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Time-lagged responses of indicator taxa to temporal landscape changes in agricultural landscapes

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ABSTRACT

Biological indicator methods represent one of the most effective and widely used strategies for understanding the influences of environmental degradation on biodiversity in various landscapes. Researchers and land managers generally assume that the present distributions of biological indicator species are influenced by the current environment. However, recent studies have suggested the importance of past environments to species distributions (i.e., a time lag between changes in species distribution and habitat alterations). Therefore, it is necessary to understand the effects of past environments on the distributions of indicator species.

We conducted a survey on the Tokachi Plain in Hokkaido, Japan. We targeted two taxa that have been widely used as indicator species (carabid beetles and bats) and investigated whether past landscape environments influenced their present distributions. We showed that past landscape environments (5 decades prior to the present) influenced the distributions of some ecological trait groups in each taxon (large body size for carabid beetles and a 25 kHz peak echolocation frequency for bats) and that these effects varied among groups. Our results suggest the need to consider the dynamics of land-use changes and the effects of past environments on the distributions of indicator taxa, otherwise we may misunderstand the effects of environmental degradation on biodiversity.

1. Introduction

Modern agricultural activities are one of the major factors for wildlife extinction (Norris, 2008; Tilman, 1999). The International Union for Conservation of Nature and Natural Resources (IUCN) reported that agricultural activities have reduced the distribution of 29% of red list species (IUCN, 2014). However, because modern agricultural areas are still rapidly increasing, with a predicted increase of more than 18% in the next 5 decades (Tilman et al., 2001), conservation of biodiversity in agricultural landscapes is urgently needed (Norris, 2008).

Biological indicators offer one of the most effective strategies for understanding the influence of environmental degradation on biodiversity in human-dominated landscapes (Kremen et al., 1994; New, 2005). Because the funding available for biodiversity conservation is limited due to the increasing challenges of food security for a growing population under changing economic conditions, the biological indicator approach (a cost-effective approach) will become even more practical in the future. The most useful indicator species are those that respond gradually to environmental degradation (Landres et al., 1988; McGeoch, 1998). Many herbaceous plant, bird, and insect species have been used to understand the status of agricultural biodiversity in several countries (e.g., Peck et al., 1998; Perner and Malt, 2003). Most of these studies have assumed that the distributions or populations of the target indicators are only influenced by the current environment. However, many reports have indicated that the distribution of organisms is affected not only by the current environment but also by past environments (e.g., Cousins and Vanhoenacker, 2011; Lindborg and Eriksson, 2004; Sang et al., 2010), as species often need more time to fully respond to environmental alterations than the time required for the environmental alteration itself (Kuussaari et al., 2009; Tilman et al., 1994). Therefore, when using biological

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indicator methods, researchers and land managers should consider how past environments have influenced current species distributions, otherwise their results may be misleading (Lindenmayer, 1999). A few studies have considered the influences of past environments on the current distributions of indicator species (see, Pacha and Petit, 2008).

Because species distributions are often influenced by the environment at several spatial scales, many studies have suggested that it is necessary to consider the time lag between alterations to the environment and changes in species distributions at both the patch scale and the landscape scale (e.g., Hanski, 2013; Hanski and Ovaskainen, 2002). However, most previous studies have focused only on patch area when analyzing time-lagged responses (however, see Wearn et al., 2012).

The aim of the present study was to clarify whether the present distributions of indicator taxa are influenced by past landscape environments. We targeted two taxa (carabid beetles and bats) that have been used as powerful biological indicators of environmental degradation in agricultural landscapes (Jones et al., 2009; Rainio and Niemelä, 2003).

1.1. Target taxa and ecological traits

Carabid beetles comprise a diverse group of insects that are widely distributed. This taxon is sensitive to environmental changes (Januschke et al., 2014; Rykken et al., 1997) and has been used as a biological indicator, particularly in agricultural landscapes (e.g., Rainio and Niemelä, 2003). Bats represent one-fourth of all mammalian species (both terrestrial and aquatic species), and their species richness contributes greatly to regional mammalian diversity (Buckley et al., 2010). As bat abundance responds gradually to habitat modifications, bats have been used as biological indicators in various habitats, including agricultural landscapes (Solari et al., 2002). The suitability of carabid beetles and bats as biological indicators is further enhanced by the fact that these two taxa are taxonomically well known (Jones et al., 2009; Rykken et al., 1997).

Although different animal species, including carabid beetles and bats, can show different responses to environmental alterations (Jones et al., 2009; Rainio and Niemelä, 2003), species with similar ecological traits generally display similar responses (Keddy, 1992). Previous studies have shown that carabid beetle body size is strongly related to habitat preference (e.g., Cole et al., 2002). Additionally, bats with similarly structured echolocation calls select similar aerial spaces (i.e., habitats; Bogdanowicz et al., 1999). Because of close associations of carabid beetle body size and bat echolocation calls with habitat conditions, we used these ecological traits for the present study. Thus, we categorized carabid beetle species into small, medium, and large body size groups (Cole et al., 2002) and bats into 25 kHz and 45 kHz peak echolocation frequency groups (Ohdachi et al., 2009) respectively.

2. Materials and methods

2.1. Study area

The study was conducted on the Tokachi Plain in central Hokkaido, Japan (Fig. 1), one of the major agricultural areas in Japan. The mean annual precipitation in this region is 887.8 mm (data from 1981 to 2010, provided by Obihiro Climatological Observatory, located within the study area). Oak-dominated forests (*Quercus dentata*) had originally covered this region (Yajima et al., 2002). Most of the oak forests were converted to agricultural land after 1896, and approximately 14% of the remnant oak forests were replaced by larch plantations (*Larix kaempferi*) after the 1960s

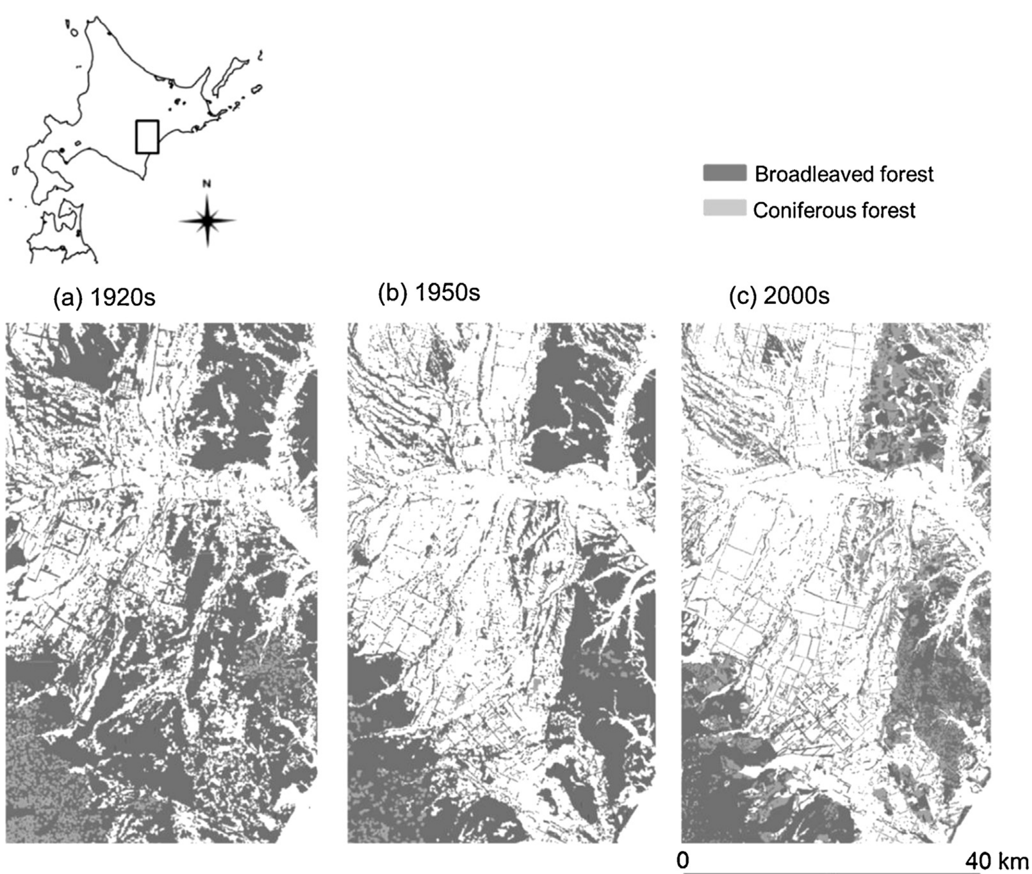

Fig. 1. Study area in Tokachi plain, Hokkaido, Japan. The forest distribution at the three periods: (a) the 1920s, (b) 1950s, and (c) 2000s.