

Relationship between the Abundance of Native Honey Bee Species (*Apis cerana*) and Distance to Natural Forests in Hyuganatsu (*Citrus tamurana*) Orchards in Aya Town, Japan

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Abstract: This study aimed to examine the relationship between the ecosystem services of pollination offered by native honey bees (*Apis cerana*) and the distance to natural forests (as an indicator of landscape structure) in hyuganatsu (*Citrus tamurana*) orchards in Aya Town, Miyazaki Prefecture, Japan. Two statistical models were developed to predict the number of visits of native honey bees to hyuganatsu tree. The area-distance model (AD-model) considered the area of natural forests and distance from natural forests and the area model (A-model) considered the total area of the surrounding natural forests, and the results of the two models were compared. The estimated parameters of both models suggested a positive effect of natural forests on pollination services. Further, the estimated effect of the landscape structure of the AD-model was greater than that of the A-model. These results suggested that the distance to natural forests is an important landscape factor for evaluating pollination services by native honey bees.

Keywords: Bayesian calibration, distance dependent model, landscape structure, native honey bee, pollination service

1. Introduction

Ecosystem services are essential to harmonize the conservation of natural ecosystems and the development of local communities and economy. Pollination services provided by insects and other animals have significant positive effects on food production. For instance, approximately 75% of the leading global crops are dependent on these pollination services (Klein et al. 2007), and the total economic value of such pollination services worldwide is estimated as 153 billion Euro (Gallai et al. 2009). The quality and amount of pollination services are affected by local landscape structure (Ricketts 2004; Taki et al. 2010). Restoring damaged natural ecosystems would contribute to the improvement of pollination services (Dixon 2009; Lamb 2018). Thus, pollination services are fundamental ecosystem services for achieving a sustainable society, economy, and biosphere in the future.

Previous studies have assessed the relationships between pollination services and landscape structures (e.g., Cane 2005; Bosch et al. 2006; Isaacs and Kirk 2010). Areas of each land use type have been used as indicators of landscape structure and have been related to the abundance of pollinators, which are regarded as indicators of pollination services. For example, pollinators were more abundant in the agricultural fields of water melon (Kremen et al. 2002), buckwheat (Taki et al. 2010), and sweet cherry (Holzschuh et al. 2012) that were surrounded by extensive natural forests. Another major indicator of landscape structure is the distance from the natural forest. Carvalho et al. (2010) determined important relationships between mango production and the distance from natural forests.

In previous studies, surrounding natural forests have shown a positive effect on the abundance of native honey bees (*Apis cerana*) in hyuganatsu (*Citrus tamurana*) orchards in Aya Town, Miyazaki Prefecture, Japan (Yumura et al. 2016; Mitsuda et al. 2019), and the developed statistical model estimated that large areas of natural forests surrounding a hyuganatsu tree promoted an increased number of native honey bee visits, thus, suggesting that natural forests are good nesting habitats for native honey bees that provide pollination services to hyuganatsu trees. To further confirm this assumption, the present study aimed to examine the relationship between the abundance of native honey bees (as an indicator of pollination service) and distance from natural forests (as an indicator of landscape structure) in hyuganatsu orchards in Japan. A statistical model was developed to predict the abundance of native honey bee in the areas surrounding natural forests and the distance from natural forests, and the results were compared with those of the previous model.

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2. Materials and Methods

The study was conducted in Aya Town, Miyazaki Prefecture, Japan. The Aya Town government began promoting agricultural development, which was in harmony with ecosystem conservation in 1973, with approximately 90% of agricultural fields following organic farming or conventional farming with reduced proportion of chemicals. The town was designated as a United Nations Educational, Scientific and Cultural Organization biosphere reserve in 2012 because of extensive areas of lucidophyllous forests and an ancient tradition of organic agriculture. The target crop in the present study was hyuganatsu, an important agricultural product in Aya Town. Hyuganatsu is a citrus fruit with strong self-incompatibility; therefore, it requires pollinators for fruiting.

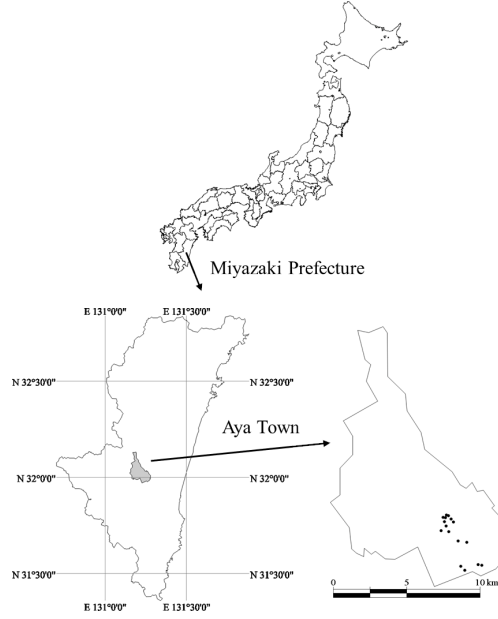


Figure 1. Location of the sample sites.

In the study area, 16 sampling sites were selected, and 1–4 trees were selected for further study from each site (Figure 1). The number of visits of native honey bees, an indicator of pollination service, was measured by field surveys wherein 2–3 observers walked around each sample tree for 3 min and counted the number of honey bee visits. Moreover, the sample trees were photographed to determine their flowering level (1 to 5) and to measure their crown areas. Field surveys were conducted for 5 days from April 29 to May 12, 2016 (flowering season of hyuganatsu) either once or twice during 10:00–12:00, 12:00–15:00, or 15:00–17:00. Total number of observers was 7 persons. In total, 397 observations distinguished by the sample tree, day, observation time, and observer were recorded. The land use map of Aya Town was manually developed by visual interruption from ortho photos of Miyazaki Prefecture captured in 2013 and 2016. Natural forest patches were extracted from this land use map for further analysis (Figure 2). To consider the area and distance from the natural forest, a 500-m resolution grid was established on the natural forest distribution map (Figure 2). The areas of natural forests and the distance between each sample tree from the center point of the grid were calculated. Further, the area of the surrounding natural forest within a 2000-m radius was also calculated for each sample tree.

The statistical model developed in this study to predict the abundance of native honey bees in the areas surrounding natural forests and the distance from natural forests comprised two parts: 1) an ecology model representing the effects of ecological factors on the abundance of pollinators using a generalized linear mixed-effect model (Eq.[1] and [2]) an observation model representing the differences in the ability to search native honey bees (Eq.[2]).

$$[1] \quad \log(N_t) = LE + \beta_{0,FL} + \log(TS) + r,$$

$$[2] \quad N_{obs} = N_t \times P,$$

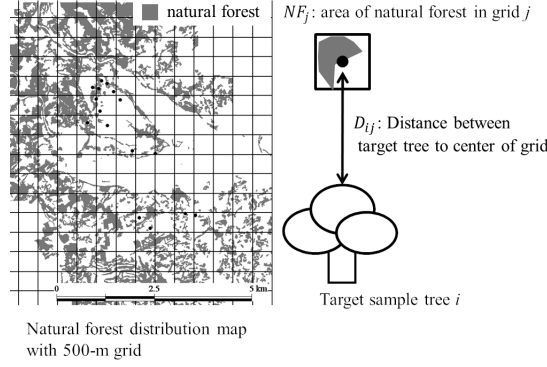


Figure 2. Natural forest distribution map and the 500-m grid for calculating the distance from natural forests to sample trees.

where N_t is the true number of honey bee visits, LE is the effect of landscape structure, FL is the flowering level, $\beta_{0,FL}$ is the coefficient vector for each of the five flowering levels, TS is the tree crown area regarded as an offset term, and r is the random effect of the combination of trees, days, and observation periods. Further, in Eq.[2], N_{obs} is the observed number of honeybee visits, and P is the probability of searching bees.

The effect of landscape structure (LE) on the abundance of honey bee visits in the ecological model can be expressed in two methods by considering both the effects of area and distance. The effect of landscape structure for sample tree i (LE_i) is expressed as follows:

$$[3] \quad LE_i = \sum_j \beta_{11} NF_j \frac{1}{1 + \exp(\beta_{12}(D_{ij} - \beta_{13}))},$$

where NF_j is the area of the natural forest in grid j , D_{ij} is the distance from grid j to sample tree i , and β_{11} , β_{12} , and β_{13} are coefficients of regression. In this function, a flexible sigmoid shape function was adopted to represent the gradually decreasing effect of natural forest with distance.

A previous study used the total area of the surrounding natural forest within a 2000-m radius as an explanatory variable, which showed a positive effect on the abundance of honey bee visits (Mitsuda et al. 2019). To discuss the effects of landscape structure on pollination services, LE was also expressed as a function of the total area of the surrounding natural forest as follows:

$$[4] \quad LE_i = \beta_2 \times NF2000_i,$$

where $NF2000_i$ is the standardized total surrounding area of natural forests within a 2000-m radius of sample tree i , and β_2 is a coefficient of regression.

Thus, the following two statistical models were developed to predict native honey bee visits to the hyuganatsu tree: 1) a model considering the area of natural forests and distance from natural forests (area-distance model, AD-model) and 2) a model considering the total area of surrounding natural forests (area model, A-model), and the results of both models were compared.

The coefficients of regression (β s), standard deviation of random effect (σ), and varying probabilities of searching bees among the seven observers were estimated for both models. A Poisson distribution was assumed for the objective variable (native honey bee visit, N_{obs}). Further, the Hamiltonian Monte Carlo method was applied for parameterization using R (R Core Team 2019) and Stan (Stan Development Team 2014). Three parallel chains were run for 100,000 iterations with thinning at 50 intervals, and the first 80,000 iterations were dropped as the warm-up period.

3. Results

The median and the 25th and 75th percentiles of the posterior distributions of parameters for both models are shown in Table 1. The converged diagnostics ($\hat{R}$) were below 1.1 for all parameters, indicating that all parameters converged well (Gelman et al. 2003). The medians of each posterior distribution of the parameters were used as estimates of each parameter for further analyses. The

estimated parameter value of β_{11} (0.005) of the AD-model was positive, suggesting a positive effect of natural forest on the abundance of native honey bee visits. Additionally, the estimated parameter values of β_{12} (0.010) and β_{13} (469 m) of the AD-model suggested that the positive effect of natural forests decreased with distance.

Figure 3 shows that the relative effect decreased with the distance from the natural forests, as calculated by Eq.[5].

$$[5] \quad RED = \frac{1}{1 + \exp(\beta_{12}(Dist - \beta_{13}))},$$

where RED is relative effect of distance and $Dist$ is distance. The estimated parameter value of β_2 (0.201) of the A-model was positive, suggesting a positive effect of the total area of surrounding natural forests within a 2000-m radius on the abundance of native honey bee visits, which was similar to a previous study (Mitsuda et al. 2019).

Table 1. Estimated parameter values of both AD-model and A-model.

	AD-model				A-model		
	25%	median	75%		25%	median	75%
β_{11}	0.003	0.005	0.009	β_2	0.159	0.201	0.244
β_{12}	0.005	0.010	0.028				
β_{13}	319	469	657				
β_0 - FL1	-3.426	-3.153	-2.902	β_0 - FL1	-3.049	-2.780	-2.541
β_0 - FL2	-1.066	-0.867	-0.671	β_0 - FL2	-0.628	-0.456	-0.300
β_0 - FL3	-0.203	-0.060	0.081	β_0 - FL3	0.200	0.297	0.394
β_0 - FL4	0.339	0.431	0.540	β_0 - FL4	0.777	0.841	0.893
β_0 - FL5	0.555	0.653	0.747	β_0 - FL5	0.979	1.036	1.096
P_1	0.851	0.885	0.926	P_1	0.853	0.887	0.925
P_2	0.826	0.852	0.891	P_2	0.831	0.865	0.906
P_3	0.837	0.875	0.924	P_3	0.837	0.880	0.925
P_4	0.818	0.841	0.876	P_4	0.817	0.841	0.879
P_5	0.941	0.967	0.985	P_5	0.942	0.973	0.987
P_6	0.945	0.970	0.986	P_6	0.941	0.967	0.986
P_7	0.820	0.846	0.884	P_7	0.820	0.848	0.888
σ	0.581	0.610	0.647	σ	0.588	0.622	0.653

FL: Flowering level

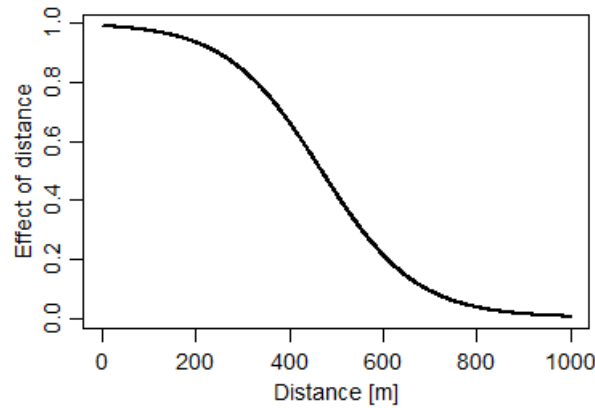


Figure 3. Relative effect of natural forest decreasing with the distance from natural forests.

The effects of the landscape structure for each sample tree were calculated using Eqs.[3] and [4] for the AD- and A-models, respectively, and the relationships between the calculated effects of landscape structure (exponential transformation) and the mean of observed honey bee visits for each sample tree are shown in Figure 4. The LE exponential values ranged from 1.0 to 2.0 for the

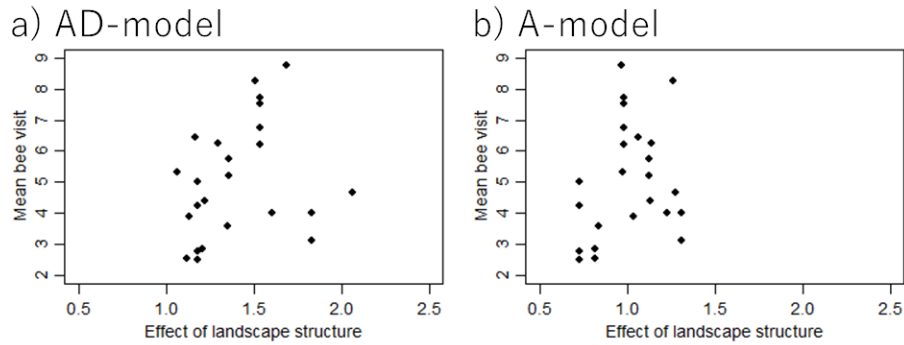


Figure 4. Relationships between the calculated effects of landscape structure and the average number of observed honey bee visits.

AD-model and greater than that of the A-model ranging from 0.7 to 1.3. The estimated standard deviations of random effect of the AD-model and A-model were 0.610 and 0.622, respectively.

4. Discussion

Two statistical models (AD-model and A-model) were developed to predict the number of native honey bee visits to the hyuganatsu tree using landscape structure as an explanatory variable. The estimated parameters suggested a positive effect of natural forests on pollination service in both models. These results were similar to those observed in previous studies conducted on hyuganatsu in Aya Town (Yumura et al. 2016; Mitsuda et al. 2019) and for other agricultural crops in other regions (Kremen et al. 2002; Carvalheiro et al. 2010; Holzschuh et al. 2012). The main nesting habitats of native honey bees are natural forests (Taki et al. 2010; 2011); therefore, restoration of degraded natural forests can assist in improving pollination services and contribute to increased agricultural production.

The estimated effects of the landscape structure of the AD-model were higher than those of the A-model, suggesting that the distance from natural forests to a target hyuganatsu tree is an important factor for understanding the effects of landscape structure on pollination services. This result also reinforced the assumption of this study that natural forests provide good nesting habitats for native honey bees and that these bees visit hyuganatsu trees from adjacent natural forests. The parameter β_{13} (with an estimated value of 469 m), of the AD-model was designed to represent the distance at which the positive effect of natural forest decreased to 50%. The estimated relative effect at a distance of 1000 m from the target hyuganatsu tree was lower than 1% (Figure 3). A previous study reported that the home range of native honey bees is approximately 2 km (Fujiwara and Washitani 2017). The results of this study, however, showed that the effective distance from the natural forest was comparatively shorter probably because during the flowering season of hyuganatsu, other food sources for native honey bees are available.

In a previous study, the areas surrounding agricultural fields and grasslands showed positive effects in predicting the abundance of native honey bee visits (Yumura et al. 2016; Mitsuda et al. 2019). The standard deviations of the random effect for both AD-model and A-model in this study were relatively higher, implying that the random effect in both statistical models explained a major part of the variations in the observed number of honey bee visits. Thus, explaining the abundance of honey bee visits using variables that described the landscape structure of natural forests was difficult. The statistical model developed in this study should be modified by adding landscape variables of other land use types (e.g. agricultural field, grass land, and residential area).

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