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Amazon protected areas and its ability to protect stream-dwelling fish fauna

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ABSTRACT

Large protected areas have been created in Brazilian Amazon intending to safeguard as much of its biodiversity as possible. Despite these intentions, such megareserves were created predominantly focusing on terrestrial organisms and ecosystems. Here, we assessed the ability of the current Brazilian Amazon protected areas network to efficiently safeguard its stream-dwelling fish fauna. Ecological niche models were built for 138 stream fish species using MaxEnt software. We performed a gap analysis and spatial prioritization under three different Amazon protected areas scenarios: (1) strictly protected areas (SPAs) only; (2) SPA plus sustainable use areas (SPA + SUA); and (3) SPA + SUA plus indigenous territories (SPA + SUA + IT). The species were classified according to their distribution range size and required representation targets. Widespread species usually had lower area under the curve (AUC) and true skill statistics (TSS) values, which would be expected for large and heterogeneous areas such as the Amazon. Only partial gap species were found, with 20% to 90% of required representation targets included in PAs, which was not enough for a complete protection. Most of the officially protected areas in the Brazilian Amazon do not correspond to areas with high direct conservation values for stream fishes, once the priority areas for these species conservation were outside the PAs, leaving a high portion of the regional vertebrate fauna inadequately protected. We conclude that fishes and other freshwater organisms and habitats should be explicitly included during systematic conservation planning in order to thoroughly protect the Brazilian Amazon biodiversity.

1. Introduction

Protected areas (PAs) are designed to safeguard and conserve all environmental components that maintain biodiversity, including habitats, species, populations, and ecosystem services (Margules and Pressey, 2000). In order to ensure that conservation areas can feasibly reach their goals, Margules and Pressey (2000) proposed implementing systematic conservation planning (SCP) efforts. SCP was created to optimize the effectiveness of protected areas by maintaining natural processes and viable populations under scenarios of limited resources. To do so, the principle of biodiversity complementarity, rather than species richness, has been used when deciding on target areas for conservation (Justus and Sarkar, 2002). The complementarity principle in a network of PAs requires choosing areas that complement each other in relation to biodiversity composition. Given that one of the purposes of SCP is to optimize the limited funding allocated to PAs, this principle has increasingly been incorporated in conservation planning worldwide (Justus and Sarkar, 2002; Rodrigues et al., 2003).

Environmental niche models (ENM) are powerful tools for SCP, intending to address the usual lack of accurate information concerning species distributions (Araújo et al., 2005; Diniz-Filho et al., 2009; Strecker et al., 2011) by determining suitable areas for the occurrence of species (Jiménez-Valverde and Lobo, 2007). The ENM approach is based on a species' Grinnellian niche (Soberón, 2007) and provides data that can be useful to delineate areas harboring potential habitats for the species, considering assumptions related to dispersal. Thus, this method is an important tool for conservation of high levels of diversity in data-poor areas, such as the tropics (Esselman and Allan, 2011; Nóbrega and De Marco Jr, 2011; Vilar et al., 2015; Fagundes et al., 2016). Maps of species distribution and suitable habitat areas generated by ENM could also be used to allow gap analyses to identify unprotected species in a PA network (Diniz-Filho et al., 2009; Nóbrega and De Marco Jr, 2011; Fagundes et al., 2016). Moreover, this method can also be employed when prioritizing areas for conservation (Moilanen, 2005, 2012).

In the past decade the conservation of freshwater ecosystems starts to get more attention (Abell, 2002; Linke et al., 2007, 2011; Turak and Linke, 2011). The discussion of SCP in freshwater ecosystems is highlighting new methods that take into account some specific

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characteristics from these ecosystems (Berger et al., 2010; Linke et al., 2011; Hermoso et al., 2011, 2016; Turak and Linke, 2011). Freshwater systems are composed of hierarchical networks, which render them highly complex and vulnerable both to local direct and large-scale indirect impacts, which include disturbances directly in the water courses or in the surrounding terrestrial ecosystem (Castello et al., 2013). Thieme et al. (2016) also showed that the PAs design and correct designation for freshwater ecosystems needs are important for conservation of freshwater biodiversity, once PAs usually have freshwater ecosystems (rivers) as their boundaries. Despite all advances in the knowledge of the structure, dynamics, and biological importance of aquatic systems, the selection of priority areas for conservation is still established mainly based on data concerning terrestrial organisms and ecosystems. This holds true for Brazil, where some authors argue that large protected "terrestrial" areas, or so-called megareserves, may encompass the diversity of aquatic habitats, and thus, be considered surrogate areas for freshwater ecosystems conservation (Peres and Terborgh, 1995; Peres, 2005). According to Peres (2005), the areas needed to maintain viable populations of large terrestrial predators should be large enough to protect many other wide-ranging terrestrial and aquatic species. This could hold true and would be classified according to Amis et al. (2009) as "*incidental integration*"; however, the opposite could also be possible since protecting large river catchments could lead to the conservation of terrestrial environments and organisms.

Brazil established the standards for the creation, implementation, and management of its PAs only in 2000, the *Sistema Nacional de Unidades de Conservação da Natureza* - SNUC (National System of Conservation Units http://www.planalto.gov.br/ccivil_03/leis/l9985.htm). In 2003, the Brazilian government created the *Programa Areas Protegidas da Amazônia* - ARPA (Amazon Protected Areas Program), and since then approximately 46 conservation units have been created in the region, summing 24 million hectares (http://programaarpa.gov.br/en/arpa-in-numbers//). These PAs were created between 2003 and 2010 in areas at high risk of human impacts, mostly intending to decrease deforestation rates (Veríssimo et al., 2011). The conservation units in the Amazon include the largest PAs in Brazil, and currently approximately 43% of the Brazilian Amazon is formally protected by conservation units of indirect or direct use (Veríssimo et al., 2011). Since almost half of Brazilian Amazon territory is under protected areas, it could be expected that freshwater biodiversity would also be adequately represented. However, Fagundes et al. (2016) found that Amazonian PAs do not protect freshwater turtles satisfactorily, which they attributed to the fact that conservation planning is focused mostly in terrestrial vertebrates and plants as targets. Thus, the ability of those units to protect fish and other aquatic elements of biodiversity is also questionable.

It is important to highlight that, even with all the advances in preserving the Brazilian Amazon forest as well as in reducing carbon emission rates, little attention has been given to its freshwater ecosystems, and the regional planning and management of water resources remains unsatisfactory (Castello et al., 2013; Castello and Macedo, 2016). Currently in Brazil, freshwater fishes are among the most threatened vertebrates, due to progressive habitat loss and the scarcity of knowledge concerning the ecological needs of most species (Nogueira et al., 2010). The Amazon Basin comprises approximately 7 million km^2, harbors the highest species richness of freshwater fish in the world, and 70% of this basin is in Brazil (Goulding et al., 2003; Abell et al., 2008). The majority knowledge concerning the Amazon fish fauna is concentrated on medium- to large-sized species that dwell in large river-floodplain systems and are exploited by commercial fisheries. However, below the vast canopy of upland forests there is a dense and complex hydrological network of small-order streams, regionally called *igarapés*, with a very rich and poorly known fish fauna. Bearing in mind the efforts taken to protect Amazon ecosystems, our main objective here was to verify the ability of the current Brazilian Amazon PAs network to conserve stream-dwelling fishes. Considering the strong ecological dependence between upland forest streams and the surrounding landscape, we selected only stream-dwelling species to test the hypothetical surrogacy stated by Peres (2005). In order to accomplish our goal, and facing the lack of knowledge on the ecological characteristics of most of these species, we performed a Gap Analysis and a spatial prioritization procedure using Environmental Niche Models.

2. Methods

2.1. Data

First- to third-order streams depend almost exclusively on allochthonous sources of energy and nutrients, with strong dependence on the surrounding terrestrial ecosystem (Faush et al., 2002; Soininen et al., 2015). These small headwater streams are not affected by the seasonal flood pulse or lateral expansion of the channel of large rivers, and are mainly influenced by local precipitation. In order to only select true stream-dwelling species and to work with quantitatively comparable data, we used species occurrence data harbored by the Igarapés Project database (www.igarapes.bio.br), as our main source of information. Besides, we also obtained additional information (occurrences) from the Species Link website (http://splink.cria.org.br/). We only selected for modeling species with no obvious taxonomic problems (i.e. those positively identified and checked against comparative material in collections and museums) that also had > 15 occurrence points with no duplicate records per pixel (Online Appendix – Table A1), since building models with low number of occurrence points may increase bias in the results. Despite of that, MaxEnt algorithm has been shown to have a good performance even in such situations, generating reliable models (Hernandez et al., 2006; Frederico et al., 2014) to stream species. Considering the above-mentioned criteria and data availability, we got information for a total of 138 stream-dwelling species and 8232 occurrence points.

Environmental variables were chosen based on the intrinsic collinearity of many limnological, macro-climatic, and macro-topographical variables, in order to include the best set of environmental layers to model Amazon stream fish species (see Frederico et al., 2014). The climatic macroscale variables were obtained through WordClim (www.worldclim.org) and included annual mean precipitation (AMP), annual mean temperature (AMT), seasonality of precipitation (SP), and seasonality of temperature (ST), which describes the variation among hydrological periods. We also included variables that could be used as surrogates for nutrients and sediments in streams and rivers (Angermeier and Karr, 1983; Sioli, 1985; Goulding et al., 2003) based on the study of Frederico et al. (2014). Thus, terrain slope and flow accumulation were chosen, with data obtained from Hidro1k (www.usgs.gov) database to represent differences in water flow and river orders; furthermore, information on soil characteristics was obtained from World Soil Information (ISRIC) (www.isric.org). All descriptor variables were at a pixel resolution of 4 km, and to build the models we used the first six axes of a Principal Components Analysis (PCA), which accounted for 96% of the original variance, to reduce the number of variables in later analyses.

2.2. Modeling procedures and evaluation

The algorithm MaxEnt was used to build species distribution models in the *dismo* package of R software (R Development Core Team, 2012), which works with presence data and perform well even when only a few occurrence points are included (Hernandez et al., 2006; Nóbrega and De Marco Jr, 2011). MaxEnt estimates the probability of the distribution of a given species by fitting a function close to the uniform distribution while considering the environmental information associated with the occurrence points (Phillips et al., 2006). This method