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Predicting potential impacts of climate change on freshwater fish in Korea

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ABSTRACT

Climate change is expected to have profound effects on the distribution and phenology of species and the productivity of aquatic ecosystem. In this study, we projected the impacts of climate change on the distributions of 22 endemic fish species in Korea with climatic and geographical variables by using species distribution models (SDMs). Six different SDMs – linear discriminant analysis, generalized linear model, classification and regression trees, random forest, support vector machine, and multivariate adaptive regression splines – were implemented for the prediction, and compared for their prediction capacity. The results showed that the random forest displayed the highest predictive power for the prediction of current species distributions. Therefore, the random forest was used to assess the potential impacts of climate change on the distributions of 22 endemic fish species. The results revealed that five species (*Acheilognathus yamatsutae*, *Sarcocheilichthys variegatus wakiyae*, *Squalidus japonicus coreanus*, *Microphysogobio longidorsalis*, and *Liobagrus andersoni*) have a high probability of becoming extinct in their respective habitable sub-watersheds by the 2080s due to climate change. The sensitivity analysis of the model showed that geo-hydrological variables such as stream order and altitude and temperature-related variables such as mean temperature in January and difference between the minimum and maximum temperatures exhibited relatively higher importance in their contributions for the prediction of species occurrence than that other variables. The decline of endemic fish species richness, and their occurrence probability due to climate change, would lead to poleward and upward shifts, as well as extinctions of species. Finally, we believe that our projections are useful for understanding how climate change affects the distribution range of endemic species in Korea, while also providing the necessary information to develop preservation and conservation strategies for maintaining endemic fish.

1. Introduction

The evaluation of climate change effects on the structure and function of the ecosystem is one of the most researched issues in modern ecology (Daufresne and Boët, 2007), and various studies have shown that the recent climate change has already affected species' geographical distributions and persistence of their populations (Heikkinen et al., 2006; Moore, 2003; Parmesan, 1996; Parmesan and Yohe, 2003; Walther et al., 2002). Furthermore, the projected climate change is likely to have an even greater impact on biota (Berry et al., 2002; Hill et al., 2003; Thomas et al., 2004; Thuiller et al., 2005; Li et al., 2013; Li et al., 2014). The most immediate effects of climate change are shifts in species' geographical range, prompted by shifts in the normal patterns of temperatures delimiting species boundaries (Thuiller, 2007).

In particular, climate change can have a greater effect on freshwater biodiversity than either terrestrial or marine biodiversity, by increasing water temperatures and altering stream flow patterns (Jenkins, 2003; Poff et al., 2002; UNESCO, 2003). Revenga et al. (2005) showed that the projected rate of species loss in freshwater ecosystems is estimated to be five times greater than that of terrestrial fauna in North America, and rates are likely to increase in the future. These changes are expected to have profound effects on the distributions and phenology of species and productivity of aquatic ecosystems (Parmesan, 2006). Changes of environmental factors can be stresses on ecosystems and biota. Environmental stresses have caused extensive transformation and deterioration of various environments (MA, 2005; Brook et al., 2008; Staudt et al., 2012). Climate change has serious impacts on ecosystems mentioned above and climate change effects are projected to be an increasingly important source of stresses in the future (Staudt et al., 2012). Therefore, ecological risk assessment of climate change is needed. Ecological risk assessment is the assessment of environmental effects of certain stresses and their immediate and long-term damage or harm to an ecosystem and it has been widely recommended for environmental decision making (Chen et al., 2011, 2013).

Fish are an important component of aquatic ecosystems through functions, including their consumption of organisms at lower trophic levels and their regulatory effects on a variety of ecosystem-level properties (Carpenter et al., 1985; Power et al., 1985; Wootton and Power, 1993). Fish can also reflect habitat changes, environmental degradation,

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and overall ecosystem health (Karr and Freemark, 1985; Kouamélan et al., 2003; McCauley, 1990). Distribution and abundance of fish are affected by various environmental factors, including geological, hydromorphological, physicochemical, climatic, and biological factors (Kwon et al., 2012). Among them, climatic ones are fundamental to fish distributions because most fish do not have the physiological ability to regulate their body temperatures (Wood and McDonald, 1997). Freshwater fish also cannot disperse across terrestrial areas because their dispersal abilities are constrained by the network structure of their drainage basins, and are consequently limited to the river basin in which they currently live, making them vulnerable to broad-scale environmental changes, such as climate change (Buisson et al., 2008). Thus, climate change is of considerable importance for determining future fish distributions.

Species distribution models (SDMs), also known as habitat modeling and niche modeling, are useful tools for predicting the potential spatial distribution of a phenomenon because they relate sites of known occurrences to predictor variables (Hijmans and Elith, 2013). The common applications of this method assess the potential impacts of climate change and predict species distribution ranges based on climate data by using various methods that include the following: generalized additive models (GAM; Leathwick et al., 1996; Araújo et al., 2004; Luoto et al., 2005), generalized linear models (GLM; Araújo et al., 2004; Thuiller et al., 2005), multivariate adaptive regression splines (MARS; Prasad and Iverson, 2000), and classification and regression trees (CART; Iverson and Prasad, 1998; 2002). Each method has been shown to produce high levels of predictability in each of the aforementioned studies. However, they have different properties and have been applied under different conditions. Therefore, it is valuable to compare the performance of each of the different modeling methods with the same datasets. Meanwhile, Fukuda et al. (2013) demonstrated the applicability of several modeling methods to model the species–habitat relationship of spawning European graylings (*Thymallus thymallus*), and Buisson et al. (2010) have focused on applying a range of SDMs to a set of fish species occurring in French streams. However, they did not consider climatic factors in the models. In this study, we predicted occurrences of endemic fish species with climatic and geographical variables using six different modeling methods, and compared their prediction capacities. In addition, we intended to estimate the potential distribution range of each species under a climate change scenario by using the best-suited modeling method, and to evaluate the relative importance of environmental variables for the prediction of species distribution.

2. Materials and methods

2.1. Fish data

The dataset consisting of presence/absence of fish species was obtained from the database of the National Aquatic Ecological Monitoring Program, which is operated by the Ministry of Environment and the National Institute of Environmental Research, Korea. According to the standardized sampling protocol of the program (MOE/NIER, 2008), the samples were collected at 960 sampling sites in five major rivers (Han, Nakdong, Geum, Yeongsan, and Seomjin rivers) and their tributaries and small streams across the entire stream system of the country from 2008 to 2012 (Table 1). In the dataset, a total of 145 fish species belonging to 29 families were recorded. Based on the occurrence frequency in the sampling sites, *Zacco platypus* was the most frequently observed species in Korea. *Pseudogobio esocinus*, *Odontobutis platycephala*, and *Carassius auratus* were the most abundant species in the Han River watershed, the Nakdong River, and Seomjin River watersheds, and the Geum River and Youngsan River watersheds, respectively. Endemic fish species that occurred in greater than 10% of the 953 sampling sites (excluding the 7 sites on Jeju Island) were retained to reduce errors by the rare species, resulting in a dataset with 22 endemic fish species. The presence–absence of species was used in this study.

2.2. Climatic and geo-hydrological data

To develop the species distribution models and evaluate the potential effects of climate change on the distribution of fish species, we obtained climate data regarding a climate change scenario from the Korea Meteorological Administration (KMA, http://www.climate.go.kr). The representative concentration pathway (RCP) scenario was based on the 5th report of the Intergovernmental Panel on Climate Change (IPCC) and reflects the recent trends in the changing greenhouse gas concentrations. The RCP scenario is comprised of four different scenarios of greenhouse gas concentrations (RCP 2.6, 4.5, 6.0, and 8.5). Among these scenarios, we considered the RCP 8.5 scenario (i.e., 936 ppm atmospheric CO_2 in 2100), in which greenhouse gases are emitted at the current level, to predict changes in the species distributions due to climate change. From the RCP 8.5 scenario data, we extracted 12 climatic variables related to temperature and precipitation, because temperature (Begon et al., 2006; Somero, 1997) and precipitation (Milly et al., 2005) are the key climatic factors influencing fish species distribution (Buisson et al., 2008b; Gillanders et al., 2011; Matthews, 1998; Pont et al., 2005; Wehrly et al., 2003). Among the 12 climatic variables, 8 variables, including average annual temperatures and precipitations for January, April, July, and October, were used to account for seasonality of three different decades: the 2000s, 2040s, and 2080s (Table 2). In addition, the differences between the maximum (July) and minimum (January) temperature and precipitation values were also used to account for annual variation. The 2000s were selected as the current climate situation, and the other two decades (2040s and 2080s) were selected to represent climate change.

To reflect the physical characteristics of fish habitats and the limitations of fish distributions due to geo-hydrological characteristics, we also considered three geo-hydrological variables: altitude, slope, and stream order of each sampling site. Altitude was measured from a Digital Elevation Map (DEM), and slope and stream order were obtained from the Water Management Information System (WAMIS, http://www.wamis.go.kr) of the Ministry of Land, Transport and Maritime Affairs, Korea. Both RCP scenario and geo-hydrological data were extracted from the ESRI-GRID format using ArcGIS (Version 9.3, ESRI, 2008).

Finally, 15 environmental variables (12 climatic variables and three geo-hydrological variables) were used in the study. Environmental

Table 1
Characteristics of fish assemblage at different watersheds.

Watershed	Number of species			Dominant species	
	Total	Exotic	Endemic	1st	2nd
Han River	110	6	35	*Zacco platypus*	*Pseudogobio esocinus*
Nakdong River	103	4	37	*Zacco platypus*	*Odontobutis platycephala*
Geum River	92	5	32	*Zacco platypus*	*Carassius auratus*
Youngsan River	76	3	22	*Zacco platypus*	*Carassius auratus*
Seomjin River	75	3	26	*Zacco platypus*	*Odontobutis platycephala*
Total	145	6	54	*Zacco platypus*	*Pseudogobio esocinus*