Ecological Modelling 228 (2012) 66–75

Contents lists available at SciVerse ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Multiplex modeling of physical habitat for endangered freshwater mussels

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ARTICLE INFO

Article history:
Received 30 December 2010
Received in revised form
16 December 2011
Accepted 25 December 2011
Available online 25 January 2012

Keywords:
Endangered species
Dwarf wedgemussel
Habitat modeling
Suitability criteria
Complex hydraulics
Multi-scale model

ABSTRACT

Quantification of the potential habitat available for endangered freshwater mussels can be a challenging task, as habitat use criteria are very complex and often only low numbers of species observations are available. To address this problem in a riverine environment, we developed a concept of a multivariate, multi-scale, and multi-model (multiplex) habitat simulation through combining multivariate time-series analysis of complex hydraulics (CART and logistic regression), micro-scale (River2D), and meso-scale (MesoHABSIM) habitat models, to develop macro-scale management criteria. This concept has been applied and tested on the Upper Delaware River (USA) for the protection and enhancement of existing populations of *Alasmidonta heterodon*, an endangered freshwater mussel. The physical habitat conditions of approximately 125 km of the Delaware River were described using digital aerial imagery and ground-based surveys. The temporal and spatial variabilities of complex hydraulics simulated by a River2D model at 1547 locations were statistically analyzed to select ranges of attributes that corresponded to mussel presence. We applied these criteria to the river's meso-scale hydromorphological unit mappings to identify suitable mesohabitats, which then served as a calibration data set for the coarser scale model. The final meso-scale model's predictions were hydraulically validated offering encouraging results. The meso-scale habitat suitability criteria defined moderately deep, slow-flowing, and non-turbulent hydromorphologic units as providing good conditions for *A. heterodon*. All three of the developed suitability models (descriptive statistics, CART and logistic regression model) indicated the species preference for hydraulically stable habitats.

1. Introduction

The assessment of habitat suitable for endangered species can be limited by the low numbers of species observations occurring in their natural environment. Paucity of data limits our ability to learn from direct observation where environmental conditions correspond with the species' presence or absence (Fielding and Bell, 1997; Guisan and Zimmermann, 2000; Engler et al., 2004). Cost effective management planning commonly utilizes coarse spatial scales, where multiple observations are merged into a few key data points. Habitat management however, commonly occurs at a much finer scale and scientists are expected to provide practical guidance applicable at this level. This creates an incompatibility between rigorous science and the need for effective action to protect endangered species and enhance their habitat.

Freshwater mussels belong to the most endangered animal group on the planet, Mollusca Unionacea (Bogan, 1993; Williams and Neves, 1995; Baldigo et al., 2003–2004). North America supports the highest number mussel species and each of these organisms play a crucial role in maintaining river ecosystems by filtering up to 110 l of water per day (McMahon and Bogan, 2001). As a filter feeder, freshwater mussels are particularly sensitive to water pollution, especially during their early life stages (Milam et al., 2005; Pip, 2006; Wang et al., 2010). They are long-lived organism with a reproductive cycle requiring interaction with sometimes very specific fish host species. Hence, freshwater mussels are recognized as multifaceted indicators of ecosystem health (Simmons and Reed, 1973; Kearns and Karr, 1994; Grabarkiewicz and Davis, 2008).

Mussels are sedentary organisms that can do little more than close their shells in response to environmental stress and as a result, can be strongly affected by temporal habitat variability (e.g. Steuer et al., 2008; Daraio et al., 2010a). Consequently, an investigation of mussel habitat to predict their distribution for watershed

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doi:10.1016/j.ecolmodel.2011.12.023

management purposes requires consideration of temporal as well as spatial patterns. Therefore, the ideal management tool needs to capture the temporal variability of environmental factors that correspond with each animal's location (microhabitat) as well as with their overall spatial distribution in the river (macrohabitats).

Ecological niche or habitat suitability models with their associated habitat suitability maps are a very useful and increasingly popular tool in predicting the potential distribution of species in endangered management (Sillero, 2011). They statistically relate environmental variables associated with the niche to field observations of the organisms. The result is the prediction of locations that have potential (suitability) for use by the targeted species (Hirzel et al., 2006).

A number of studies have documented that the near-bed complex hydraulic conditions are good predictors of suitable microhabitat for mussels (e.g. Layzer and Madison, 1995; Statzner et al., 1988). Specifically, they documented that shear stress is related to mussel presence at low flows. Other authors considered micro-scale models less applicable for large river sections and have attempted to predict mussel habitats at the macro-scale (e.g. Baldigo et al., 2003–2004; Strayer and Ralley, 1993; Hopkins, 2009). Recently published research has incorporated temporal changes and habitat persistence into the modeling effort (e.g. Bovee et al., 2007; Steuer et al., 2008), showing that events occurring at specific times can have different effects. Findings that mussel distribution is also strongly affected by hydraulic conditions during extreme events such as high and low flows (Zigler et al., 2008; Daraio et al., 2010b; Allen and Vaughn, 2009) are also noted.

This paper presents the development of multiplex instream habitat simulation models for the dwarf wedgemussel (*Alasmidonta heterodon*), a federally endangered species of Atlantic slope drainages from New Brunswick, Canada to North Carolina, USA (Master, 1986; Hanson and Locke, 2000). Change in hydraulic habitat was listed as one of the key causes for the species' decline, next to siltation and contamination (US Fish and Wildlife Service, 1993). Since neither siltation nor contaminants are known to be unusually high in Upper Delaware River, the presented models and management recommendations focus on the relationship between habitat hydraulics and distribution of the species. The models serve as a planning tool applicable to future flow management and habitat restoration of the Upper Delaware River.

2. Methods

2.1. Study area

The Upper Delaware River (Fig. 1) is located in the Catskill Mountains Region about 200 km northwest of New York City. The system consists of three main fourth order rivers that flow into the Delaware's main stem: the West Branch Delaware, East Branch Delaware and the Neversink River. The Upper Delaware is an alluvial upland river system of straightened-confined and meandering character with a pluvio-nivial flow regime (i.e. high flows related to rain and snowmelt in the fall and spring, and low flow in the summer (Parde, 1968)). The river's gradient is moderate compared to headwater streams, and multiple wetlands accompany its course. The river flows over unstable glacial deposits in a U-shaped valley that was heavily forested in pre-colonial times (Kudish, 2000). The project area encompasses 125 km of the Upper Delaware River from the confluence of the East and West Branch to Montague, NJ. The watershed corridor along the study area is mostly rural in character and is dominated by mixed-forests. Urbanization increases near the downstream end of the study area near the town of Port Jervis, NY. The valley corridor changes periodically throughout its length, widening and narrowing as the river meanders through its flood plain. The water of the tributaries to the Upper Delaware River is used for potable water supply (including over 50% of New York City's water), hydropower generation and recreation. Both of these first two water uses modify flow patterns in the river (see Parasiewicz et al., 2010 for more detail). The dwarf wedgemussel is distributed in only three known locations within the river's main stem (Lellis, 2001, 2002). Six study sites (Fig. 1), three of which include narrow clusters (each several hundred meters in length) of the known mussel beds, were chosen for intensive field study and habitat mapping within the project area. The combined length of these sites totaled approximately 22.4 km or 18% of the total project river segment. The study sites enveloping mussel locations represent only 9% of the total length of our study area.

2.2. Habitat models

In order to develop river-wide management strategies aimed at the protection and recovery of endangered freshwater mussels, we propose to use physical habitat suitability models in a multi-scale and multi-model (multiplex) process. In the first step, we apply a multivariate, micro-scale habitat model to analyze the temporal variability of complex hydraulics as a predictor of mussel presence. The model predicts locations that have favorable conditions for the organism outside of the currently occupied habitats. In the second step, hydro-morphological features with a high concentration of locations determined to be suitable for colonization by the species are then identified by the model predictions. In the third step, the identified features serve as calibration data for a smaller scale model, allowing for the simulation of scenarios that support watershed based management decisions. Fig. 2 presents a conceptual diagram of this process.

Due to the large geographical extent of the study area and the need to investigate dwarf wedgemussels habitat suitability at a very fine scale, a combination of River2D (Steffler and Blackburn, 2002) and MesoHABSIM (Parasiewicz, 2001, 2007) was applied to extrapolate the information collected from sampling sites to the study area scale. River2D serves as a support tool for the development of microhabitat suitability criteria, while MesoHABSIM serves here as a vehicle to transfer the habitat characteristics from the scale of meters to many kilometers (Fig. 2). We developed microhabitat suitability criteria by taking into account the temporal variability of complex hydraulics (shear stress, Reynolds number, etc.) on a large sample of random points that included mussel locations. Our study includes the analysis of temporal changes in hydraulic patterns caused by flow fluctuations during the 2007 summer season (July 1st to September 30th), which allowed us to capture the range of hydraulic conditions that mussels are exposed to during the water-limited time of the year. The microhabitat models are then applied to describe the spot locations with hydraulic characteristics similar to those where individual organisms have been found. These suitable microhabitats with a high probability of finding mussels are overlain over a detailed hydraulic survey of meso-scale hydromorphologic units (HMUs) to predict macro-scale patterns. The HMUs with large proportions of surface area covered by the suitable microhabitats are considered suitable as a whole and serve as calibration data for the mesoscale habitat model that predicts habitat suitability for the whole study area at different measured flows.

2.2.1. Microhabitat model

To determine the suitability of the hydraulic environment for *A. heterodon* at the micro-scale, we modeled the hydrodynamics of hydraulically representative portions of the six sites. The sub-sites (total length of 15.25 km) were chosen to capture hydraulics of all HMUs present in the sites. The bathymetry and riparian corridor of the sub-sites were surveyed in high detail using LIDAR; on-foot topographic surveys using a total station and Radio