases and bibliographical review) about the presence of *H. brasiliensis* and *H. unifasciatus* in a single presence dataset for each species.

A total of 15,438 observations were reported, which is adequate to run the model (Fig. 1a and 1b). A total of 256 *H. brasiliensis* records were extracted from Aquamaps, 13,498 presences were reported in Gbif, two presence records were reported in Species Link, and 136 presence records were found in bibliographical sources. On the other hand, 193 presence records of *H. unifasciatus* were reported in Aquamaps, 1122 were reported in Gbif, eight records were reported in Species Link, and 223 presence records were found in bibliographical sources. Once duplicates were excluded, 13,542 single records remained for *H. brasiliensis* and 1282 for *H. unifasciatus*.

2.2. Environmental data

Four abiotic variables were considered as potential predictors of *H. brasiliensis* and *H. unifasciatus* distribution: sea surface temperature (SST in °C), sea surface salinity (SSS in PSU), depth (in meters), and sea bottom ruggedness. One biotic variable was considered: net primary production (NPP in mg $Cm^{-2}\,d^{-1}$).

SST and SSS were both extracted with a 1° x 1° (~ 100 km) spatial resolution from NODS_WOA09 as long-term climatology provided by NOAA / OAR / ESRL PSD, in Boulder, Colorado, USA at their website: http://www.esrl.noaa.gov/psd/. These variables were chosen because together they affect physiological processes of individuals, and therefore, species distribution (Lalli and Parsons, 1997).

Depth was derived from the database MARSPEC, (http://www.marspec.org), corresponding to a global ocean dataset with a 1° x 1° spatial resolution, developed to be used in marine spatial ecology (Sbrocco and Barber, 2013). This variable was chosen because it is one of the major environmental gradients that control spatial patterns of marine species (Costa et al., 2017; Dell'Apa et al., 2017).

Rugosity was derived from the depth map using the "Terrain" feature of the "raster" package (Hijimans, 2017) in the R software (R Core Team, 2019). This feature generates a rugosity index (Terrain Ruggedness Index) as the mean of absolute differences between the value of a cell and the value of the adjacent eight cells. Low rugosity values indicate that there are no variations in terrain, e.g. an unconsolidated substrate (for example, mud and sand), while high rugosity values are associated to potential rocky substrates (Fonseca et al., 2017). When there is no detailed information available about the type of sediment, this parameter is largely used as a predictor of species distribution (Pennino et al., 2019). Rugosity is used in marine species distribution models since many species, especially demersal species, tend to restrain their occupation to the bottom, where they find food or shelter (Dunn and Halpin, 2009). Pelagic ones, as the ones in this study, might be affected by the rugosity of the sea floor if that defines their feeding habitats or nursing sites, for example (Maravelias, 1999).

Net primary production (NPP) was extracted from a global 920 ×

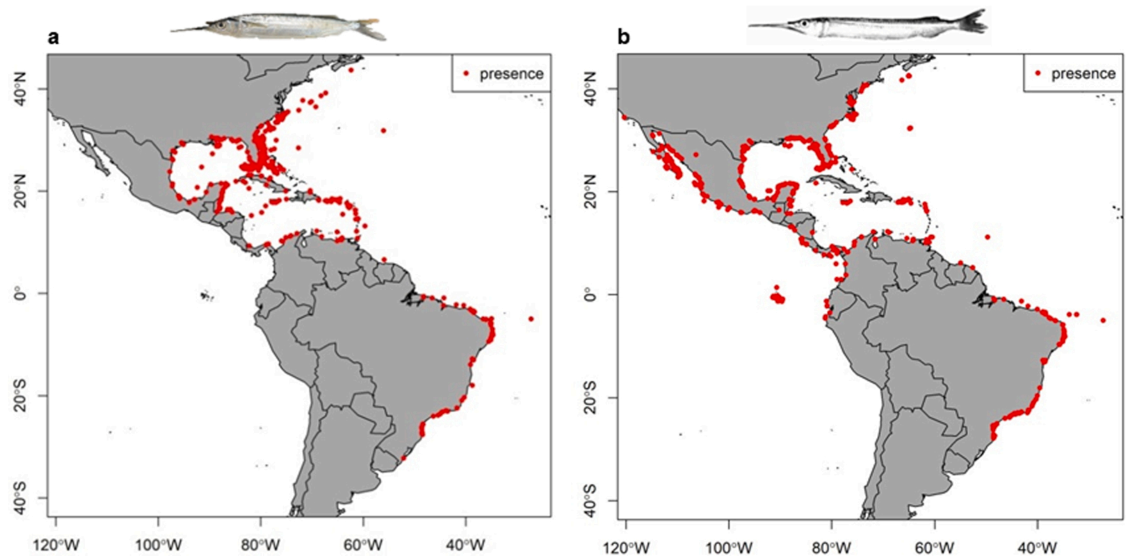

Fig. 1. Presence sites (red circles) of *Hemiramphus brasiliensis* (a) and *Hyporhamphus unifasciatus* (b), identified by searching the literature and databases (Aquamaps, Gbif, and Species Link). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

1680 NPP grid and calculated according to chlorophyll, available light, and photosynthetic efficiency using the entire chlorophyll record from SeaWIFS (1998–2016), at the Ocean Productivity website, with a 1° x 1° resolution (http://www.science.oregonstate.edu/ocean.productivity/index.php). Net primary production was chosen as it is an indicator of food availability at the base of the marine food chain, thus favoring the presence of small pelagic fishes (Durbin, 1979).

Caution was taken to ensure that the spatial resolution used (1° x 1°) was the same for each environmental predictor, since they were extracted from different sources. All environmental variables were standardized to allow the comparison of relative weights between variables (Kinas and Andrade, 2014).

Multicollinearity was checked using Pearson's correlation index and VIF (Variance Inflation Factor). Typical data exploitation procedures were routinely performed according to Zuur et al. (2010). All variables used in the model had correlations lower than $r = 0.65$ and VIF lower than 3.

Additionally, spatial models were generated to check future scenarios for 2050 and 2100, using different predictions for variables extracted from the Intergovernmental Panel on Climate Changes (IPCC) using the database BioOracle (http: //www.biooracle.org) with 1° x 1° spatial resolution. Greenhouse gas concentration trajectory was based on Representative Concentration Pathways (RCP), which are scenarios that describe alternative trajectories for carbon dioxide emissions and the resulting atmospheric concentration between 2000 and 2100, considering an optimistic stabilization scenario (RCP 2.6) and a pessimistic "business-as-usual" scenario (RCP 8.5). We particularly used the mean value between RCP 2.6 and RCP 8.5 for 2050 and 2100, which includes future SSS and SST scenarios. Depth and rugosity were kept constant, as well as NPP, since there is no spatial prediction for these variables (as they are not supposed to change significantly).

2.3. Sampling of uncertainties

Data collection from several sources (literature, Aquamaps, Gbif, and Species Link) might generate the so-called observer's bias, caused by the individual behavior of the observers, by either random aspects or unobserved sampling characteristics. Overlooking this data dependence could lead to an invalid statistical inference (Roos et al., 2015; Costa et al., 2017). In order to remove this potential bias in the sampling process, the observer effect was added to the models as a random effect, since understanding the specific nature of the observers was not the object of this study.

2.4. Statistical models

Probability of occurrence of *H. brasiliensis* and *H. unifasciatus* was estimated using the iCAR Bayesian model, which considers a potential spatial autocorrelation in the data (Latimer et al., 2006) and different sources of uncertainties. We used a Gaussian intrinsic conditional autoregressive (iCAR) model (Besag, 1974) for the spatial autocorrelation between observers, assuming that the probability of presence of species at a given site depends on the probability of presence of the species at neighboring sites. The dataset of absences was randomly generated in the model as pseudoabsences, considering known species distribution. The number of pseudoabsences was exactly the same as the number of presences. Pseudoabsences and actual presences were then combined in a single spreadsheet to be used in the binomial model. Particularly, the random variable Y_i might be assumed as following a Bernoulli distribution, and thus, its value might be either 1 or 0 depending on whether the habitat is either suitable ($Y_i = 1$) or not ($Y_i = 0$), so that:

$$Y_i \sim \text{Bernoulli}(\pi_i)$$

$$\text{logit}(\pi_i) = X_i\beta + Z_i + W_{j(i)}$$

where X_i is the matrix of covariates, β represents the vector of the regression coefficients, W represents the spatial random effect of observation i in grid cell j (i.e. matrix of neighbors), and a logit link is used to model the relationship between the probability of occurrence π_i, the covariates of interest and spatial effect.

Vague priors centered at zero with a higher variation of 100 were used for all parameters involved in the model, and a uniform distribution was used for the variance of spatial effect.

These models were adapted using the "hSDM" package (Vieilledent et al., 2014) in the statistical environment (R Core Team, 2019).

All resulting models obtained from the combination of variables mentioned and respective interactions were adjusted and compared using both backward and forward approaches, using the Deviance Information Criterion (DIC) (Spiegelhalter et al., 2002) and Watanabe–Akaike information criterion (WAIC) (Watanabe, 2010). Lower DIC and WAIC values represent a better fit between adjustment and parsimony.

In order to track the effect between the selected environmental variables and predicted values, the "ggplot" (Wickham et al., 2019) package from R software was used.

Once relevant variables were estimated for the species, three types of predictions were performed for species occurrence area: 1) current distribution; 2) distribution for 2050; and 3) distribution for 2100. For future distributions, the RCP 2.6 and RCP 8.5 scenarios were used as predictor for 2050 and 2100, using only the relevant variables selected.

The basic code used in the modeling presented here is available at https://github.com/MgraziaPennino/Fisheries_Research_Guerra.

2.5. Model validation for occurrence

For each prediction, we validated the best model selected using an internal 10-fold cross-validation based on training and testing datasets selected randomly (which were created using a random selection of 75 % and 25 % of data, respectively) (Fielding and Bell, 1997), with the "PresenceAbsence" package (Freeman and Moisen, 2008) in R. The model's performance was evaluated using the area under the receiver-operating characteristic curve (AUC) (Fielding and Bell, 1997), the "True Skill Statistic" (TSS) (Allouche et al., 2006) and the root mean square error (RMSE). The RMSE represents the standard error of the differences between predicted values and observed values. The closer this statistic is to zero, the better the model's prediction (Potts and Elith, 2006).

3. Results

The occurrence of *H. brasiliensis* and *H. unifasciatus* seems to be mostly determined, in order of importance, by depth, sea surface temperature (SST), sea surface salinity (SSS), and ruggedness, as well as by the spatial component that represented the residual spatial autocorrelation. Net primary production (NPP) relevance was very low (probability lower than 20 %) for both species and was removed from the final model.

The results showed a positive correlation between depth (though non linear), SST, SSS, and the probability of occurrence of *H. brasiliensis* and *H. unifasciatus*, which means that there is higher probability of finding these species in shallower, warmer, and saltier waters. On the other hand, ruggedness had a negative relationship with occurrence, indicating that the probabilities of finding these species are also higher in unconsolidated substrates.

Particularly, higher probabilities of occurrence of *H. brasiliensis* were found in a depths ranging between 0−50 m (mean = 2.01; CI 95 % = [1.62, 2.41]), SST between 25.5 and 28 °C (mean = 1.31; CI 95 % = [0.36, 2.36]), SSS between 32–35 PSU (mean = 0.53; CI 95 % = [0.12, 0.98]), and in unconsolidated substrates (mean = -0.14; CI 95 % = [-0.16, 0.44]) (Fig. 2a). On the other hand, although *H. unifasciatus* also has higher probability of occurrence in shallower waters (0−50 m, mean = 3.58; CI 95 % = [2.96, 4.29]), it has a slight difference in temperature range (SST between 21 and 30 °C, mean = 0.47; CI 95 % = [-0.28, 1.21]) and salinity (SSS between 30–34 PSU, mean = 0.01; CI 95 % = [-0.32, 0.34]), with preference also for unconsolidated substrates (mean = 0.67; CI 95 % = [0.33, 1.04]) (Fig. 2b).

A higher probability of occurrence of *H. brasiliensis* and *H. unifasciatus* in coastal waters was demonstrated throughout the American continent, especially in the region between northern Brazil and southern United States. However, the distribution of *H. brasiliensis* is restricted to the Atlantic, and it also has a probability of occurrence in southeastern Brazil (Fig. 3a). Similarly, *H. unifasciatus* is also likely to occur in northeastern and southeastern Brazil, although with a lower probability of occurrence, and it also occurs in the Pacific, between Ecuador and Mexico, especially in the Baja California region (Fig. 4a).

According to predicted distributions of occurrence, it is noticeable that both halfbeak species are expected to increase in the area, with higher probability of occurrence in 2050 and 2100 for both RCPs, compared to the current estimated distribution. For *H. brasiliensis*, the prediction for 2050 increases in nearly the entire Atlantic coast of the Americas and it is more significant in North America, Central America, and in the Venezuelan coast (Fig. 3b, d). For 2100, a higher increase in the predicted occurrence is located between Venezuela and Suriname and in the Brazilian coast (Fig. 3c, e). Similarly, the distribution of *H. unifasciatus* is expected to increase in nearly all the Americas, occupying both the Atlantic and a part of the Pacific by 2050 (Fig. 4b, d). This increase shall be even more significant by 2100 (Fig. 4c, e).

For model validation, reasonably high values for TSS were obtained for both species. In particular, a TSS of 0.67 and 0.64 were obtained for *H. brasiliensis* and for *H. unifasciatus,* respectively. Low values of RMSE were achieved for both species, with an RMSE of 0.94 for *H. brasiliensis* and with an RMSE of 0.98 for *H. unifasciatus.*

4. Discussion

As opposed to many other species, temperature rise tends to affect positively the future distribution of these two halfbeak species,

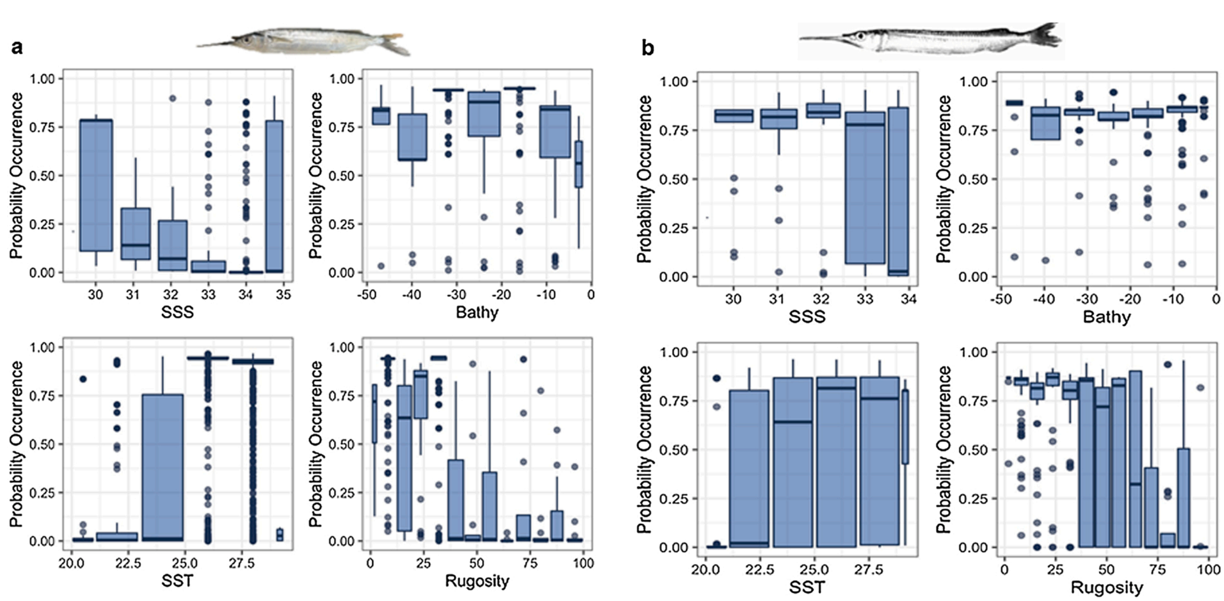

Fig. 2. Effect of the environmental variables on the predicted probability of occurrence of *Hemiramphus brasiliensis* (a) and *Hyporhamphus unifasciatus* (b).

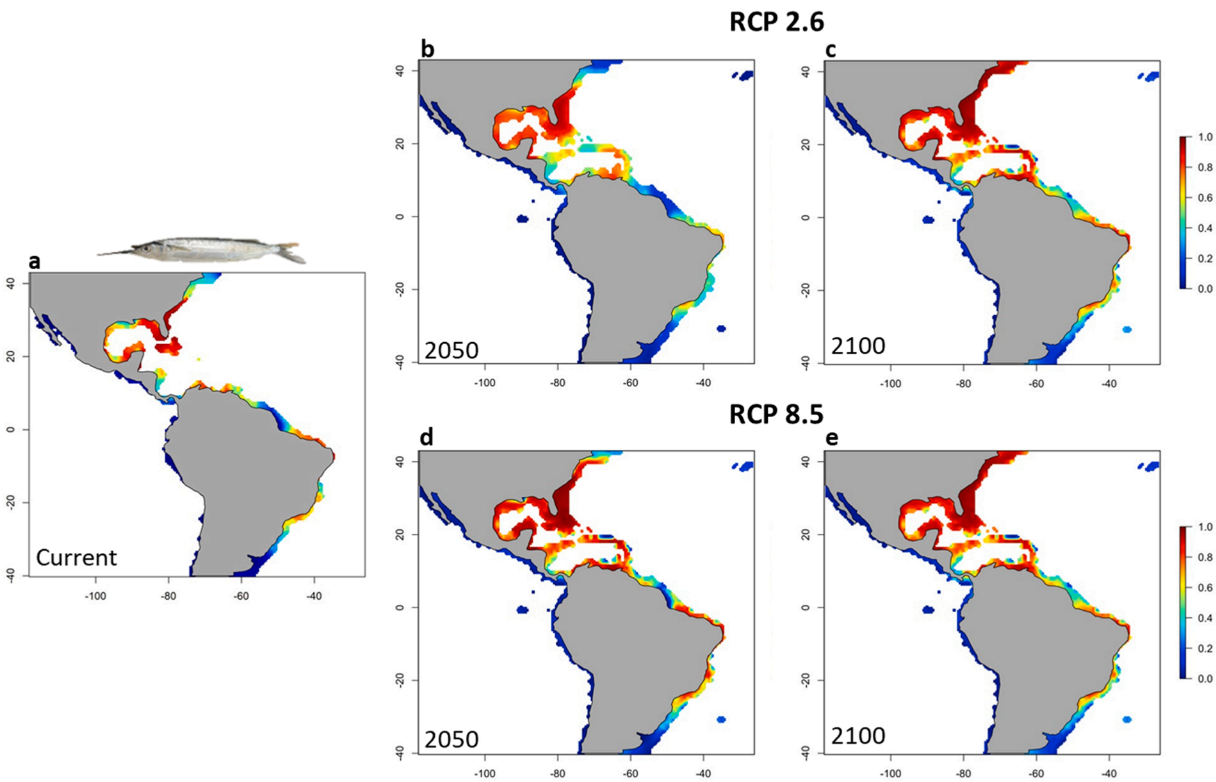

Fig. 3. Current mean probability of occurrence of *Hemiramphus brasiliensis* (a), in 2050 (b, d), and 2100 (c, e) according to the RCP 2.6 and RCP 8.5 scenarios, respectively, which are based on expected global changes.

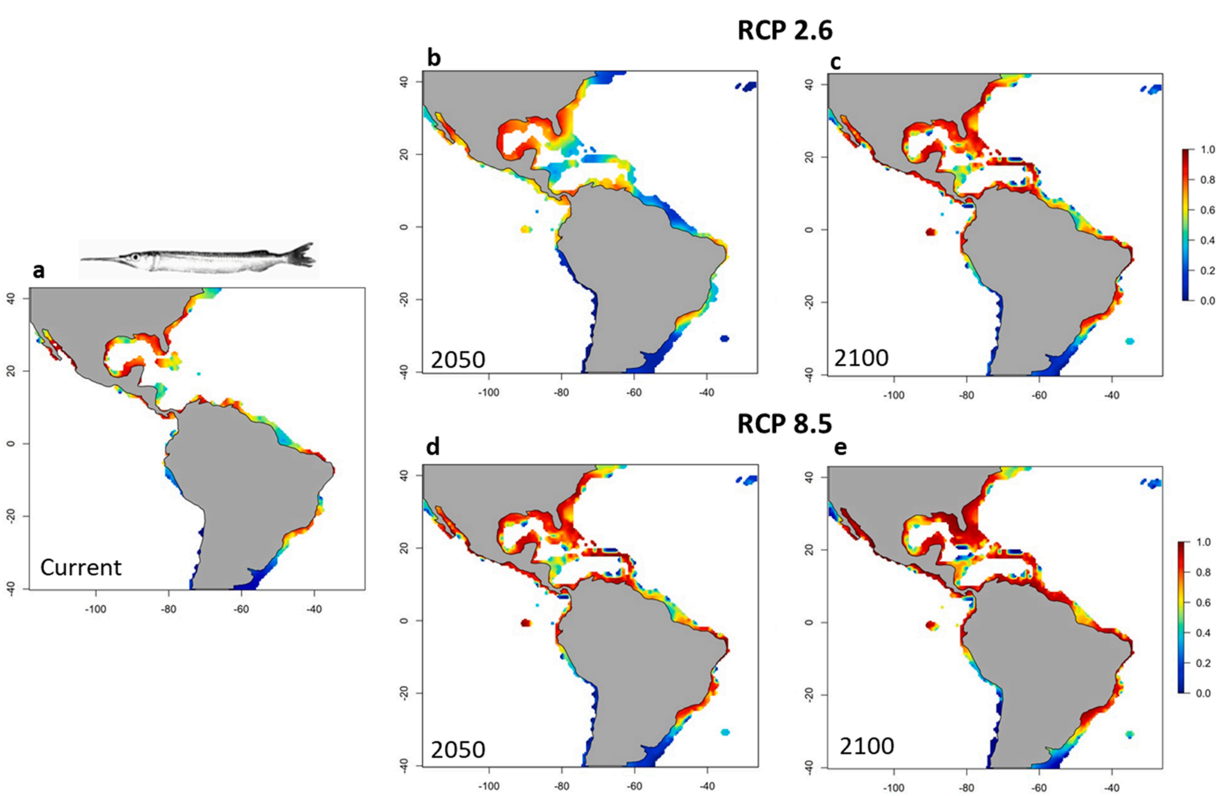

Fig. 4. Current mean probability of occurrence of *Hyporhamphus unifasciatus* (a), in 2050 (b, d) and 2100 (c, e), according to the RCP 2.6 and RCP 8.5 scenarios, respectively, which are based on expected global changes.

indicating that these small pelagic fishes, rather than migrating, are probably spreading along tropical coastal seas of the Americas. This prediction is corroborated even by the most pessimistic scenario (with the highest warmth) for 2100. Results suggest that *H. brasiliensis* and *H. unifasciatus* will probably have their distribution increased in the Americas as they have a wider tolerance range to temperature rise on the sea surface, and might thus remain within their preferred environmental conditions. However, both species do have defined tolerance limits, especially *H. brasiliensis*, which tends to collapse at surface temperatures above 27 °C. However, *H. unifasciatus* seems to tolerate slightly higher temperature, and is more capable of adjusting to the rapid changes in temperature expected to occur in a short period of time due to global warming.

Although several biotic and abiotic factors affect marine fish distribution (Dunstan and Bax, 2007; Feary et al., 2014), ocean warming seems to have a higher influence on geographic redistribution of species (Feary et al., 2014; Figueira and Booth, 2010; Nakamura et al., 2013; Verba et al., 2020). Due to changes in sea surface temperature, many fish species need to migrate to regions where temperature does not restrain their physiological needs, thus ensuring their survival (Cheung et al., 2013; Barange et al., 2014). As they are closer to their physiological limits of tolerance to temperature, some tropical species that inhabit warmer waters have a narrower range of thermal variations (Storch et al., 2014). These species are at a higher risk of extinction due to sea temperature rise, which consequently leads many other species to migrate in search of conditions that are more favorable to their development (Cheung et al., 2009). However, this does not seem to be the future of the halfbeak species studied here, owing to their high tolerance to higher temperatures.

On the other hand, temperature is one of the aspects that affect species occurrence, and other variables, such as salinity in oceans and coastal seas, are also important for the distribution of marine organisms, especially those that depend on specific salinity ranges to survive, e.g. seagrass, mollusks, crustaceans, and several fish species of ecological and economic importance (Attrill, 2002; Vega-Cendejas and Hernández de Santillana, 2004). As they are coastal species and use estuarine environments at some life phase to reproduce, find shelter, or feed (Jones, 1990; Noell, 2003; Sokolovsky and Sokolovskaya, 1999; de Vasconcelos Filho et al., 1984), halfbeaks have physiological adaptations to withstand salinity variations. Aside from salinization of coastal environments due to anthropogenic interference in the natural course of many rivers (Rapti-Caputo, 2010), IPCC projections estimate an increase in ocean salinity of 1.5 PSU by 2100 in the more pessimistic scenarios (IPCC, 2018). Even this maximum expected salinity does not seem to harm these species directly, as it might provide environments that are still suitable for their development, thus increasing their distribution in coastal waters of the Americas.

The distribution of many species also depends on factors such as depth (Costa et al., 2017; Dell'Apa et al., 2017), which may even be associated to water surface temperature, especially for species that move in the water column (Dulvy et al., 2008; Nye et al., 2009). Halfbeaks have a clear preference for shallower waters, and this is the major factor that affects their distribution. Previous studies have already indicated the preference for waters that are slightly distant from the coast, provided that their depth lay between 5−20 m, in the case of *H. brasiliensis* (McBride and Styer, 2002), while *H. unifasciatus* prefers coastal waters and protected areas inside reefs (Collette, 1978; Lieske and Myers, 1994; McBride and Styer, 2002). In this study, the higher probability of occurrence of these species lies exactly in shallow waters with depths up to 200 m. According to more pessimistic predictions, IPCC estimates a sea level rise of approximately 82 cm by 2100. Although this rise was not modeled in the present study, if this prediction is fulfilled, sea level rise might damage and even destroy coastal ecosystems, threatening not only halfbeaks, but all organisms that depend on coastal environments (Kibria et al., 2016a).

Halfbeaks have a connection with marine phanerogams in all regions where they are found; the latter are used by the former for egg deposition, as part of their diet, and even as shelter against predators (Berkeley and Houde, 1978; Noell, 2003; Sokolovsky and Sokolovskaya, 1999; de Vasconcelos Filho et al., 1984). Their relationship with these plants might probably explain the preference of these fishes for shallower sites and unconsolidated substrates. These sites are generally preferred by the phanerogam *Halodule wrightii*, a plant that is abundant where arenite and coral reefs isolate areas with gentle and shallow waters, as well as in mouths of less polluted rivers (Laborel-Deguen, 1963). In rocky bottoms, i.e. consolidated substrates, these marine plants are less frequent (Laborel-Deguen, 1963), and this possibly explain the lower probability of finding halfbeaks at these sites, since they need a favorable environment to feed and to successfully breed, in order to ensure their maintenance and expansion.

Although the modeling performed in this study indicates a higher success of species analyzed in climate change scenarios, it is important to acknowledge that the results only represent partial scenarios that do not control for additional factors. In this specific case, the future of marine phanerogams, for instance, on which halfbeaks depend, is not considered. Marine phanerogams could undergo a decline if temperature rises beyond their thermal tolerances (Hyndes et al., 2016). They could also suffer increased herbivoria due to climate change (Vergés et al., 2014), which could cause increased abundance of some exotic and invasive herbivore fishes (Fodrie et al., 2010), which in turn consume seagrass at higher rates than those of native herbivores (Prado and Heck, 2011). In addition, the region over which the two halfbeak are expected to occupy may undergo local impacts, as these are coastal species. Coastal zones suffer from several anthropogenic pressures, especially unplanned growth and its corresponding consequences, and poor management of their natural resources (de Barros et al., 2013; Lopes et al., 2015; Haupt et al., 2017).

Local anthropogenic impacts may thus frustrate the expected geographic expansion of those species that could benefit from increased temperature or salinity, as is the case of halfbeaks. For instance, anecdotal information provided by experienced fishermen from the Brazilian northeastern coast suggests that the common halfbeak (*H. unifasciatus*) practically disappeared when meadows of *H. wrightii* decreased. These meadows started to be removed in large quantities and with no proper management to feed manatees (*Trichechus manatus*) in a conservation project for this species (*Projeto Peixe Boi*), during the 1980's and 1990's (personal communication). Thus, even in the occasional cases in which climate changes seem to be positive to marine organisms, it is still important to consider that these scenarios represent limited and simplified views of the future. In many cases, other anthropogenic interferences, such as those that occur at a local scale, might account for the reduction and even extinction of species and populations (Jackson et al., 2001; Giglio et al., 2017). There are also other biological interactions that are not modeled here that define the success and distribution of a species, such as interaction between prey species and between other chain links (Harley et al., 2006; Hsieh et al., 2008). Still, the results provided here help understand which environmental variables have higher influence on the occurrence of a species, and emphasize the role of temperature in determining species distribution in coastal seas. In this specific case, the hypothesis of ocean "tropicalization" is confirmed, and in this scenario, some species are likely to occupy new niches and potentially benefit from climate change (Vergés et al., 2014).

Although the spatial resolution of 1° x 1° is too general to capture subtle changes in coastal regions, such as the dynamic distribution of phanerogams spots (Sbrocco and Barber, 2013), this is the lowest scale where all variables, i.e., temperature, salinity and depth, can be modeled together. In the future, with new technologies and consequently finer scales of spatial resolutions, forecasts will likely be improved.

Finally, it is worth emphasizing that this is the first study to use a Bayesian approach to predict the distribution of these halfbeak species in the Americas, analyzing current predictions, and future predictions for 2050 and 2100, under two different scenarios. These predictions indicate that these fishes could benefit from climate change by expanding their distribution significantly in coastal waters of the Americas. However, the complexity of relationships that determine species occurrence is related to a wide array of environmental abiotic and biotic factors. Therefore, even if predictions indicate that some resident species may benefit from a scenario of ocean warming, there are still local environmental issues that shall play a decisive role in species distribution and occurrence. As we understand better the role of environmental variables and refine the models to incorporate local aspects, we shall be able to predict more accurately the interaction between the climate crisis and the use of resources.

CRediT authorship contribution statement

Thiago Pereira Guerra: Investigation, Writing - original draft. **Josiene Maria Falcão Fraga dos Santos:** Writing - review & editing. **Maria Grazia Pennino:** Methodology, Formal analysis. **Priscila Fabiana Macedo Lopes:** Conceptualization, Supervision, Methodology, Writing - review & editing.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fishres.2020.105815.

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