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Relative importance of landscape features, stand structural attributes, and fruit availability on fruit-eating birds in Japanese forests fragmented by coniferous plantations

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ABSTRACT

Replacement of natural forests with plantations is causing forest loss and fragmentation worldwide. There is a great need for conservation and restoration of fauna in these fragmented forests, particularly those with special ecological functions, such as fruit-eating birds. In this 3-year study, we explored the relative importance of landscape-level and local factors for the richness and abundance of fruit-eating birds in broad-leaved forest patches scattered within a coniferous plantation in Japan. As local factors of remnant forests we included fleshy fruit availability and stand structural attributes, and then analyzed how the relative importance of these factor varies between the breeding (May–August) and non-breeding (September–December) seasons and among three bird size classes. Our results provide new insights into seasonal variations in the factors associated with bird richness and abundance and demonstrate the importance of fruit availability in the remnant forest patches. The main factors showing positive associations with bird richness/abundance were stand structural attributes (e.g., tree basal area) and landscape variables (e.g., proportion of broad-leaved forest) during the breeding season, whereas it was fruit availability during the non-breeding season, when migrating birds are dominant. We detected only minor variations in the associated factors among the three size classes. Thus, preserving continuous mature forests is of great importance for conserving breeding communities of fruit-eating birds, and maintaining fruit availability is an effective approach for supporting migrating birds during the non-breeding season. These findings are applicable to forest management aimed toward biodiversity conservation in regions being replaced or to be replaced by plantations, such as in many areas of temperate East Asia.

1. Introduction

Land-use changes caused by anthropogenic activities present a major threat to biodiversity worldwide (Fahrig, 2003; Fischer and Lindenmayer, 2007). Loss and fragmentation of forests due to timber, crop, and livestock production or urbanization can cause declines in the species richness of a wide variety of taxa (Koh and Wilcove, 2008; Laurance et al., 2002; Sekercioglu et al., 2002; Stouffer et al., 2006).

The replacement of natural forests with plantations is progressing throughout the world, becoming a major driver of forest loss and fragmentation. According FAO data, between 1990 and 2015 global forest cover decreased from 31.9% to 30.9%, while the proportion of plantation for wood production in total forest cover increased from 4.1% to 7.0% (Payn et al., 2015). The plantation area is increasing most rapidly in temperate regions of East Asia, Europe, and North and South America and this trend is expected to continue (Payn et al., 2015). This situation highlights the great need for quick action to conserve and restore fauna in this type of fragmented landscape (Brockerhoff et al., 2008), as well as the need for a sustainable management of forest plantations (Fischer et al., 2006). In these activities, conserving animals involved in key biological interactions is of primary importance (Fischer et al., 2006), because their extinction or decline can have cascading negative impacts on forest communities. From this perspective, fruit-eating birds are a main target of conservation due to their role as seed dispersers and their vulnerability to disturbance (Whelan et al., 2008). Exploring factors associated with the richness and abundance of these birds in such fragmented landscapes can advance our understanding of conditions critical for the persistence of their communities and contribute to sustainable, biodiversity-conserving plantation practices.

Empirical and theoretical studies have demonstrated that the richness and abundance of birds in a fragmented forest are intricately

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influenced by both local factors (i.e. habitat conditions within patches) and landscape-level factors (Estades and Temple, 1999; Lindenmayer et al., 2002; Smith et al., 2011; Vergara and Armesto, 2009). Local factors are critical for species occurrence and thus can be strong indicators for bird richness and abundance (Hansen et al., 1995; Mortelliti et al., 2010). Previous studies mainly considered structural forest attributes, such as tree density, tree diversity, and cover of various layers within a stand (Blake and Karr, 1987; Canterbury et al., 2000; Hino, 1985; Uezu and Metzger, 2011). Landscape-level studies usually address the effects of habitat size and habitat configuration (Andren, 1994; Schmiegelow and Mönkkönen, 2002; Villard et al., 1999). Habitat size (or amount), measured as the area of suitable habitat in a given landscape, has a strong impact on bird communities (Andren, 1994; Fahrig, 2003, 2013; Lindenmayer et al., 2002). Habitat configuration, which reflects the degree of isolation or connectivity of patches, can affect the persistence of bird populations (Enoksson et al., 1995; Martensen et al., 2008). In addition, the strengths of these two factors can be modulated by the type of matrix in which the forest patches are embedded (Deconchat et al., 2009; Sisk et al., 1997).

While the structural attributes of local stands are often used as indirect measures of 'habitat quality', more proximate estimates of habitat quality that reflect the amount of available (food) resources are optimal (Mortelliti and Boitani, 2007). Local food availability, however, was rarely considered as a candidate factor in previous studies of bird richness and abundance in fragmented forests. Thus, we still lack a comprehensive understanding of how much and under what conditions food availability affects the dynamics of bird richness and abundance, together with local stand structures and landscape-level factors (Mortelliti and Boitani, 2007). Consideration of the food resource is of particular significance for understanding the responses of fruit-eating birds to fragmentation, because these birds are known to migrate to available fruit resources that fluctuate temporally and spatially, particularly in the non-breeding season. Several studies have detected the spatial and temporal covariance of birds and fruit availability between or within locations and posited it as evidence of "resource tracking" behavior by the birds (Kwit et al., 2004; Rey, 1995; Tellería et al., 2008, 2014). Fruit tracking by birds has large implications not only for the conservation of bird communities, but also for the preservation of seed dispersal functions, as the behavior implies the prevalence of the seed dispersal service throughout the landscape (Garcia et al., 2010). Classic theory on resource tracking by animals assumes the idealized condition that the temporal activity of animal can reflect the spatial and temporal distribution of its food, as well as its temporal requirement of the food item (Kozakiewicz, 1995). However, in natural forest landscapes, fruit tracking and consequent positive associations between fruit availability and birds can be hindered by landscape structures modified by human activity (Lehouck et al., 2009) as well as local stand attributes, except fruit availability (Martínez and García, 2015). Additionally, the success of fruit tracking by birds can largely depend on the species or individual traits (Tellería et al., 2008) or their seasonal cycles of territorial behaviors and dietary requirements (Blendinger et al., 2015).

Previous studies revealed associations between ecological and life-history traits of a bird species and their response to an array of the abovementioned factors in a fragmented landscape (Estades and Temple, 1999; Lindenmayer et al., 2002; Newbold et al., 2013; Uezu and Metzger, 2011). Among bird traits, body size is often a major indicator of the sensitivity to forest disturbances and fragmentation (Estades and Temple, 1999; Henle et al., 2004; Kattan et al., 1994; Newbold et al., 2013). This trait is also crucial for the bird's seed dispersal distance and hence its potential as a long-distance disperser (Lenz et al., 2011). Moreover, the responses of birds to these factors can vary between seasons because of cyclical differences in the territoriality, food habits, migration stages, and species compositions of birds (Naoe et al., 2011; Vergara and Marquet, 2007). Because large numbers of birds depend on fleshy fruit resources to a lesser extent in the breeding season than in the non-breeding season in temperate regions (Carnicer et al., 2009; Yoshikawa and Osada, 2015), the relative importance of candidate factors is expected to change between seasons, although this seasonal aspect has been overlooked in most studies.

In this 3-year study, we investigated the relative importance of local factors, including both stand structural attributes and fruit availability, and landscape-level factors for the richness and abundance of fruit-eating birds in broad-leaved forest patches scattered within a coniferous plantation in central Japan. Large areas of natural or secondary broad-leaved forest in Japan were converted to coniferous plantations in response to a surge in timber demand after the Second World War. As of 2012, coniferous plantations occupied approximately 60% of the forest area of the country (Forestry Agency, Ministry of Agriculture, Forestry and Fishery, Japan; http://www.rinya.maff.go.jp/j/keikaku/genkyou/h24/1.html), causing fragmentation of natural broad-leaved forests and biodiversity loss in mountainous areas (Nagaike and Kamitani, 1999). We explored the relative importance of these factors in the breeding (spring–summer) and non-breeding (autumn–winter) seasons and also separately for three bird size classes. In this work, we addressed the following questions: (1) How are the distribution and abundance of birds defined by local factors, namely stand structural attributes and fruit availability, and by landscape-level factors? (2) Does the relative importance of these factors vary between the breeding and non-breeding seasons and among bird size classes? For question (1), we predicted that during the breeding season, when birds exhibit territorial behavior and have low dependence on fruits, landscape variables and stand attributes would be relatively more important for bird richness/abundance than fruit availability, whereas fruit availability would be more important during the non-breeding season. For question (2), we expected that the abundance of larger birds would be more sensitive to landscape variables due to their requirement of a larger home range.

2. Materials and methods

2.1. Study site

This study was conducted in selected areas in the cities of Kitaibaraki and Takahagi, Ibaraki Prefecture, central Japan (36°45′ N, 140°39′ E; Fig. 1). The study area is a mountainous region with an elevation range of 330–840 m, mean annual temperature of 13.0 °C, with monthly means ranging from a minimum of 3.6 °C in January to a maximum of 23.5 °C in August, and mean annual precipitation of approximately 1450 mm at the Kitaibaraki Meteorological Station (Japan Meteorological Agency, 2015). Data from 2012 reveal that about 60% of the entire forest area of the prefecture is occupied by coniferous plantation (Forestry Agency, Ministry of Agriculture, Forestry and Fisheries, Japan; http://www.rinya.maff.go.jp/j/keikaku/genkyou/h24/1.html). The coniferous plantations of the region are mainly composed of *Cryptomeria japonica* and *Chamaecyparis obtusa*, the most common native plantation species in central Japan. Thus, patches of various sizes of broad-leaved forest, ranging from <0.01 ha to >500 ha, are scattered among the coniferous plantations in the area (Fig. 1). The main components of the remnant broad-leaved forests are the acorn-bearing *Quercus serrata*, nut-bearing *Castanea crenata*, the tree *Carpinus laxiflora* (wind-dispersed seeds), and the fleshy-fruited tree *Prunus verecunda* (Yamaura et al., 2009).

We established 14 study sites within broad-leaved forest patches over an area of approximately 15 km × 10 km (Fig. 1), taking care to include wide range of landscape features. Ten sites were set up in 2011 and another four sites were added in 2012. For each site, we fixed a common center for plots to monitor the bird assemblages, forest stand structures, and availability of fleshy fruit resources. This center was selected so that the plots represent surrounding (within-patch) forest conditions. The center was also used as a base for quantifying landscape structures around the site.