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Potential geographic distribution and conservation of Audubon's Shearwater, *Puffinus lherminieri* in Brazil

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ABSTRACT

*Audubon's Shearwater (*Puffinus lherminieri *Lesson 1839) is a tropical seabird occurring mainly between southern Canada and the southeast coast of Brazil.* Puffinus lherminieri *is considered Critically Endangered on the Brazilian Red List because it only occurs in two known localities, both of which contain very small populations. However, many offshore islands along the Brazilian coast are poorly known and the discovery of new colonies would be of considerable significance for the conservation of this species. The aim of this study was to estimate the potential geographic distribution of Audubon's Shearwater in Brazil, based on ecological niche model (ENM) using Maxent algorithm with layers obtained from AquaMaps environmental dataset. The ENM was based on 37 records for reproduction areas in North and South America. The model yielded a very broad potential distribution, covering most of the Atlantic coast ranging from Brazil to the US. When filtered for islands along the Brazilian coast, the model indicates higher levels of environmental suitability near the states of São Paulo, Rio de Janeiro, Espírito Santo and Bahia. However,* P. lherminieri *prefers islands in environments with warm saline water. Thus, based on the influence of currents that act on the Brazilian coast we can infer undiscovered colonies are most likely to occur on islands on coast of Bahia, Espírito Santo and extreme north of the Rio de Janeiro. These should be intensively surveyed while the islands south of Cabo Frio should be discarded. The existence of new populations would have profound effects on the conservation status of this enigmatic and rarely seen seabird.*

Key-Words: Audubon's Shearwater; Ecological niche model; Maxent; Brazilian coast.

INTRODUCTION

Audubon's Shearwater, *Puffinus lherminieri* Lesson, 1839 is a tropical seabird, mainly distributed across the Indian Ocean, throughout the northeast and central Pacific, including the Galapagos Islands (del Hoyo *et al.,* 1992). In western Atlantic, breeding in the island of the Caribbean Sea and Gulf of

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Mexico (Carboneras, 1992; Austin *et al.,* 2004; Onley & Scofield, 2007). Tobago was initially thought to be the breeding station closest to the South American continent (Murphy, 1936), and until 1970 no colonies were found in the South Atlantic (Bourne & Loveridge, 1978). However, in 1989 a breeding colony of a Little Shearwater was recorded on the archipelago of Fernando de Noronha (Antas, 1991), northeastern Brazil. Later, Soto & Filippini (2003) and recently, Silva e Silva & Olmos (2010) confirmed that the shearwaters of Fernando de Noronha belonged to the small *loyemilleri* form of Audubon's Shearwater. In 1993 another colony was recorded on the Itatiaia Archipelago, southeastern Brazil (Efe & Musso, 2001). Moreover, the fact that both colonies went unrecorded until recently also suggests that there may be other, unknown, colonies on some of the less well surveyed islands along the Brazilian coast (Efe, 2004).

Audubon's Shearwater is considered Critically Endangered on the Brazilian Red List due to its apparently restricted distribution (two localities) and very small population size (Efe, 2008). Given the lack of detailed data about seabird distributions on Brazilian coastal islands (Efe, 2004), one of the priority actions for conservation is to search for new populations (Neves *et al.,* 2006). However, petrels and tropical seabird species in general are notoriously difficult to locate (Day & Cooper, 1995); they are also remarkably difficult to identify at sea due to their very fast flying action. Moreover, many species, including Audubon's Shearwater, arrive in the colony after dark and leave it before dawn. During daylight hours, adult Audubon's Shearwaters remain in the nest, giving little sign of being present (Efe, 2004). Given the labor-intensive nature of detecting colonies of this species by several researchers in the past (*e.g.,* Ridley, 1888; Murphy, 1936; Olson, 1981; Nacinovic & Teixeira, 1989), survey efforts need to be concentrated on islands that are most likely to harbor populations. Identifying islands with suitable habitat for this species can be achieved through a combination of 'Ecological Niche Models' (ENMs). Such models produce a prediction of the potential distribution of a given species by relating the species known occurrence records with environmental data (Guisan & Zimmermann, 2000; Papes, 2007).

In this scenario, 'Ecological Niche modeling' has been shown to be a useful tool to predict actual species distribution, and are considered important tools in conservation biology (Rodríguez *et al.,* 2007). ENM can direct collection efforts in areas lacking ecological and biological knowledge, optimizing field activities, reducing costs and contributing to conservation strategies (Guisan *et al.,* 2006; Siqueira *et al.,* 2009). Therefore, the aim of this work was to estimate the potential geographic distribution of Audubon's Shearwaters in Brazil, based on ENM.

METHODS

Data collection

A database with geo-referenced breeding areas of the Audubon's Shearwaters was constructed using information from scientific literature citations and information publically available. The data was checked in the DIVA-GIS software (Hijmans *et al.,* 2002) for bias and errors. The coordinates of the breeding areas were then adjusted using Google Earth®. The islands in the Brazilian coast were geo-referenced through Google Earth®. A 1 degree gridfile was then created, where each cell containing at least one island was registered as "island presence" for further analysis after modelling (see below). The usage of 1 degree cells can lead to somewhat coarser distributional predictions, but this will prevent errors produced by non-exact coordinates from the breeding areas.

Analysis

The potential distribution of Audubon's Shearwaters was estimated by an ecological niche model using the Maximum Entropy (Maxent) algorithm (Phillips *et al.,* 2006), considered of high predictive efficiency for threatened species and species with few known occurrence records (Pearson *et al.,* 2007).

The layers used in the modeling were obtained from the AquaMaps environmental dataset (Kaschner *et al.,* 2010). The variables were: maximum and minimum depth, mean annual sea ice concentration, distance of land, mean annual primary production, mean annual surface and bottom salinity and mean annual surface and bottom temperature. Even though variables such as bottom temperature and salinity are not expected to have a direct effect over this species, they should have indirect effects as they can influence resource availability. Distance from land and ice concentration are important variables to prevent the model from making too much broad distributions, including areas that are certainly outside the species range.

The generated models were visualized as maps using the software DIVA-GIS. Maxent's predicted conditions (a scale that goes from less to more suitable habitat for the modelled species) was divided

TABLE 1: Data sources used to estimate the potential geographic distribution of Audubon's Shearwaters in Brazil.

ID	Latitude	Longitude	Local	Source
1	22.093	-74.528	Mira Por Vos Islands	BirdLife International 2013
2	32.344	-64.661	Castle Harbour Islet	Olson 2010
3	17.638	-63.226	Saba Island	Lee & Mackin 2009
4	16.336	-61.693	Saint Barthélemy	Olson 2013
5	27.270	-78.417	Western Abaco Island (AB42), Walkers Cay	Kushlan & Steinkamp 2007
6	27.272	-78.420	Western Abaco Island (AB46), Walkers Cay	Kushlan & Steinkamp 2007
7	27.043	-78.170	Western Abaco Island (AB34), Sale Cay	Kushlan & Steinkamp 2007
8	17.021	-61.809	Antigua and Barbuda	Lee & Mackin 2009
9	18.195	-63.099	Anguilla	Lee & Mackin 2009
10	13.330	-59.628	Barbados	Lee & Mackin 2009
11	18.429	-64.521	British Virgin Islands	Lee & Mackin 2009
12	20.054	-74.714	Cuba	Lee & Mackin 2009
13	18.019	-63.026	San Martin	Lee & Mackin 2009
14	12.044	-61.635	Grenada	Lee & Mackin 2009
15	19.665	-73.155	Haiti	Lee & Mackin 2009
16	17.866	-77.628	Jamaica	Lee & Mackin 2009
17	14.410	-60.886	Martinique	Lee & Mackin 2009
18	18.396	-75.015	Navassa Island	Lee & Mackin 2009
19	18.070	-67.874	Mona Island, Puerto Rico	Lee & Mackin 2009
20	11.296	-60.492	Little Tobago, Trinidad and Tobago	Lee & Mackin 2009
21	22.182	-75.711	Ragged Islands	Lee & Mackin 2009
22	21.657	-71.510	Turks and Caicos Islands	Lee & Mackin 2009
23	18.323	-64.932	US Virgin Islands	Lee & Mackin 2009
24	11.873	-66.723	Isla Los Roques	Masi 2010
25	11.774	-66.147	Isla La Orchila	Masi 2010
26	9.211	-81.917	Tiger Rock islands	Masi 2010
27	18.311	-65.347	Cayo del Agua, Culebra	Masi 2010
28	-3.872	-32.438	Ilha da Viuvinha, Fernando de Noronha	Silva e Silva & Olmos 2010
29	-3.873	-32.435	Ilha do Leão, Fernando de Noronha	Silva e Silva & Olmos 2010
30	-20.362	-40.279	Ilhas Itatiaia, Vila Velha	Efe & Musso 2001

into three equal parts, thus producing three levels of environmental suitability. Only cells predicted with values above Maxent's "Maximum training sensitivity plus specificity" threshold were considered, since this choice is expected to generate optimistic models, suitable for considering new areas where the species might be found. Finally, the potential distribution map was filtered using the "island presence" grid cells in order to refine the results of the model focusing on areas with the most suitable habitat for this species.

RESULTS

A total of 30 records were identified as breeding areas in North and South America (Table 1, Fig. 1), coincident with the western Atlantic distribution area recognized for Audubon's Shearwaters (BirdLife International, 2014). The ecological niche model generated by Maxent (the area under the ROC curve, a measure of model performance was 0.987) yielded a very broad potential distribution, covering the Atlantic coast ranging from Brazil to the Mexico, including Greater and Lesser Antilles (Fig. 2a, b).

The areas with the highest values of environmental suitability, however, were much more restricted, with only a few grid cells with high values. From south to north, it was possible to identify three coastal areas with high environmental suitability: i) Espírito Santo to Maranhão (Brazil); ii) Venezuela, and; iii) the Greater and Lesser Antilles. This last-named region had the largest area of environmental suitability.

When filtered for the presence of islands along the Brazilian coast (Fig. 3a, b), the model indicates to higher environmental suitability near the states of Rio de Janeiro, Espírito Santo, Bahia and Pernambuco, ranging from latitudes 22° to 03°S.

FIGURE 1: Known colonies of Audubon's Shearwater on Americas Atlantic coast used to estimate the potential geographic distribution of Audubon's Shearwaters in Brazil.

FIGURE 2: Potential distribution of Audubon's Shearwater based on the Maxent algorithm with marine environmental data (a = with colonies of Brazil; b = without colonies of Brazil). Darker colors signify higher environmental suitability.

DISCUSSION

In the North Atlantic, Audubon's Shearwater has a large geographic range including the Caribbean Sea and Gulf of Mexico (Carboneras, 1992). These areas are strongly associated with South Equatorial and Gulf Currents, indicating that the species prefers islands in environments with warm, salty water. Our model supported this occurrence pattern and expanded the potential distribution of species in the South Atlantic. This can be explained by influence of Brazil Current; this system runs south along the coast of Brazil carrying warm and salty subtropical water.

Is fact that global oceanic circulation patterns strongly influence the places where seabirds feed (Hunt Jr., 1991). Therefore, once the seabird distribution is not random, but often intimately associated with the inconsistencies in the ocean environment (Shealer, 2001), the Brazil Current and its associated oceanographic processes can provide ideal conditions for feeding the population of *P. lherminieri* on south Atlantic. In addition, the Brazil Current has greater intensity in the austral summer, corresponding with the period in which *P. lherminieri* frequents the known Brazilan colonies.

Equally important, physical processes can cause predictable aggregations and together with biotic activity, influence seabirds to locate prey resources in the ocean (Shealer, 2001). Within the potential South Atlantic distribution, the points of higher suitability were between the coasts of Rio de Janeiro and Pernambuco. When analysis included the presence of

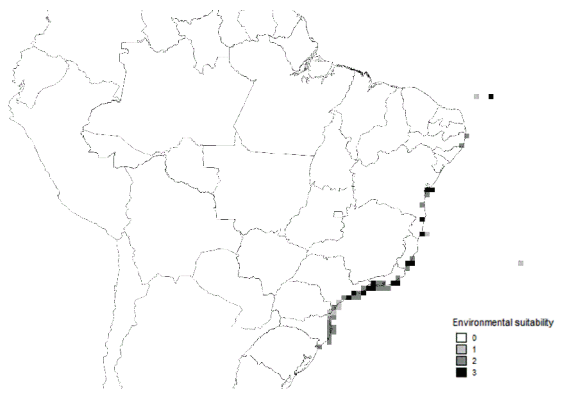

FIGURE 3: Potential distribution of Audubon's Shearwater in Brazil using Maxent algorithm with marine environmental data, filtered by grid cells containing islands (a = with colonies of Brazil; b = without colonies of Brazil). Darker colors mean higher environmental suitability.

islands along the Brazilian coast, the model indicated higher environmental suitability for islands along the coasts of Bahia, Espírito Santo and Rio de Janeiro. This southern limit appears to be influenced by the penetration of the branch cold Malvinas Current during winter between 30°S and 23°S (Castro *et al.,* 2006). This system is characterized by low temperatures and low salinities (Sverdrup *et al.,* 1942; Brandini *et al.,* 2000), changing oceanographic conditions preferred by the species. Based on this data the most effective and efficient survey protocol would focus on the islands off the coast of Bahia, Espírito Santo and extreme north of the Rio de Janeiro. Conversely, the islands south of Cabo Frio (23°S) are much less likely

to contain unknown populations of *P. lherminieri* and should be excluded from systematic surveys.

Conservation implications

In Brazil, Audubon's Shearwater is considered Critically Endangered (Machado *et al.,* 2008), mainly on the basis that the populations size is estimated to be fewer than 50 mature individuals. Moreover, by breeding in just two locations (Itatiaia and Fernando de Noronha Archipelagos), this shearwater is particularly vulnerable to introduced predators (Imber, 1978; Moors & Atkinson, 1984; Russell & Le Corre, 2009; Silva e Silva & Olmos, 2010). The known populations consist of fewer than 15 pairs (Neves *et al.,* 2006), nesting in Viuvinha and Leão (Fernando de Noronha Archipelago) and, to a lesser degree, on the Itatiaia Archipelago (Efe & Musso, 2001).

The population of the archipelago of Fernando de Noronha has recently been subject to monitoring, and several conservation strategies for this species have been planned by members of the National Action Plan for the Conservation of Albatrosses and Petrels – PLANACAP. These plans include the eradication of introduced species on islands with known colonies and a systematic search for new populations. Efforts are also needed to strengthen the population of the Archipelago Itatiaia and to more effectively monitor their population status.

Given the difficulties associated with locating new colonies, the Brazilian population of Audubon's shearwater may be underestimated, highlighting the importance of dedicated and efficient surveys. If the existence of new populations is confirmed, conservation measures can be adjusted accordingly and the long-term viability of the southernmost populations of this enigmatic seabird species can be assured.

RESUMO

*A pardela-de-asa-larga (*Puffinus lherminieri *Lesson 1839) é uma ave marinha tropical que ocorre entre o sul do Canadá e a costa sudeste do Brasil.* Puffinus lherminieri *é considerado Criticamente Ameaçado na lista vermelha do Brasil principalmente porque ocorre somente em duas localidades, ambas contendo pequenas populações. Porém, muitas ilhas ao longo da costa Brasileira são pouco conhecidas e a descoberta de novas colônias pode ser significativa para a conservação desta espécie. O objetivo deste estudo foi estimar a distribuição geográfica potencial da pardela-de-asa-larga no Brasil, baseada em modelagem de nicho ecológico (MNE) usando o algorítimo Maxent com camadas obtidas do banco de dados ambientais AquaMaps. A MNE foi baseada em 37 registros de áreas de reprodução nas Américas do Norte e Sul. O modelo mostrou uma ampla distribuição potencial, cobrindo a maior parte da costa Atlântica do Brasil e EUA. Quando filtrada para as ilhas ao longo da costa Brasileira o modelo indicou altos níveis de adequação ambiental próximo aos estados de São Paulo, Rio de Janeiro, Espírito Santo e Bahia. Porém,* P. lherminieri *prefere ilhas em ambientes com água quente e salina. Então, baseado na influência das correntes que atuam na costa Brasileira nós podemos inferir que colônias são mais prováveis de ocorrer em ilhas da costa da Bahia, Espírito Santo e extremo norte do Rio de Janeiro. Estas devem ser intensamente pesquisadas enquanto as ilhas ao sul de Cabo Frio devem ser descartadas. A existência de novas populações pode ter profundos efeitos no estado de conservação desta ave marinha enigmática e raramente vista.*

Palavras-Chave: Audubon's Shearwater; Ecological niche model; Maxent; Brazilian coast.

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