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Development and assessment of indices to determine stream fish vulnerability to climate change and habitat alteration

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ABSTRACT

Understanding the future impacts of climate and land use change are critical for long-term biodiversity conservation. We developed and compared two indices to assess the vulnerability of stream fish in Missouri, USA based on species environmental tolerances, rarity, range size, dispersal ability and on the average connectivity of the streams occupied by each species. These two indices differed in how environmental tolerance was classified (i.e., vulnerability to habitat alteration, changes in stream temperature, and changes to flow regimes). Environmental tolerance was classified based on measured species responses to habitat alteration, and extremes in stream temperatures and flow conditions for one index, while environmental tolerance for the second index was based on species' traits. The indices were compared to determine if vulnerability scores differed by index or state listing status. We also evaluated the spatial distribution of species classified as vulnerable to habitat alteration, changes in stream temperature, and change in flow regimes. Vulnerability scores were calculated for all 133 species with the trait association index, while only 101 species were evaluated using the species response index, because 32 species lacked data to analyze for a response. Scores from the trait association index were greater than the species response index. This is likely due to the species response index's inability to evaluate many rare species, which generally had high vulnerability scores for the trait association index. The indices were consistent in classifying vulnerability to habitat alteration, but varied in their classification of vulnerability due to increases in stream temperature and alterations to flow regimes, likely because extremes in current climate may not fully capture future conditions and their influence on stream fish communities. Both indices showed higher mean vulnerability scores for listed species than unlisted species, which provided a coarse measure of validation. Our indices classified species identified as being in need of conservation by the state of Missouri as highly vulnerable. The distribution of vulnerable species in Missouri showed consistent patterns between indices, with the more forest-dominated, groundwater fed streams in the Ozark subregion generally having higher numbers and proportions of vulnerable species per site than subregions that were agriculturally dominated with more overland flow. These results suggest that both indices will identify similar habitats as conservation action targets despite discrepancies in the classification of vulnerable species. Our vulnerability assessment provides a framework that can be refined and used in other regions.

1. Introduction

Stream ecosystems have some of the most imperiled communities on Earth, and freshwater biodiversity is declining at a higher rate than most other taxa groups (Allan and Flecker, 1993; Abell, 2002; Dudgeon et al., 2006). Anthropogenic habitat alteration, changes in stream temperatures, and change in flow regimes

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will likely cause continuing declines in aquatic biota (Ricciardi and Rasmussen, 1999; Dudgeon et al., 2006). Conservation actions to protect aquatic biodiversity are critical for preventing future biodiversity losses (Master et al., 1998). In order to plan for long-term biodiversity conservation, a better understanding of how impacts and threats, such as climate change and habitat alteration, affect aquatic species is needed. Conservation and management of stream fish species will require researchers and managers to identify which species are vulnerable, or likely to experience harm, under future conditions (Turner et al., 2003; Glick et al., 2011; Poff et al., 2012). An assessment of stream fish vulnerability requires the identification of species which are threatened by primary drivers of future stream fish declines such as habitat alteration, predicted changes in stream temperatures, and predicted change in flow regimes (Malmqvist and Rundle, 2002; Poff et al., 2002).

Climate change, which is expected to increase stream temperatures and alter flow regimes, is one of the most significant threats facing stream fish (Eaton and Scheller, 1996; Poff et al., 2002). In Missouri, USA, the average annual air temperature is expected to rise approximately 4 °C by 2095 based on an intermediate (A1B) climate scenario (Girvetz et al., 2009). This is expected to increase stream temperature by an average of 3.6 °C (Eaton and Scheller, 1996), which may have a substantial effect on stream fishes. In Wisconsin, USA, a 3 °C air temperature increase is predicted to result in loss of 343,034 km of stream habitat for cool- and cold-water fishes, which includes a species extirpation (Lyons et al., 2010). Studies have predicted substantial losses of cool- and cold-water stream habitats (15–50%) with a doubling of atmospheric CO_2 (Eaton and Scheller, 1996; Mohseni et al., 2003). Warm-water streams in the Great Plains, USA, achieve maximum temperatures at or near the physiological limits of some resident fish species, and an increase in stream temperature of just a few degrees is predicted to result in local extirpation and extinction (Matthews and Zimmerman, 1990). In addition, decreases in fitness based on changes in energetics and growth may be a non-lethal consequence of warming temperatures (Pease and Paukert, 2014; Westhoff and Paukert, 2014). These studies provide strong evidence that some stream fish species may decline or face local extirpations as stream temperatures warm.

Changes to flow regimes are also expected to have substantial impacts on stream fish (Poff et al., 2002). Predicted increased frequency and extremes of flood and droughts may lead to shifts in species composition and local species extirpations (Poff et al., 1997, 2002). In Missouri, mean annual precipitation is expected to increase only slightly (~10 mm) between historic (1965–2015) and future (2080–2100) time periods, however this precipitation is expected to come in the form of heavier precipitation (~10 mm increase on wet days) on fewer days (12 less wet days) (Girvetz et al., 2009). The variability of precipitation patterns is likely to increase, which may cause declines in species which exhibit equilibrium or periodic life history strategies (Poff et al., 2002; Olden and Kennard, 2010; Mims and Olden, 2012, 2013).

Habitat alteration caused by anthropogenic modifications including the conversion of land to agricultural or urban uses or the direct modification of streams and rivers from channelization, dredging, and damming often result in altered and degraded stream conditions and losses of aquatic biodiversity (Malmqvist and Rundle, 2002; Allan, 2004). Indices of biological integrity (IBIs) have identified many stream fish species as intolerant of habitat alteration (Esselman et al., 2011), and life history traits sensitive to the effects of habitat alteration such as lithophilic spawning, and benthic invertivory have been used as criteria for IBIs measuring habitat alteration (Berkman and Rabeni, 1987; Barbour et al., 1999; Simon, 1999).

A framework for the assessment of stream fish vulnerability (i.e., the extent to which a species is likely to be impacted by the cumulative effects of climate change and habitat alteration [Turner et al., 2003; Schnieder et al., 2007; Glick et al., 2011]) can be developed by associating the effects of climate change and habitat alteration with species or trait-specific impacts. Vulnerability is often determined using a framework that assesses a species' sensitivity, exposure, and adaptive capacity to threats (Turner et al., 2003; IPCC, 2007; Glick et al., 2011; Poff et al., 2012; Staudinger et al., 2013). A number of vulnerability assessments have been developed using this framework (Bagne et al., 2011; Glick et al., 2011; Young et al., 2011). Two prominent vulnerability assessment tools (the System for Assessing Vulnerability of Species (SAVS); Bagne et al., 2011), and the NatureServe Climate Change Vulnerability Index (NSCCVI; Young et al., 2011) could not be applied to Missouri stream fish due to a lack necessary data for evaluating many of the criteria these assessment techniques use. These assessments depend on models of current and future climate conditions which have not yet been developed for stream temperature and flow in Missouri. Additionally, these tools were designed for a wide array of taxa over large spatial scales, and they depend on information which is largely unknown for stream fish species; examples include knowledge of a species' reliance on interspecific interactions, measures of genetic variation, occurrence of bottlenecks in recent evolutionary history, and phenological response to changing seasonal temperature and precipitation dynamics (Bagne et al., 2011; Young et al., 2011). Currently available information is too limited to broadly apply these assessment tools to stream fishes in Missouri. The inability to apply currently available vulnerability assessment tools to determine stream fish vulnerability necessitates the development of a new methodology.

Poff et al. (2012) developed a framework for assessing the threat posed by climate change to freshwater diversity. This framework is a function of three components: exposure to the flow and temperature conditions which deviate from regional baselines; sensitivity of species based on intrinsic factors related to a species environmental tolerance, dispersal ability, genetic adaptation, range, and population size; and habitat resilience or the level of connectivity of habitat which provides opportunities for adaptation via dispersal. Although this framework deviates from the definitions and structure presented by Glick et al. (2011), we believe that it provides a mechanism for assessing stream fish vulnerability based on the information that is currently available, so we adapted it for our use.

Species environmental tolerances, which are often expressed as sensitivity in the vulnerability assessment literature, specifically to habitat alteration, changes in stream temperature, and change to flow regimes, as well as factors such as a species range, rarity, dispersal ability, and the hydrological connectivity of a species habitat can be incorporated into this framework to create a method for assessing the vulnerability of stream fish species. Our analysis of species vulnerability will focus on the sensitivity and habitat resilience components of the Poff et al. (2012) framework as adequate information is not yet available to assess exposure in Missouri.

Species tolerance of habitat alteration, changes in flow regimes, and increasing stream temperatures have been assessed using two different approaches; species trait associations (Angermeier, 1995; Parent and Schriml, 1995; Poff, 1997; Olden et al., 2007, 2008; Culp et al., 2011; Mims and Olden, 2013) and measured species responses (Hering et al., 2006; Poff and Zimmerman, 2012; Lyons et al., 2010). We developed two separate indices, one which scores environmental tolerance based on traits and the other which scores based on species responses. The same scoring framework was used for both indices, however the indices used different methods for classifying environmental tolerance. The trait association approach to classifying environmental tolerance is based on traits which have been linked to vulnerability to habitat alteration, changes to flow regimes, and increases in stream temperature in peer-reviewed literature, and the species response approach is based on