Kim et al. Journal of Ecology and Environment (2018) 42:24
https://doi.org/10.1186/s41610-018-0088-x

Journal of Ecology
and Environment

RESEARCH

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Comparisons of microhabitat use of Schlegel's Japanese gecko (*Gekko japonicus*) among three populations and four land cover types

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Abstract

Background: The effective use of habitats is essential for the successful adaptation of a species to the local environment. Although habitats exhibit a hierarchical structure, including macro-, meso-, and microhabitats, the relationships among habitats of differing hierarchy have not been well studied. In this study, we studied the quantitative measures of microhabitat use of *Gekko japonicus* from three field populations in Japan: one at Tsushima Island, one at Nishi Park, Fukuoka, and one at Ohori Park, Fukuoka. We investigated whether land cover type, a higher hierarchical habitat component, was associated with quantitative microhabitat use, a lower hierarchical component, in these populations.

Results: The substrate temperature where we located geckos (SubT) and the distance from the ground to the gecko (Height) were significantly different among the three populations. In particular, SubT on Tsushima Island was lower than it was in the other two populations. Irradiance at gecko location and Height were significantly different among the land cover types. In particular, Height in evergreen needleleaf forest was significantly lower than that in deciduous broadleaf forest. Furthermore, significant interactions between population and land cover type were observed for the SubT and Height variables.

Conclusions: The quantitative measures of microhabitat use of *G. japonicus* varied with population and land cover type, which exhibited significant interaction effects on microhabitat use variables. These results suggest that higher hierarchical habitat components can affect the quantitative measures of lower hierarchical microhabitat use in nocturnal geckos.

Keywords: Nocturnal gecko, Habitat, Hierarchy, Interaction

Background

Habitat is defined as an area that compromises biotic and abiotic factors that are critical for the survival of a species in the area (Hall et al. 1997; Morris 2003). Habitats are hierarchically organized from higher to lower as follows: macrohabitats, mesohabitats, and microhabitats. For example, vegetation structures are mesohabitat components, whereas various objects and structures such as bushes and logs are microhabitat components (Anderson 2007). Studies on habitat characteristics have been conducted in various vertebrates, including reptiles (Morrison et al. 1992; Ackley et al. 2015). Nevertheless, relationships among different hierarchical habitat components have not been well studied. For example, land cover type is well known to predict the distribution patterns of species in reptiles (Ballesteros-Barrera et al. 2007; Stabler et al. 2012). However, whether land cover type, a higher hierarchical habitat component, is related to microhabitat use, a lower hierarchical component, has rarely been explored. Considering the rapid changes in land cover types due to human activities (Ballesteros-Barrera et al. 2007), studies are needed to better understand how land cover

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changes affect the use of lower hierarchical habitat components. *Gekko japonicus* is an appropriate species to perform such a study because this lizard is easily detectible near light sources at night and its habitats are often within small sections of urban or suburban areas (Werner et al. 1997).

Schlegel's Japanese gecko (*Gekko japonicus*) is a small nocturnal gecko found throughout inland and central-eastern regions of China, Japan (excluding Okinawa), and southern regions of the Korean peninsula (Zhao and Adler 1993; Wada 2003; Lee et al. 2004; Kim et al. 2017). In China, this species is found near mountain areas and suburban areas, whereas in Japan and Korea, it is mostly found in residential areas and city parks and near suburban forests. In Korea, the species was first reported in 1907, potentially introduced from China (Stejneger 1907). *Gekko japonicus* is commonly active from late April to late October and starts its daily activity soon after sunset, with peak activity for 2–3 h after sunset (Ji et al. 1991; Tawa et al. 2014). In addition to hunting its main prey items, i.e., insects, at light sources, *G. japonicus* forages for various arthropods in the dark (Saenz 1996; Lee et al. 2004). Studies on a variety of topics, such as population distribution, morphological characteristics, daily activity pattern, selection of oviposition site, and mitochondrial genome, have been performed on this species (Ji et al. 1991; Ota and Tanaka 1996; Toda et al. 2003; Zhang et al. 2009; Caldwell et al. 2014; Kim et al. 2016; Park et al. 2018), but the microhabitat use of *G. japonicus* in field populations is not well known.

In this study, we studied the quantitative measures of microhabitat use of *G. japonicus* in three field populations in Japan: one at Tsushima Island, one at Nishi Park, Fukuoka, and one at Ohori Park, Fukuoka. We explored whether land cover type, a higher hierarchical habitat component, was associated with the quantitative microhabitat use, a lower hierarchical component, in these populations.

Materials and methods

Study site and field investigation

The quantitative measures of microhabitat use of *G. japonicus* were investigated at Nishi Park (33.599283° N, 130.375279° E) and Ohori Park (33.588363° N, 130.379618° E) in Fukuoka on July 10, 2017, and at Tsushima Island (34.657339° N, 129.472603° E) on July 12, 2017 (Fig. 1). To exclude seasonal effects on quantitative microhabitat use (Christian et al. 1983; Martín and López 1998), we completed the field investigations within 3 days. In the investigations, three persons slowly

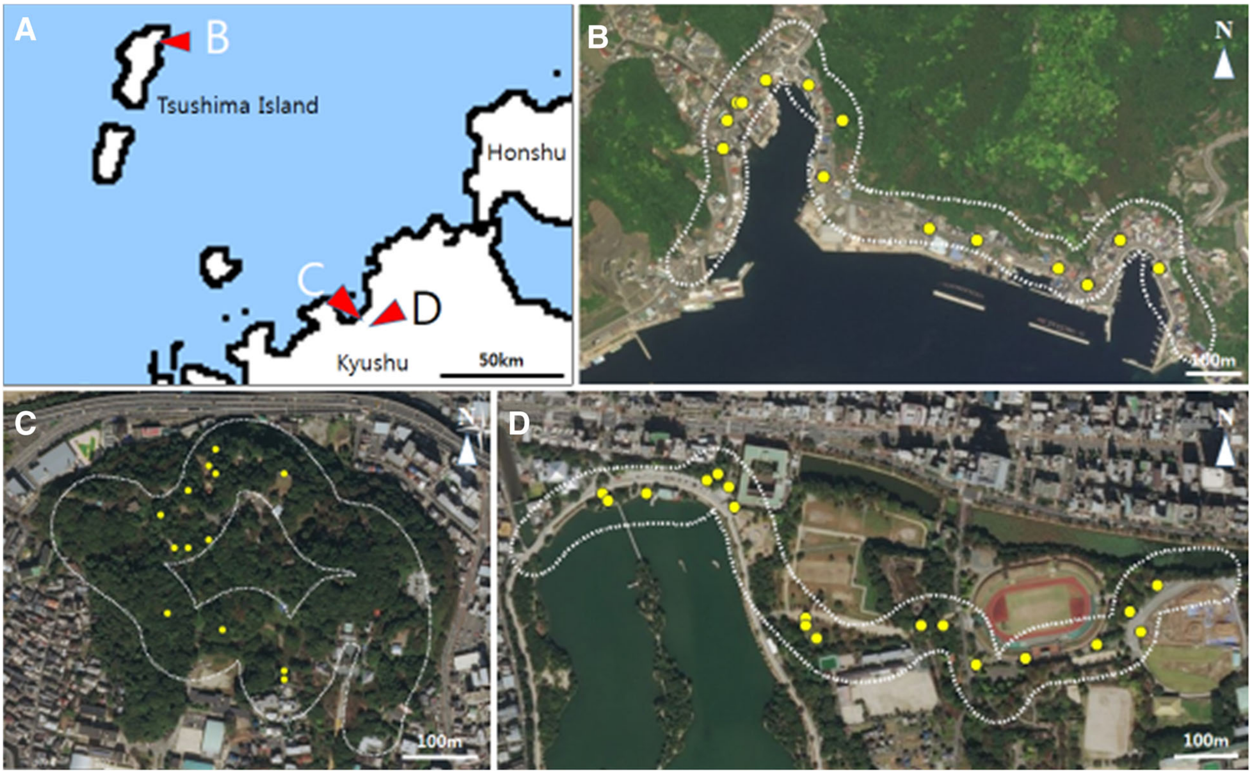

Fig. 1 Study site photographs of three *Gekko japonicus* field populations (**a**) at Tsushima Island (Tsush, **b**) and at Nishi (FukuP, **c**) and Ohori (FukuR, **d**) parks in Fukuoka, Japan. The survey line transects (not shown) spanned the areas within the dotted lines, and the yellow dots indicate the locations where geckos were found

walked across a 1.5-km line transect from 40 to 123 min after sunset in Nishi Park, a 1.5-km line transect from 151 to 268 min after sunset in Ohori Park, and a 1.3-km line transect from 51 to 173 min after sunset on Tsushima Island. While walking along the line transects, we mainly searched for geckos on the walls of fences and buildings and on the planes of other structures, such as street-light poles, exhibition boards, and embankments, using head lanterns and flashlights.

The investigation site at Tsushima Island (hereafter, Tsush) extended between the Hitakatsu International Port and Hotel Kamiso, and we searched the walls and crevices of private houses, stores, official buildings, and street-light poles along the edges of streets (Fig. 1b). Most geckos were found on the walls of buildings and street lights. Nishi Park (approximately 300 × 500 m, hereafter FukuP) is a typical city park located approximately 150 m from the sea and has an altitude range of 10–28 m (Fig. 1c). In the park, there are four pavilions (approximately 3 m diameter), two toilets, one Japanese shrine, and one store and teahouse located along the park roads. Additionally, there are street lights every 50 m. Geckos were mainly found on the roofs of pavilions, on the walls of toilets, and on street lights. Ohori Park (hereafter FukuR) is approximately 1 km from Nishi Park and is closer to the city center (Fig. 1a, d). Between the two parks, there are city barriers of buildings and stores. The investigation areas comprised parts of Maizuru Park, Ohori Park, Heiwadai Stadium, and the Korokan Historical Museum. The altitudes of these areas are below 10 m. Geckos were mainly found on the walls of two stores, at three toilets, and on the walls of the stadium and museum. Although there were street-light poles every 50 m, few geckos were found on the poles.

Because there were few juveniles present, we focused on adult *G. japonicus* (approximately > 50 mm snout-vent length, SVL). When a gecko was found, we recorded the GPS location (Oregon 550, Garmin Ltd., USA) and sampling time (later transformed into time after local sunset via www.timeanddate.com). When we found multiple geckos at a site, we recorded the GPS location once. We also determined gecko sex based on the relative size of the cloacal spurs (Tokunaga 1984). We measured four quantitative measure variables of microhabitat use based on previous studies (Gomez-Zlatar et al. 2006; Williams and McBrayer 2007). The four variables included the substrate temperature where the gecko was found (hereafter, SubT), the irradiance at the location (Irradiance), the shortest distance to the nearest potential refuge (DisR), and the shortest height from the ground to the gecko location (Height). SubT was measured to the nearest 0.1 °C using an infrared thermometer (AR-320, Smart Sensor Inc., Hong Kong). We measured temperature within 1 m of the gecko's location as possible as. The skin temperature of *G. japonicus* has been reported to be very similar to the temperature of its substrate (Hu and Du 2007). To record the irradiance at the observation location, we placed a digital illuminometer (TES-1337, TES, China) along the body axis of the gecko from the head to the tail on the same plane and measured the irradiance intensity in units of 0.01 lx. Additionally, DisR and Height were measured to the nearest millimeter using a laser distance meter (Fluke 414D, Fluke Korea, South Korea). In July, *G. japonicus* might differentially use microhabitats for foraging or predation avoidance (Ji et al. 1991; Gomez-Zlatar et al. 2006). However, categorizing microhabitats by function would have been a difficult and time-consuming task. Therefore, we did not consider the functions of the microhabitats.

To investigate whether higher hierarchical habitat variables affect the quantitative measures of microhabitat use, a lower hierarchical habitat component, in *G. japonicus*, we selected land cover type as a higher hierarchical habitat variable based on previous studies (Ballesteros-Barrera et al. 2007; Ackley et al. 2015). We extracted the land cover type data for each sampling location where we found geckos from the Japan Aerospace Exploration Agency (JAXA; http://global.jaxa.jp/), which have 10 m resolution (2006–2012, v16.09). The ten land cover types comprised water, urban, rice paddy, crop, grassland, deciduous broadleaf (hereafter, DBF) and needleleaf forest (DNF), evergreen broadleaf (EBF) and needleleaf (ENF) forest, and bare land. For this analysis, we used QGIS (ver. 3.0, http://dowload.qgis.org/).

Data analysis

Before the statistical analyses, we identified outliers in the field data using SPSS-PC and excluded them from subsequent analysis. In addition, we converted the categorical variable of land cover type to an indicator variable using the data-transformation option given in SPSS-PC. Out of the ten possible land cover types, six were detected in the study areas. Because there was only one case of rice paddy and three cases of EBF, we treated these types as crop and ENF, respectively, resulting in a total of four land cover types: urban, crop, DBF, and ENF. To increase the central tendency of the data, we log-transformed ($\log_{10}$) the microhabitat variables, including the time after sunset when geckos were found (hereafter, TimeAS). However, after transformation, none of the microhabitat variables passed the normality test (Kolmogorov-Smirnov, $P < 0.05$).

We applied the chi-square test to test whether the composition of land cover types differed among the three populations (Preacher 2001). Where the result was significant, the chi-square test was used again for post hoc tests. Then, to determine the relationships among the studied quantitative microhabitat variables, we executed the Spearman correlation test. Furthermore, to evaluate whether the microhabitat variables differed among the populations and land cover types and between the sexes, we executed a multivariate general linear model (MGLM) analysis. In the analysis, population (Tsushima Island, Nishi Park, and Ohori Park), sex (female and male), and land cover type (urban, crop, DBF, and EBF) were included as independent variables, and the four microhabitat variables (SubT, DisR, Irradiance, and Height) were the dependent variables. Where significant results were obtained, conservative Bonferroni pairwise tests were conducted as post hoc tests in the MGLM. All analyses were performed using SPSS-PC (ver. 18.0), and numerical data are presented as the mean ± SE.

Results

We obtained quantitative microhabitat data from 75 geckos: 27 at Tsush (female 9, male 18), 19 at FukuP (F 14, M 5), and 29 at FukuR (F 16, M 13). Seventeen out of 300 microhabitat data were identified as outliers (5.7%) and removed, of which six were from Tsush, five were from FukuP, and six were from FukuR. Regarding the relationships between microhabitat variables, SubT showed a significant negative correlation with Height ($r = -0.262$, $P = 0.025$, $n = 73$). TimeAS was not correlated with any microhabitat variable ($P > 0.267$). The remaining relationships were not significant ($P > 0.220$).

The composition of land cover types was significantly different among the three populations ($\chi^2 = 66.021$, df = 6, $P < 0.001$, Fig. 2), and all pairwise post hoc tests between any two populations also revealed significant differences ($P < 0.05$). Tsush had the greatest percentage of the urban land cover type among the populations, whereas FukuP mainly exhibited ENF. In FukuR, the urban and crop types occupied 55.2% and 31.0%, respectively, of the total land cover (Fig. 2). Because actual crop fields are not present in FukuR, the crop area might correspond to garden areas (see Fig. 1).

None of the microhabitat variables differed between the sexes ($P > 0.314$), and sex did not interact with either population or land cover type in affecting any microhabitat variable ($P > 0.165$). SubT ($F_{2,59} = 3.182$, df = 2, $P = 0.051$) and Height ($F_{2,59} = 5.344$, df = 2, $P = 0.008$) were significantly different among the populations (Fig. 3a). Furthermore, Irradiance ($F_{3,59} = 3.135$, df = 3, $P = 0.035$) and Height ($F_{3,59} = 6.774$, df = 3, $P = 0.001$) were significantly different among the land cover types (Table 1, Fig. 3b). The remaining microhabitat variables did not differ among the populations or land cover types ($P > 0.05$). Bonferroni post hoc tests revealed that SubT was significantly lower in Tsush than in FukuP ($P < 0.05$) and that Height was significantly lower in ENF than in DBF ($P < 0.05$, Fig. 3a, b). The remaining comparisons revealed no significant differences ($P > 0.05$). Population and land cover type showed significant interaction effects on the microhabitat variables SubT ($F_{2,59} = 3.669$, df = 2, $P = 0.033$) and Height ($F_{2,59} = 3.496$, df = 2, $P = 0.039$) (Table 1).

Discussion

Some of the quantitative microhabitat variables of *G. japonicus* varied among the three populations and four

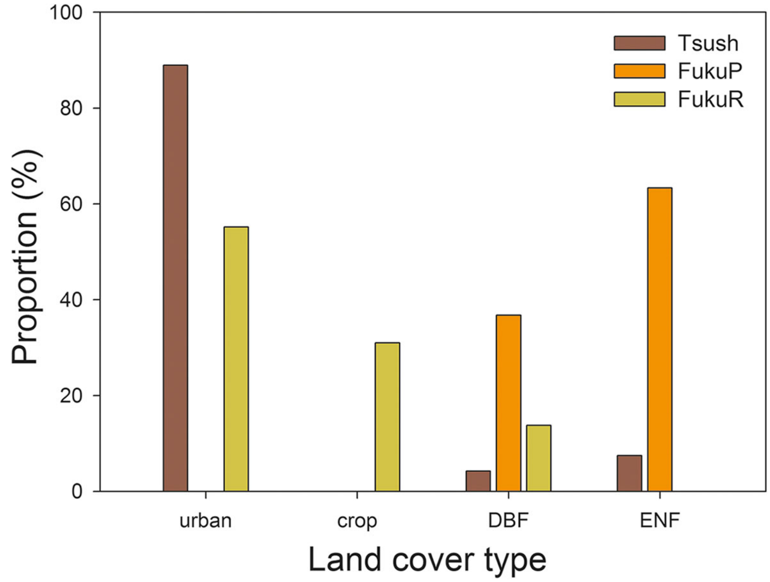

Fig. 2 The compositions of land cover types (urban, crop, deciduous broadleaf forest: DBF, and evergreen needleleaf forest: ENF), analyzed at 10 m resolution, in the three *Gekko japonicus* field populations at Tsushima Island (Tsush, $n = 27$) and at Nishi (FukuP, $n = 19$) and Ohori (FukuR, $n = 29$) parks in Fukuoka

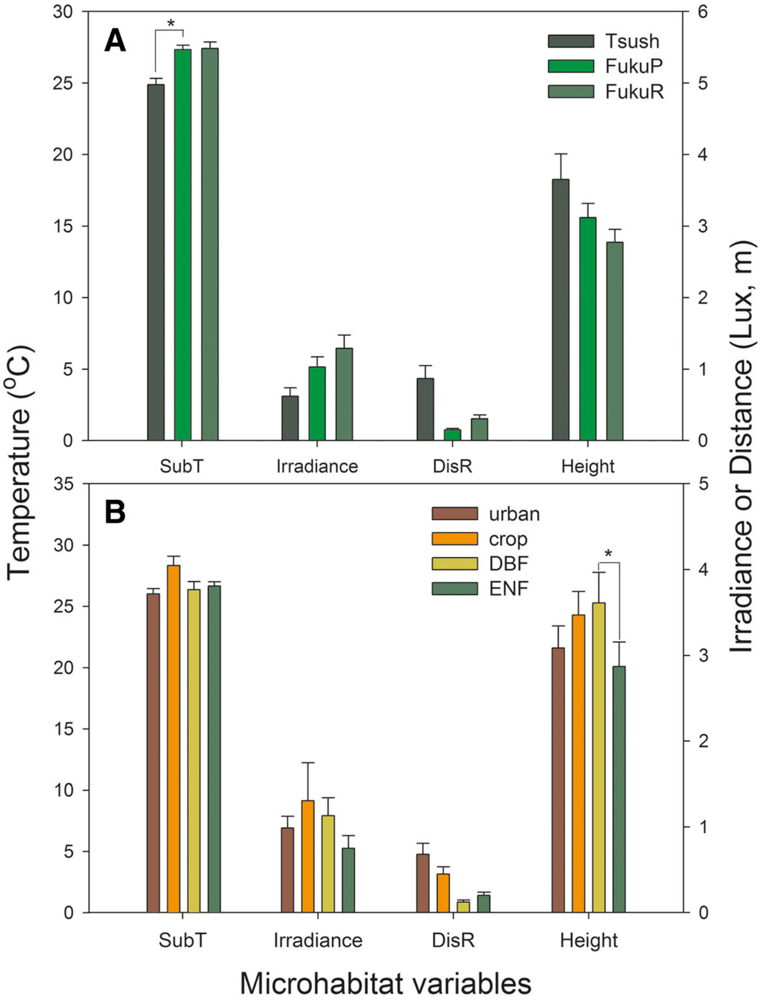

Fig. 3 The quantitative measures of microhabitat use of *Gekko japonicus* in the three field populations at Tsushima Island (Tsush) and at Nishi (FukuP) and Ohori (FukuR) parks in Fukuoka (**a**) and in different land cover types: urban, crop, deciduous broadleaf forest (DBF), and evergreen needleleaf forest (ENF, **b**). SubT, substrate temperature; DisR, shortest distance to potential refuge; Height, height above ground. The left-hand *Y*-axis title denotes SubT, and the right-hand *Y*-axis titles denote the remaining variables. *$P < 0.05$ in the post hoc test

Table 1 Results of a multivariate general linear model of quantitative microhabitat use variables as functions of population, sex, and land cover type

Dependent variable				
Independent variable	Quantitative microhabitat use variable			
	SubT	Irradiance	DisR	Height
Population	$F = 3.182$ $P = 0.051$	$F = 2.344$ $P = 0.108$	$F = 1.088$ $P = 0.345$	$F = 5.344$ $P = 0.008$
Land cover type	$F = 2.113$ $P = 0.111$	$F = 3.135$ $P = 0.035$	$F = 0.587$ $P = 0.627$	$F = 6.774$ $P = 0.001$
Sex	$F = 0.404$ $P = 0.528$	$F = 1.036$ $P = 0.314$	$F = 0.212$ $P = 0.647$	$F = 0.315$ $P = 0.577$
Population × land cover type	$F = 3.669$ $P = 0.033$	$F = 0.105$ $P = 0.901$	$F = 0.124$ $P = 0.884$	$F = 3.496$ $P = 0.039$

land cover types. Furthermore, a significant interaction effect of land cover type and population was observed for each of the SubT and Height variables. These results suggest that differences in land cover type among populations can partially explain population differences in the quantitative measures of microhabitat use of *G. japonicus*.

Differences in land cover types among the populations affected the quantitative measures of microhabitat use in *G. japonicus* in these populations. In this study, the irradiance and height at the sites where geckos were found were significantly different among the different land cover types. In particular, Height was significantly lower in ENF than in DBF. The characteristics of ENF trees, such as pines, which provide dense habitat conditions and various invertebrate food sources, might be responsible for this result (Johnston 2000). On such trees, geckos might select their microhabitats at various heights above the ground. Previous studies in various lizards revealed that land cover type affected the selection of microhabitat type (Germaine and Wakeling 2001; Gomez-Zlatar et al. 2006; Williams and McBrayer 2007). Furthermore, our results suggest that land cover type affects the quantitative measure aspects of microhabitat use in nocturnal geckos. Regardless of population, *G. japonicus* was found at lower heights in ENF than in other land cover types, indicating that the ENF type allows the lizards to meet their summer habitat requirements for feeding and mating at lower heights than is possible in other areas. Along with Height, Irradiance was related to land cover type. For *G. japonicus*, appropriate irradiance in the summer is important for efficient foraging (Saenz 1996). The levels of irradiance at which geckos can obtain prey might vary with land cover type. Land cover type and population showed significant interaction effects on the variables SubT and Height, suggesting that population differences in land cover types can affect the quantitative measures of microhabitat use in *G. japonicus* populations.

In Tsush, geckos were found at lower SubT but at greater Height than in the other two populations. The quantitative measures of microhabitat use of *G. japonicus* in Tsush might have two explanations. First, the distance between the survey sites and the sea in Tsush was within 50 m, with the sea probably having large effects. At night, the sea breeze might produce a temperature decrease that exceeds that in the other two populations (Shitara 1955). Such sea-related factors might be responsible for the low SubT in Tsush. Second, in Tsush, very few survey sites were covered by vegetation. Geckos were found mainly in the outer walls of buildings, on electric poles, and on street lamps, where vegetation, particularly trees, was not present. Such locations are exposed, have low temperatures, and are high above the ground. These habitat characteristics in Tsush are well matched to the features of the urban land cover type (Germaine and Wakeling 2001). In our comparisons of land cover types, we found that Tsush had a greater proportion of the urban land cover type than did the other two populations. In contrast to geckos in Tsush, geckos in FukuP and FukuP were found at higher SubT but at lower Height. This result can be largely explained by the characteristics of the land cover types in FukuP and FukuR. The widely distributed vegetation, including various types of trees, throughout the survey areas in FukuP and FukuR might prevent large temperature drops at night while providing appropriate habitats for effective foraging at preferred heights above the ground.

Conclusions

The quantitative measures of microhabitat use of *G. japonicus* varied among the populations and the different land cover types. The significant interaction of land cover type and population in affecting the quantitative microhabitat use of *G. japonicus* suggests that higher hierarchical habitat components affect the use of lower hierarchical microhabitat components in nocturnal geckos. In future studies, this relationship should be explored further by addressing additional hierarchical habitat components.

Abbreviations

DBF: Deciduous broadleaf forest; DisR: Distance from the location where a gecko was found to the nearest potential refuge; ENF: Evergreen needleleaf forest; FukuP: Nishi Park at Fukuoka; FukuR: Ohori Park and near complex at Fukuoka; Height: Distance from the location where a gecko was found to the ground; SubT: Substrate temperature at the location where a gecko was found; TimeAS: Time after sunset when a gecko was found; Tsush: Tsushima Island

Acknowledgements

We thank Dr. Hidetoshi Ota for his help during the field investigation of *G. japonicus* in Japan.

Funding

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2016R1D1A1B03931085).

Availability of data and materials

Data are available from the authors upon reasonable request.

Authors' contributions

The study was designed by DIK and DP. DIK, IKP, JSK, WJC, IHK, and DP collected and analyzed the data. DIK, WJC, and DP drafted the manuscript. All authors read and approved the final manuscript.

Ethics approval

This research was conducted within the guidelines of the Institutional Animal Care and Use Committee of Kangwon National University (KW-161128-2).

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

Publisher's Note

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Received: 5 September 2018 Accepted: 1 November 2018

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