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Review

Implications of movement for species distribution models - Rethinking environmental data tools

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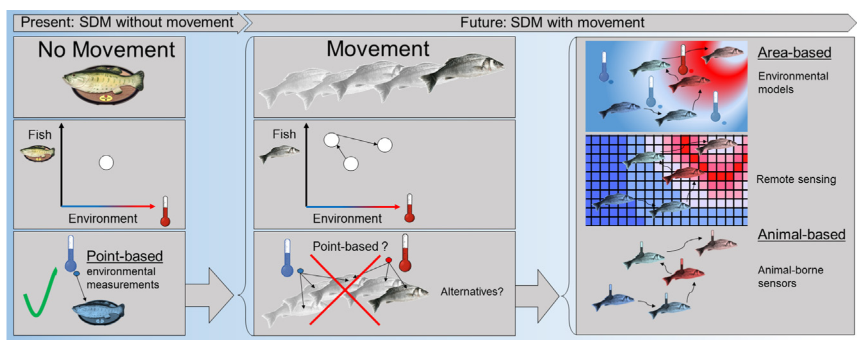
HIGHLIGHTS

- Sampling techniques like telemetry allow integration of movement in SDMs.
- Integrating complex ecological processes influences conceptual and data requirements.
- Abiotic data requirements are often overlooked in SDMs.
- The conceptual conflict between biotic and abiotic data leads to ambiguous results.
- Alternative abiotic data acquisition techniques may resolve this conceptual conflict.

GRAPHICAL ABSTRACT



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ABSTRACT

Movement is considered an essential process in shaping the distributions of species. Nevertheless, most species distribution models (SDMs) still focus solely on environment-species relationships to predict the occurrence of species. Furthermore, the currently used indirect estimates of movement allow to assess habitat accessibility, but do not provide an accurate description of movement. Better proxies of movement are needed to assess the dispersal potential of individual species and to gain a more practical insight in the interconnectivity of communities. Telemetry techniques are rapidly evolving and highly capable to provide explicit descriptions of movement, but their usefulness for SDMs will mainly depend on the ability of these models to deal with hitherto unconsidered ecological processes. More specifically, the integration of movement is likely to affect the environmental data requirements as the connection between environmental and biological data is crucial to provide reliable results. Mobility implies the occupancy of a continuum of space, hence an adequate representation of both geographical and environmental space is paramount to study mobile species distributions. In this context, environmental models, remote sensing techniques and animal-borne environmental sensors are discussed as potential techniques to obtain suitable environmental data. In order to provide an in-depth review of the aforementioned methods, we have chosen to use the modelling of fish distributions as a case study. The high mobility of fish and the often highly variable nature of the aquatic environment generally complicate model development, making it an adequate subject for research. Furthermore, insight into the distribution of fish is of great interest for fish stock assessments and water management worldwide, underlining its practical relevance.

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Contents

1. Introduction

The distribution of species and communities in space has been a major focus of study in ecological research (Austin, 2002; Guisan and Thuiller, 2005; Elith and Leathwick, 2009). In order to assess how species will be affected by climate change (Ramirez-Villegas et al., 2014; Dulvy et al., 2008; Austin and Van Niel, 2011) or how current species distributions came to be (Wiens and Donoghue, 2004; Varela et al., 2011), a firm understanding of the functional relationships between species and the environment is required. Ecological traits of species, which are associated with the preference for specific environmental conditions, are key to understand why species prefer one habitat over the other (Stoll et al., 2014). In general, these habitat preferences are described as correlative species-environment relationships using habitat suitability models (HSMs) also often referred to as species distribution models (SDMs). However, in a strict sense of the word, the suitability of a habitat for a certain species does not necessarily imply the presence of that species (Meynard and Kaplan, 2013). Besides ecological traits, species also own a wide set of biological traits (Costello et al., 2015). Biological traits are referred to as the physiological and behavioural characteristics of a species and include among others the ability to interact and to disperse (Costello et al., 2015). SDMs aim to predict the distribution of species, but to do so they need to account for both the ecological and biological traits of species (Forio et al., 2017; Verberk et al., 2010).

In the context of SDMs, the term dispersal is often used instead of movement, mainly because the accessibility of habitats by species or populations is considered rather than the underlying process of movement itself (Datry et al., 2016; Austin, 2002; Elith et al., 2006; Guisan and Thuiller, 2005). Dispersal can as such be defined as the cumulative movement of a species or population between habitats over a longer period (Soberon and Peterson, 2005; Guisan and Thuiller, 2005; Holloway et al., 2016). However, there is more to movement than merely being in function of tracking and reaching suitable habitats. First, habitats are seldom well-aligned areas with constant borders in time within which populations remain stationary. The scale at which habitats are observed may allow to approximate habitats as well-aligned points in space rather than complex areas, but this depends on the characteristics of the studied ecosystem. Second, characteristics of the movement of individuals may in fact be necessary to provide a sound description of movement-related biological traits and to distinguish dispersal from other types of movement such as migration or within-habitat-displacement. Movement in SDMs is currently described as a population-based post hoc derivative of movement with binary response (habitats are or are not accessible) (Guisan et al., 2006), but being able to label and quantify movement more directly, may entail more realistic predictions and quantifications of uncertainty (Holloway et al., 2016; Uribe-Rivera et al., 2017; Singer et al., 2016; Dedecker et al., 2006).

The level-up of biotic data quality, driven by technological advancements in biotic data acquisition techniques, is expected to stimulate the integration of movement in SDMs (Guisan and Thuiller, 2005; Thuiller et al., 2013). Such models are potentially much more powerful in explaining observed species distributions than the more traditional SDMs which only incorporate environment-species relationships. An important issue that should be kept in mind in this evolution of models is how the currently used abiotic data acquisition techniques impact the overall quality of the model outcomes. In other words: How is model accuracy influenced by the quality of environmental data? Before addressing this issue, we first require some insight into the development of SDMs and the new sampling technologies. After having identified the deficiencies of current SDMs and the potential of new technologies to deal with them, we discuss new challenges and propose some ways to tackle them.

The importance of upscaling biological data quality with more detailed movement data depends on the studied species and ecosystem (Thuiller et al., 2015). For sessile organisms, like most macroinvertebrates, the issue of integrating distance-related biological processes may be less pressing than for more mobile species. Fish are typically mobile species and thus their movement may be of great importance for their geographical distributions. Furthermore, as some aquatic habitats are spatially and temporally very dynamic, the quality of environmental data is also expected to play an essential role in the accuracy of SDMs. A central assumption in traditional SDMs is that species are in equilibrium with their environment (Araújo and Pearson, 2005; Elith et al., 2010). However, this might not necessarily be the case in dynamic environments such as tropical forests, estuaries and anthropogenically influenced areas. After fire disturbances for example, species are unlikely to be in equilibrium with the disturbed environment (Tucker et al., 2012). The scale of the disturbance in relation to the spatial structure of plant populations, associated with seed dispersal and seed bank characteristics, will determine if a species will be able to persist, reestablish itself or be excluded from the habitat. Another key example involves climate change which might drive populations to extinction due to rapidly changing environmental conditions and lacking interconnectivity between suitable patches (Araújo and Pearson, 2005; Travis et al., 2013; Sinclair et al., 2010). Furthermore, insights into the movement pathways, movement limitations, ecological and biological traits of invasive species are vital to predict their future distributions and to adapt biodiversity policies accordingly (Gallien et al., 2012; Boets et al., 2014). Hence, it is expected that the quality of SDMs for mobile species in dynamic environments will strongly depend on the integration of movement and the quality of used environmental data.