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Bird based Index of Biotic Integrity: Assessing the ecological condition of Atlantic Forest patches in human-modified landscape

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ABSTRACT

Wooded biomes converted to human-modified landscapes (HML) are common throughout the tropics, yielding small and isolated forest patches surrounded by an agricultural matrix. Diverse anthropogenic interventions in HMLs influence patches in complex ways, altering natural dynamics. Assessing current condition or ecological integrity in these patches is a challenging task for ecologists. Taking the Brazilian Atlantic Forest as a case study, we used the conceptual framework of the Index of Biotic Integrity (IBI), a multimetric approach, to assess the ecological integrity of eight small forest patches in a highly disturbed HML with different configurations and histories. The IBI was developed using bird assemblages found in these patches, and its performance was compared with analytical approaches commonly used in environmental assessment, such as general richness and Shannon's diversity index. As a first step, the IBI procedure identifies an existing gradient of human disturbance in the study region and checks which biotic characteristics (candidate metrics) vary systematically across the gradient. A metric is considered valid when its' relationship with the gradient provides an ecological interpretation of the environment. Then, the final IBI is elaborated using each valid metric, obtaining a score for each site. Over one year of sampling, 168 bird species were observed, providing 74 different bird candidate metrics to be tested against the disturbance gradient. Seven of them were considered valid:richness of threatened species; richness of species that use both "forest and non-forest" habitats; abundance of endemics, abundance of small understory-midstory insectivores, abundance of exclusively forest species; abundance of non-forest species, and abundance of species that forage exclusively in the midstory stratum. Each metric provided complementary information about the patch's ecological integrity. The resulting IBI showed a significant linear relationship with the gradient of human disturbance, while total species richness and Shannonís diversity index did not. Application of numerical approaches, such as total species richness and Shannon's diversity, did not distinguish ecological traits among species. The IBI proved better for assessing and interpreting ecological and environmental condition of small patches in highly disturbed HML. The IBI framework, its multimetric character, and the ease with which it can be adapted to diverse situations, make it an effective approach for assessing environmental conditions in the Atlantic Forest region, and also for many other small forest patches in the tropics.

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1. Introduction

1.1. Forest patches in human-modified landscapes

Tropical forests are critical for the maintenance of Earth's biodiversity and are subject to unprecedented destruction by human activities (Dirzo and Raven, 2003; Lambin et al., 2003; Wright, 2010; Haddad et al., 2015). Because most tropical forests are located within countries with ongoing economic development, tropical forests continue to be converted to human-modified landscapes at a rapid pace (HMLs; Lambin et al., 2003; Wright, 2005, 2010). Well known consequences of conversion of contiguous forest into fragments are: species loss (Turner, 1996; Dirzo and Raven, 2003; Ferraz et al., 2003; Anjos, 2006; Anjos et al., 2011), biodiversity homogenization (Lôbo et al., 2011), loss of functional diversity (Newbold et al., 2013; Bregman et al., 2014) and the spread of invasive species (Saunders et al., 1991; Goosem, 2000; Acurio et al., 2010; Tabarelli et al., 2012).

The Brazilian Atlantic Forest is the second largest biome in South America (Galindo-Leal and Câmara, 2003). Although considered a Biodiversity Hotspot (Myers et al., 2000; Mittermeier et al., 2005), only 16% of the original cover remains (Ribeiro et al., 2009, 2011). The forest now occurs largely as small and isolated patches (Ribeiro et al., 2009) with different origins, history of human influence (e.g., Prevedello and Vieira 2010; Melo et al., 2013; Ferraz et al., 2014), and highly varied environmental conditions (e.g., Ferraz et al., 2014). As a result, there are strong concerns about the state of Atlantic Forest biota, but lack of detailed knowledge of biological responses to various human influences limits our ability to mitigate biodiversity declines.

Past studies emphasized that landscapes that have>20% forest cover are most suitable for biodiversity conservation in the Atlantic Forest (e.g., Pardini et al., 2010; Martensen et al., 2012; Banks-Leite et al., 2014; Magioli et al., 2015). In contrast, little attention is given to forest patches in highly disturbed and deforested HMLs. Nonetheless, these patches can serve as ecological corridors and stepping-stones (Boscolo et al., 2008; Uezu et al., 2008; Rocha et al., 2011), provide viable habitat for some forest species (Ferraz et al., 2012), and harbor other threatened ones (Willis and Oniki 2002; Ribon et al., 2003; Antunes 2005; Magioli et al., 2016). Because of these findings, further investigations of the species requirements in small patches of HMLs have been encouraged (e.g., Tabarelli et al., 2010; Melo et al., 2013). This knowledge gap limits environmental assessments of patches, which undermine support for future conservation planning and human impact mitigations (i.e., within the Environmental Impact Assessment procedure, see Glasson and Salvador, 2000; Lima et al., 2010; Silveira et al., 2010; Koblitz et al., 2011; Sánchez and Croal, 2012; Alexandrino et al., 2016).

Bird communities are often the focus of researchers assessing environmental conditions of patches, as they serve as bioindicators (Anjos and Boçon, 1999; Anjos, 2004; Piratelli et al., 2005; Magalhães et al., 2007; Cavarzere et al., 2009; Manhães and Loures-Ribeiro, 2011; Pereira and Azevedo, 2011; Arendt et al., 2012). The diverse ecological niches of birds (Sekercioglu, 2006, 2012) makes them an appropriate proxy for biodiversity and a descriptor of the existing ecological integrity (Temple and Wiens, 1989; Stotz et al., 1996; Byron, 2000; Sekercioglu, 2006; Johnson, 2007; Chambers, 2008). However, results from some widely used approaches (e.g., richness, species diversity, species composition) may fail to properly assess environmental conditions of patches in HMLs (see Metzger, 2006; Vasconcelos, 2006; Silveira et al., 2010; Alexandrino et al., 2016). Therefore, testing analytical approaches used in environmental assessments is an instructive way to provide knowledge for professionals involved with conservation actions (Verdade et al., 2014) and is a key goal of our paper.

1.2. Index of biotic integrity

The "integrity" concept first invoked by Aldo Leopold (1949), refers to an ecosystem that is not altered as a result of human actions. It is the condition and character of living systems that are the product of evolutionary and biogeographic processes (Angermeier and Karr, 1994; Karr, 1996; Karr and Chu, 1999). The Index of Biotic Integrity (IBI) assumes that any ecological system (i.e., natural or disturbed) has biotic elements (e.g., communities and populations) and ecological processes (e.g., intraspecific and interspecific interactions). Thus, the condition measurement of a given system, in comparison to an undisturbed correspondent, will identify the changes suffered in the biotic elements and ecological processes (Karr, 1991, 2006; Angermeier and Karr, 1994; Westra, 2005).

The IBI was originally created to assess the biological condition of aquatic ecosystems based on fish assemblages (Karr, 1981). Since then, this approach has been widely used to assess streams and rivers worldwide, examining fish (e.g., Karr et al., 1986; Lyons et al., 1995; Karr, 2006; Pinto and Araújo, 2007; Casatti et al., 2009; Costa and Shulz, 2010), aquatic macroinvertebrates (e.g., Kerans and Karr, 1994; Fore et al., 1996), aquatic plants (e.g., Grabas et al., 2012; Rooney and Bayley, 2012) and coral reefs (Jameson et al., 2001). Assessments of terrestrial ecosystems using the IBI have mainly been done in the northern hemisphere using invertebrates (e.g., Kimberling et al., 2001; Karr and Kimberling, 2003) and birds (e.g., Bradford et al., 1998; O'Connell et al., 2000; Bryce et al., 2002; Glennon and Porter, 2005; Bryce, 2006; see Ruaro and Gubiani, 2013 for a further review).

The IBI is designed to measure multiple biological dimensions of complex ecosystems (Karr and Chu, 1999; Karr 2006). The first step is to identify measurable biological attributes that change consistently along a gradient of human disturbance in the study region (Dale and Beyeler, 2001; Niemi and McDonald, 2004). This gradient is identified by taking into account multiple environmental variables that are expected to influence the living biota. Each biological attribute is a candidate metric, and those with a clear relationship with the gradient are valid metrics. Taxonomic richness, species composition and abundance, functional groups, and other biological attributes (from one or more taxonomic groups) are evaluated as potential metrics in an integrative IBI (e.g., O'Connell et al., 2000; Bryce et al., 2002; Glennon and Porter, 2005; Karr, 2006; Mack, 2007; Wilson and Bayley, 2012; Ruaro and Gubiani, 2013; Medeiros et al., 2015). Sites with minimal (or absent) disturbance are deemed to have integrity (Karr, 1981, 2006; Karr et al., 1986; Karr and Chu, 1999). The gradient should ideally encompass a range of sites with little or no influence of human disturbance up to highly disturbed sites. When rigorously employed, this procedure reveals the reference score for each valid metric (i.e., the observed metric value at minimally disturbed sites), which will be used to calculate the final metric score for each study site. The sum of metric scores defines the IBI for each study site (e.g., Karr, 1981, 2006; Bradford et al., 1998; O'Connell et al., 2000; Bryce et al., 2002; Glennon and Porter, 2005) and produces a measure that reflects how much each site deviates from the state of integrity.

Few researchers have applied this approach to assess tropical forest integrity (e.g., Anjos et al., 2009; Bochio and Anjos, 2012; Medeiros et al., 2015). The complexity of small Atlantic Forest patches (e.g., Ferraz et al., 2014) and the high bird diversity in this biome (Goerck, 1997; Lima, 2013) led us to initiate an assessment process using the principles of IBI, focusing on birds. Birds exhibit numerous ecological characteristics, which can be converted into multiple candidate metrics (e.g., foraging guild, habitat preference, etc.) useful for evaluating forest integrity.

Therefore, we aimed to develop a bird-based IBI to assess the current condition (as a divergence from integrity) of forest patches