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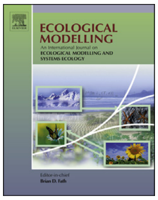

Integrating catchment properties in small scale species distribution models of stream macroinvertebrates

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ABSTRACT

Species distribution models are increasingly applied to freshwater ecosystems. Most applications use large scales, coarse resolutions and anthropocentric modelling extents, thus not being able to consider important environmental predictors and ecological processes detectable within a catchment and at finer scales. Moreover, high resolution predictions of species distribution in streams can help improve our understanding of how environmental variables within a catchment affect the distribution of stream macroinvertebrates. We built models at a resolution of 25 m × 25 m for a 488 km^2 catchment in northern Germany to determine whether the spatial approach in which environmental predictors are implemented in the model affects the overall performance. We used predictors from four different categories relevant to freshwater ecosystems: bioclimatic, topographic, hydrologic and land use. Two spatial approaches were tested: a local one, or grid based and a cumulative for the upstream area, or subcatchment specific. Models were evaluated in terms of model performance and accuracy in order to identify the approach best suited for each category, as well as the most important predictor in each. In the case of the land use category, the subcatchment approach made a significant difference, increasing performance. A final model, calibrated with the selected predictors, resulted in the highest model performance and accuracy. Our results indicate that species distribution models perform well and are accurate at high resolutions, within small catchments. We conclude that catchment wide models, especially when using predictors from multiple categories, have the potential to significantly improve modelling framework of species distribution in freshwater ecosystems. The information produced by accurate, small scale, species distribution models can guide managers and conservation practitioners, by predicting the effects of management decisions within a catchment. We suggest that highly resolved predictors be applied in models using the catchment approach.

1. Introduction

Freshwater ecosystems are considered biodiversity hotspots as they are particularly species rich and scarce in terms of the surface they occupy globally (Dudgeon et al., 2006). These ecosystems have been subjects of considerable anthropogenic pressure causing significant structural and biotic alterations, mainly because of the importance of water to humans as a resource (Malmqvist and Rundle, 2002). Concerns about their integrity were raised already in the late 19th century, when the first biological indicators of water pollution were developed (Metcalfe, 1989). Since then, laws have been specifically drafted to restore and maintain their biological integrity like the Clean Water Act of 1965 in the USA

Abbreviations: SDM, species distribution model; GCB, grid cell based; SCS, subcatchment specific; DEM, digital elevation model; GLM, generalized linear model; CTA, classification tree analysis; ANN, artificial neural networks; FDA, flexible discriminant analysis; AUC, area under curve; TSS, true skill statistic; ROA, relative occurrence area.

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(and amendments) or the Water Framework Directive of 2000 in the European Union (Griffiths, 2002; Karr, 1991). Despite these efforts, freshwater biodiversity continues to be lost and climate change increasingly exerts additional pressure on these ecosystems, calling for urgent measures to preserve habitats and species (Strayer and Dudgeon, 2010). Recent conservation efforts in the terrestrial realm have relied on species distribution models (SDMs) to deliver insights into the relationship between biodiversity and its environment, as well as predictions of suitable habitat for endangered species (Elith and Leathwick, 2009). SDMs have recently been implemented in freshwater ecosystems to identify vulnerability to climate change (Domisch et al., 2013a,b), determine loss of genetic diversity (Bálint et al., 2011) and to guide conservation measures (Dauwalter and Rahel, 2008).

Most existing applications of freshwater SDMs are broad scale studies which (a) use large spatial extents and low resolutions (≥1 km grid size) reaching conclusions that do not allow the implementation of local conservation measures; (b) chose the modelling extent frequently based on anthropocentric criteria (political boundaries, protected areas) excluding portions of the environmental ranges, which in turn truncates predictions (Austin, 2007); and (c) consider environmental conditions for each reach individually (defined as points or grid cells in SDMs), disregarding the effect of the upstream areas, an essential concept in freshwater ecosystems (Malmqvist, 2002; Vinson and Hawkins, 1998). Frequently, such shortcomings are induced by the limited availability of high resolution data suitable for SDMs, restricting the precision of the predictions.

By building freshwater SDMs from a catchment perspective, most of the issues outlined above are overcome: (a) the use of a small (<2500 km^2), well-defined, modelling extent allows to use a combination of regional to local environmental conditions, as high resolution predictors (<100 m grid size), delivering more spatially accurate predictions; (b) the modelling extent intrinsically considers the environmental conditions responsible of shaping and structuring freshwater ecosystems; and (c) the effect of the landscape on every reach can be easily incorporated by analyzing the cumulative effect of the area upstream of each modelled site. Some studies applying SDMs use the catchment as the modelling extent (e.g. Bond et al., 2011), while only few studies have included predictors that consider the upper subcatchment (Joy and Death, 2004; Hopkins, 2009; Hopkins and Burr, 2009; Hopkins and Whiles, 2011). Moreover, catchments are well suited as management units for the conservation of freshwater as a resource and as an ecosystem (Palmer et al., 2008; Saunders et al., 2002). Including these aspects is a key factor to fully harness the potential of SDMs to help bridge the gap between freshwater ecology and conservation biology (Strayer and Dudgeon, 2010).

Here we test the effect of two spatial approaches on SDMs built with environmental predictors of four categories, by looking at model performance and predictive accuracy. Subsequently, the best spatial approach is chosen for each predictor category and a final model is built. We aim at detecting the most suitable approach in which each predictor category should be incorporated in SDMs built within the extent of a catchment. Thus, results for each species are not analyzed individually but merged to represent a small, diverse community of stream macroinvertebrates. We expect our methodological framework to improve the applicability of SDMs in freshwater ecosystems, by identifying how environmental variables serve best the purpose of distribution modelling. Improved freshwater SDMs can also allow to better understand the relationships between stream macroinvertebrates and the landscape surrounding their habitats. These insights could yield particularly valuable knowledge for local conservation practitioners.

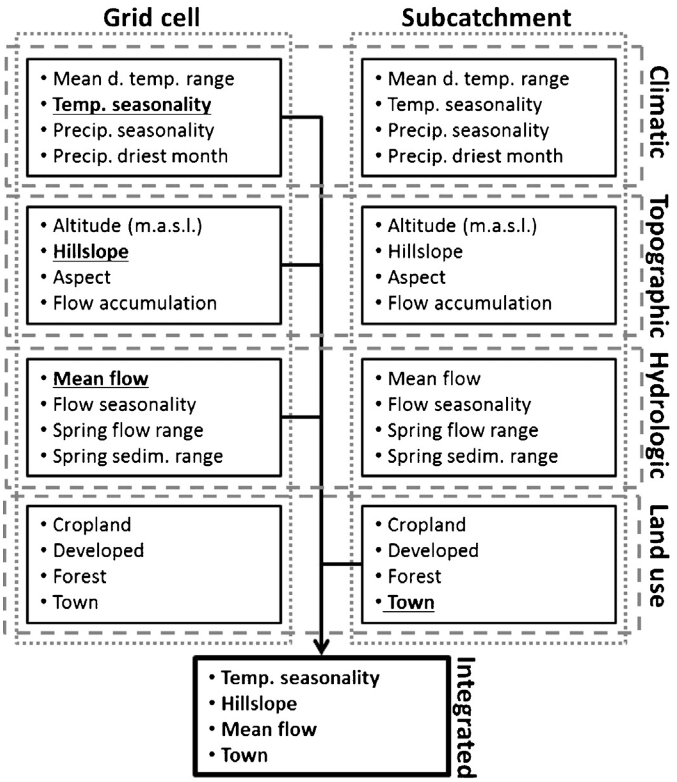

Fig. 1. Flow diagram showing the 9 models built (9 boxes) and the predictors used in each one. Four models per spatial approach (grid cell, subcatchment; dotted line box) and two per predictor category (climatic, topographic, hydrologic, land use; dashed line box); selected predictors (bold, underlined) from each model are included in the integrated model.

2. Materials and methods

2.1. *General set up*

SDMs relate known occurrences of a species with environmental conditions and, based on this relationship, predict the occurrences on areas where suitable environmental conditions are known, but no occurrences data is available (Elith and Leathwick, 2009). We built nine models using various environmental predictors and spatial modelling approaches, to predict the distribution of stream macroinvertebrates in a small catchment (Fig. 1). Climate, topography, hydrology and land use, ecosystem attributes known to influence the distribution of the macroinvertebrates, were used in this study as environmental predictor categories (Vinson and Hawkins, 1998). Two spatial modelling approaches were applied: (a) using predictor values on a grid cell basis (GCB; i.e. each cell bears the predictor's value for that single cell); and (b) calculating sub-catchment specific predictors (SCS; i.e. each cell bears the predictor's value for the entire sub-catchment). The standard procedure in SDMs – including those built for freshwater ecosystems – is the application of a GCB approach (e.g. Domisch et al., 2013a,b; Sauer et al., 2011), while only very few studies have used the SCS approach. For example, Hopkins and Burr (2009), as well as Hopkins and Whiles (2011), incorporated the cumulative effect of environmental predictors from the upstream contributing area, but for stream segments 3000 m long. In this study, only these two spatial approaches were chosen, as they are easily defined, can be readily replicated and are frequently used in studies alike. Additional spatial scales have been applied in studies relating stream biota with the environment in the catchment: some extending longitudinally along the stream network upstream from the sampled