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Original research article

Using climate and a minimum set of local characteristics to predict the future distributions of freshwater fish in Ontario, Canada, at the lake-scale

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ABSTRACT

Aim:

In order to overcome data limitations on predicting future distributions of freshwater fishes at the lake scale, our aim was to build simple species distribution models for three focal fishes from warm-, cool- and cold-water guilds, using a small set of local environmental variables paired with climate information.

Location:

A total of 6715 inland freshwater lakes across Ontario, Canada.

Methods:

Multiple logistic regression techniques were employed to model historical species occurrence with seven candidate local environmental variables, including a climate index. Model accuracy was tested by: (i) validating with a subset of the historical dataset (centered around the 1970s), and (ii) predicting species occurrence in lakes using a contemporary dataset (centered around the 2000s), representing ∼30 years of climatic change. Projected climate data was then used to model species occurrence into the 2041–2070 time period.

Results:

The models for each thermal guild performed well (average AUC of 0.79) using the historical validation dataset as well as the contemporary dataset. The final set of predictors was unique to each species; however lake surface area, and the climate index were significant in all models. In all three models, the climate index was the most influential variable. Cold-water lake whitefish and cool-water walleye are predicted to be lost from a large number of lakes (1283 and 1792, respectively) by 2041–2070 across central and southern Ontario. Nevertheless, numerous hospitable lakes will be available to both fishes in Ontario's far north (OFN), where 108 lakes are predicted to be suitable for lake whitefish and 247 are predicted to be suitable for walleye. Thousands of lakes across Ontario are predicted to be hospitable for rock bass in the future, including 35 locations in OFN.

Main Conclusions:

Modified logistic regression models, incorporating a minimum of local environmental and climate information, show promise in predicting the future distributions of fishes in

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Ontario lakes. This is an important first step in building conservation capacity for freshwater fishes in northern regions, where conservation value is very high, but data are particularly limited.

1. Introduction

Climate change is widely viewed as the single greatest threat to both humans and natural systems in the next century (IPCC, 2014). Accordingly, an increasing proportion of ecological, environmental, and conservation research is aimed at understanding how climate shapes our biosphere, and how changes in climate will affect the distribution and persistence of biodiversity on the planet in the future (Felton et al., 2009; Pettorelli, 2012).

Decades of improvements in climate modeling have yielded global and regional climate change projections with fine spatial resolution and a great deal of support from the expert academic community (IPCC, 2007, 2013). There is a consensus among scientists that climate change has already taken place, particularly at northern latitudes (Schindler, 2001; Colombo et al., 2007; Rusak et al., 2008; IPCC, 2013; Alofs et al., 2013), and that ongoing changes will occur at an accelerated pace in the years to come (IPCC, 2013). In the northern hemisphere, warming over the past 30 years is unequivocal, and each successive decade has been warmer at the earth's surface than anything observed since 1850 (IPCC, 2013). Predictions for the future include air temperature increases, altered precipitation patterns, and an increase in the frequency of extreme climatic events (IPCC, 2007, 2013). Because changes in climate are projected to be most intense at higher latitudes, northern taxa that are cold-climate specialists are expected to be among the most negatively impacted by climate change.

Freshwater systems are currently among the most threatened on the planet (Allan and Flecker, 1993; Dudgeon et al., 2006; Abell et al., 2011), and they face particularly intense climate change impacts, in conjunction with multiple additional stressors (Schindler, 2001; Keller, 2007). In lakes, climate change will lead to altered thermal characteristics, increased durations of ice-free seasons, and changes in water levels (Magnusson et al., 1997; Keller, 2007; Rusak et al., 2008). These environmental changes will alter the quality and quantity of habitat for fishes and other lake inhabitants (Keller, 2007; Lynch et al., 2016). At a broad scale, fish thermally adapted to cold waters are predicted to lose habitat at the southern edges of their range, where they may be unable to escape warm waters (Abell, 2002; Shuter et al., 2002; Minns et al., 2009; Gunn and Snucins, 2010; Shuter et al., 2012). Cool- and warm-water fishes are predicted to expand northward as new lakes become suitable beyond their current northern range limits (Magnusson et al., 1997; Chu et al., 2005; Keller, 2007; Alofs et al., 2013). Such expansions may impose additional stress on native cold-water species due to increased competition and predation (Vander Zanden et al., 1999; Jackson and Mandrak, 2002; Sharma et al., 2011).

The province of Ontario, Canada spans a large latitudinal range and contains approximately 250,000 inland lakes. Over 30,000 of these lakes are located north of the commercial limit to forestry, in what is known as Ontario's far north region (OFN), a vast and relatively undeveloped landscape. Unfortunately, little is known about the physical characteristics of the majority of these northern lakes, or the fish communities they contain. In fact, numerous researchers in Canada have identified a disparity of both physical and biological knowledge of northern lakes across the country (Chu et al., 2003; Minns et al., 2008; McDermid et al., 2015a). Climate studies project that OFN will warm significantly over the next century (greater than 10 °C in some areas) and experience altered seasonal precipitation (Colombo et al., 2007; Vincent et al., 2012; McDermid et al., 2015b). Both trends have already been detected in observational data (Magnusson et al., 1997, 2000; Schindler, 2001; Alofs et al., 2013).

Regional-scale evaluations of future climate suitability predict northward range expansions of warm- and cool-water sport fish in Ontario (Vander Zanden et al., 2004; Chu et al., 2005; Sharma et al., 2009). Despite concern that freshwater species might have a limited capacity to adapt to climate changes, due to the insular nature of freshwater habitats (Strayer and Dudgeon, 2010), such northward expansions are already being documented in lakes (Alofs et al., 2013).

Over the last century, humans have been altering the distributional patterns of numerous bait and sport fishes across Ontario, via the intentional or unintentional movements of individuals related to fishing activities (Sharma et al., 2009; Alofs et al., 2013; Drake and Mandrak, 2014), as well as the direct effects of fishing pressure. Various indicators of human use intensity, including population size, road density, or estimates of 'attractiveness' for recreational activities, have been linked with the likelihood of human mediated dispersal of fishes among inland lakes (Drake and Mandrak, 2014, Leathwick et al., 2016). Human mediated dispersal is likely to play a role in future range shifts related to changes in climate suitability (Alofs et al., 2013) and at the lake scale proxies of human use may be an important predictor of occupancy.

Additionally, making specific predictions as to which lakes will be hospitable to individual fish species in the future, under various climate change scenarios, requires the inclusion of important lake habitat characteristics into species distribution models (Jackson et al., 2001). The local climate interacts with aspects of lake size, depth and shape to determine the relative availability of different thermal habitats, and therefore the effects of climate change on species with different thermal preferences will be non-uniform within climatic regions based on variability in lake morphology (Minns, 1989, Minns et al., 2009; Minns and Shuter, 2013; reviewed in Lynch et al., 2016). Also, depending on the range of climate conditions