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Spatial conservation planning under climate change: Using species distribution modeling to assess priority for adaptive management of *Fagus crenata* in Japan

Katsuhiro Nakao[a,*], Motoki Higa[b], Ikutaro Tsuyama[a], Tetsuya Matsui[a], Masahiro Horikawa[c], Nobuyuki Tanaka[d]

[a] *Department of Plant Ecology, Forestry and Forest Products Research Institute, 1, Matsunosato, Tsukuba, Ibaraki 305-8687, Japan*
[b] *Laboratory of Plant Ecology, Faculty of Science, Kochi University, 2-5-1 Akebono-cho, Kochi 780-8520, Japan*
[c] *Toyota Biotechnology and Afforestation Laboratory, Toyota Motor Corporation, 1099 Aza Marune, Oaza Kurozasa, Miyosi-cho, Nishikamo-gun, Aichi 4700201, Japan*
[d] *Hokkaido Research Center, Forestry and Forest Products Research Institute, 7 Hitsujigaoka, Toyohira-ku, Sapporo, Hokkaido, Japan*

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ABSTRACT

Protected areas are the basis of modern conservation systems, but current climate change causes gaps between protected areas and the species distribution ranges. To mitigate the impact of climate change on species distribution ranges, revision of protected areas are necessary. Alternatively, active management such as excluding competitive species or transplanting target species would be effective. In this study, we assessed optimal actions (revision of protected areas or active management) in each geographical region to establish an effective spatial conservation plan in Japan. Gaps between the protected areas and future potential habitats were assessed using species distribution models and 20 future climate simulations. *Fagus crenata*, an endemic and dominant species in Japan, was used as a target species. Potential habitats within the protected areas were predicted to decrease from 22,122 km^2 at present to 12,309 km^2 under future climate conditions. Sustainable potential habitats (consistent potential habitats both at present and in future) without the protected areas extended to 13,208 km^2, and were mainly found in northeast Japan. These results suggest that, in northeast Japan, revisions to protected areas would be effective in preserving sustainable potential habitats under future climate change. However, the potential habitats of southwestern Japan, in which populations were genetically different from northeastern populations, were predicted to virtually disappear both within and outside of protected areas. Active management is thus necessary in southwestern Japan to ensure intraspecific genetic diversity under future climate change.

Introduction

The average global temperature has increased by 0.74 °C over the past century and is projected to increase further by 1.8–4.0 °C by 2090–2099 (IPCC 2007). This recent global warming has already begun to affect terrestrial biological systems, as shown by poleward and upward shifts in the ranges of plant and animal species distributions (Parmesan and Yohe 2003). The IPCC reviewed relevant published studies of biological systems and concluded that, on a global scale, 20–30% of plant and animal species may be at risk of extinction due to the impact of climate change (IPCC 2007). Assessments of the impact of climate change on species distribution are thus necessary to reveal the extent of the potential ecological risk, and design appropriate conservation strategies for adaptive management.

Protected areas, including national parks, nature reserves, and multiple-use conservation areas, are still the basis of modern conservation systems (Rodrigues et al. 2004), and are expected to remain an important conservation strategy under future climate change (Heller and Zavaleta 2009). However, range shifts due to climate change may cause species to evacuate protected areas. In Europe, 58% of species are projected to lose suitable climate in protected areas (Araújo et al. 2011). The need for additional protected areas in anticipation of species range shifts due to climate change has been examined using species distribution models and conservation planning tools (Hannah et al. 2007). However, the potential risk of species range loss and extinction due to climate change have

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Abbreviations: WI, warmth index; TMC, minimum temperature of the coldest month; PRS, summer precipitation; PRW, winter precipitation; PRDB, Phytosociological Relevé Database; PHs, potential habitats.

[*] Corresponding author. Tel.: +81 29 829 8221.
E-mail address: knakao1001@gmail.com (K. Nakao).

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been estimated, especially for species occupying narrow geographical ranges (Colwell et al. 2008) and edge populations (Hampe and Petit 2005). It may be difficult to maintain these species in protected areas due to the limited tolerance to climatic variation.

Active management, including exclusion of competitive species, selective thinning and transplantation, is an alternative to reduce the impact of climate change on species distributions (Jump, Cavin, & Hunter 2010). Both species with narrow geographic ranges and vulnerable populations with unique genetic features can be considered high-priority candidates for investment in active management. This is because the loss of evolutionary lineages reduces evolutionary potential and stops on going diversification processes that would affect future biodiversity (Bálint et al. 2011). Some recent studies have included effects of climate change, aiming to deploy more-effective protected areas and corridors (Faleiro, Machado, & Loyola 2013; Hannah et al. 2007), but such studies usually ignore genetic diversity. Attempts at active management of vulnerable populations occasionally encounter problems in conservation-resource allocation due to limited human resources and budgets (Heller and Zavaleta 2009). Accordingly, broad-scale quantitative assessments to identify areas where populations of particular conservation concern and risk of degradation coincide are vital for active management (Jump et al. 2010). Moreover, it is also important to incorporate revision of protected areas and active management into spatial conservation plans, to conserve species under climate change.

The impact of climate change on species has often been assessed using species distribution models (SDMs; Elith and Leathwick 2009). In Europe, tree species of temperate deciduous forests (e.g. *Fagus sylvatica*) are predicted to face high risk from a loss of climatically suitable habitats due to future climate change (Ohlemüller et al. 2006). In Japan, some SDM studies have described the potential effects of climate change, including range loss and northward habitat shifts of dominant and widespread species, from growth in the cool temperate (e.g. *Fagus crenata*; Matsui, Takahashi, et al. 2009; Matsui, Tanaka, et al. 2009) to alpine zones (*Pinus pumila*; Horikawa et al. 2009). In contrast, other studies have shown that the potential habitats of *Quercus acuta*, a dominant tree species in the northern and upper range limits in the warm temperate zone, may expand due to climate change (Nakao et al. 2011).

Fagus crenata, an endemic, dominant, deciduous, broad-leaved tree species, forms one of the key types of old-growth forest in the Japanese cool-temperate zone. Its biological and socio-cultural values were acknowledged when Shirakami-Sanchi was designated a World Heritage site (http://www.whc.unesco.org/en/list/663). Changes in the distribution and biomass of *F. crenata* may have a substantial impact on natural ecosystems because these forests are known for their importance as wildlife habitats (Hara 1996). In addition, phylogeographic studies have suggested that the phylogenetic structure of *F. crenata* varies geographically (Tomaru et al. 1998), meaning *F. crenata* may be an adequate objective for spatial conservation planning that includes revision of protected areas and active management on broad spatial scales. Previous studies predicted that *F. crenata* forests in western Japan were vulnerable to climate change, whereas some mountains in northern Japan were predicted to be possible future refugia (Matsui, Takahashi, et al. 2009). While the potential vulnerability of this species has been studied in depth, insufficient studies on conservation strategies in response to climate change have been made (but see Matsui, Tanaka, et al. 2009). The Japanese government is aiming to revise a Basic Environment Plan, which includes adaptive management of natural ecosystems to climate change (Ministry of the Environment 2012). Accordingly, assessing the impact of climate change and conservation planning for *F. crenata* should provide a useful platform for planning the adaptive management of ecosystems in Japan.

The aim of this study was to select optimal conservation actions and sites for spatial conservation planning by considering the genetic diversity of *F. crenata*, to sustain population growth and ecosystem services of this species under future climate change. To achieve this objective, the potential habitat of *F. crenata* was predicted using SDMs and 20 future climate simulations. Based on the model results, we assessed (1) locations of sustainable and vulnerable habitats of *F. crenata* within and outside protected areas and (2) means of identifying how and where to implement active management to protect populations of this species.

Materials and methods

Study area and distribution data

The scope of the study area ranged from Kyushu to Hokkaido, Japan, where *F. crenata* grows and dominantes (Fig. 1). The spatial resolution of the study was 30″ latitude × 45″ longitude (ca. 1 km × 1 km). This was called the Standard Area Grid (Geographical Survey Institute 1992) in Japan. In this study, area of one the Standard Area Grid square was defined as $1\ \mathrm{km}^2$ for convenience.

The current distribution data of *F. crenata* was extracted from the Phytosociological Relevé Database (PRDB) (Tanaka 2012), and contains 26,021 records (November 2011 version). The PRDB also contains various types of vegetation from the coast to alpine regions. Each record includes the coverage and sociability of each species within each layer and the elevation of the sampled sites. Presence and absence records were re-sampled into each grid (i.e. Standard Area Grid) to eliminate duplicate records there. If one or multiple presence records were found in a grid, it was assigned as a presence, and otherwise as an absence. After this re-sampling 1,763 presence and 10,821 absence records were obtained (Fig. 1(c)).

Climatic data

We used three different climatic datasets; current climate data generated by the Japan Meteorological Agency (1996), the Climate of the 20th Century experiment (20c3m) and a future climate simulation based on the A1B scenario. Monthly means of precipitation (1953–1976) and temperature (1953–1982) for the Standard Area Grid were extracted from the climate database generated by the Japan Meteorological Agency. From this climate data set, the present study extracted data on four climate variables considered likely to critically affect the survival and growth of plants (Fig. A1). The mean minimum temperature of the coldest month (TMC) provides an index for cold extremes (Sakai 1975), while the warmth index (WI), is defined as the annual sum of positive differences between monthly means and 5 °C (Kira 1977). WI has been widely used as an important index for forest zonation studies in East Asia rather than the mean annual temperature, since isopleths of warmth indices correspond well to the boundaries of forest zones (Kira 1977). Winter precipitation (PRW), in cool temperate regions, indicated the accumulation of snow. Deep snow insulates plants from low temperature and provides water the following spring. Summer precipitation (PRS) was an index of water supply during the growing season, whereas plant distribution is also influenced by non-climatic factors such as soil types, Matsui et al. (2004) revealed that the distribution of *F. crenata* was mainly attributable to climatic than non-climatic factors, hence only the former were taken into account to establish a species distribution model.

To assess the uncertainty of future climate simulation derived from different general circulation models (GCMs), we used 20 GCMs of the World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset as