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# Predicting Potential Distribution of an Endemic Butterfly Lizard, *Leiolepis ocellata* (Squamata: Agamidae)

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**ABSTRACT.–** Predicting available habitat and the fine scale distribution of an endemic butterfly lizard, *Leiolepis ocellata*, is important for conservation since its populations are experiencing threats from anthropogenic activities. We conducted field surveys in northern Thailand and detected *L. ocellata* at 15 of 16 surveyed localities. We then used Maxent to predict its potential distribution based on presence-only data collected from field surveys and museum specimens and predictor variables (19 bioclimatic variables). The most optimal model confirmed its geographic distribution in northern Thailand but absent from other regions in the country supported by high AUC (0.875±0.076). The most important predictor variable was isothermality followed by temperature annual range and precipitation seasonality. Its occurrence was corresponded with known sites for the species. One further site, from which an old specimen was collected and recorded in 1967, was not predicted by the model and disappeared during field surveys. Most predicted distribution range located outside protected areas, which may potentially disturb *L. ocellata* populations. Our results presented updated information on current occurrence and predicted distribution of *L. ocellata* in northern Thailand, which is useful for developing conservation strategy of this species.

**KEY WORDS:** ***Leiolepis ocellata*, distribution modeling, Maxent, northern Thailand**

## INTRODUCTION

The eyed butterfly lizard *Leiolepis ocellata* Peters, 1971 is an endemic species in northern Thailand. This species was first described as *L. belliana ocellata*, a subspecies of *L. belliana* (Hardwicke et Gray, 1827) by Peters (1971), and later it has been followed by subsequent authors (Tiedemann et al., 1994; Manthey, 2010; Chan-ard et al., 2015). But it is currently elevated as a full species based on the difference in number of chromosome (Arunyavalai, 2003), distinct external morphology (Arunyavalai, 2003), and distinguishable phylogenetic relationship (Pauwels and Chimsunchart, 2007; Das, 2010; Grismer et al., 2014).

*Leiolepis ocellata* ecologically serves as an intermediate prey for important higher-level predators such as snakes and raptors. It becomes food source for rural people in northern Thailand and likely overhunted in some areas. Other human activities such as wildfire for agricultural purposes and urban expansion could also deteriorate habitats of *L. ocellata* (Arunyavalai, 2003). Without any protection act in Thailand and also listed as “Least Concern” by the International Union Conservation of Nature (IUCN) Red List, *L. ocellata* is potentially decreasing and may lead to local extinct.

Baseline information especially on distribution of this endemic taxon is an urgent priority for conservation planning.

Northern Thailand is topographically mountainous with many large mountain ranges separating lowlands. These intermontane lowlands are important habitats for *L. ocellata*. It becomes a challenge to evaluate the distribution of *L. ocellata* since an information on its distribution is scarce and not up to date. Largest source of information came from Arunyavalai (2003) who reported *L. ocellata* in Phayao, Nan, Lampang, and Tak Province. We opportunistically took photographs of *L. ocellata* in protected areas and forest park of the Forest Industry Organization of Thailand (FIO) such as Doi Suthep-Pui National Park in Chiang Mai Province, Doi Wiang La Wildlife Sanctuary in Mae Hong Son Province, and Thung Kwian and Mae Chang Forest Park in Lampang Province. Reassessment of its distribution may reveal new unexplored populations that will be a novel resource for future research and resource management.

Species distribution modeling becomes useful for creating distribution map based on known localities and background environmental conditions (Guisan and Zimmermann, 2000). The models that require both presence and absence data on species of interest could be developed with variety of statistical methods (Phillips et al., 2006). However, true absence data is sometimes unavailable for the scattered data sources such as old reports and museum specimens that usually described only localities of capture (Phillips et al., 2006; Ponder et al., 2001). Maximum entropy modeling (Maxent) which requires only presence data, has been developed to cope with this limitation (Phillips et al., 2006). Maxent estimates habitat suitability by finding the most uniform distribution (maximum entropy) across the areas of interest given environmental constraints. Climatic variables, in particular temperature, are considered major environmental constraints for ectothermic animals (Buckley et al., 2008; Shine, 2005; Spellerberg, 1971) and influenced distribution modeling of reptiles (e.g. Gül, 2015; Javed et al., 2017). Thus, fluctuations in temperature and perhaps other environmental climatic variables across diverse topography in northern Thailand are expected to play a significant role in distribution modeling of *L. ocellata*.

The objective of this study was to survey and predict the distribution of *L. ocellata* based on presence-only data obtained from field surveys and museum collection and bioclimatic variables. We limited our analysis to Thailand where we could follow the previous records and perform field surveys. We expected that the model could predict distribution range of this endemic species which is crucial for conservation and spatial planning.

## MATERIALS AND METHODS

### Field surveys

We selected localities for our survey localities based on historical records including Arunyavalai (2003), reports from the Forest Industry Organization of Thailand (FIO) and the Department of National Parks, Wildlife, and Plant Conservation (DNP), museum records (four specimens deposited at Thailand Natural History Museum; voucher No. THNHM15653, THNHM16101, THNHM 23215, and THNHM 25974), local reports and interviews with local people. Surveys were conducted at 16 known localities (Table 1) using visual encounter

**TABLE 1.** Localities data of *L. ocellata* based on field surveys and museum records

| Localities | Provinces | Evidences | Detection during field surveys |
|---|---|---|---|
| Ban Tak District | Tak | Local report (2017) | Yes |
| Mae Wa National Park, Mae Phrik District* | Tak | Arunyavalai (2003) | Yes |
| Ban Mae La Mao, Mae Sod District | Tak | THNHM15653 (1967) | No |
| Si Satchanalai Forest Park, Si Satchanala District | Sukhothai | FIO report (2013) and THNHM23215 (2013) | Not surveyed |
| Doi Pha Klong National Park, Long District* | Phrae | Local report (2017) | Yes |
| Pha Sing Subdistrict, Mueang Nan District | Nan | Local report (2018) | Yes |
| Wiang Sa District | Nan | Arunyavalai (2003) | Yes |
| Mae Chai Subdistrict , Mae Chai District | Phayao | Local report (2017) | Yes |
| Mae Peum National Park, Pa Deat District* | Chiang Rai | Local report (2017) | Yes |
| Mae Chang Forest Park, Mae Mo District | Lampang | FIO report (2015) and THNHM25974 (2015) | Not surveyed |
| Mueang Lampang District | Lampang | Local report (2017) | Yes |
| Chae Son Subdistrict, Mueang Pan District | Lampang | Local report (2017) | Yes |
| Thung Kwian Forest Park, Hang Chat District | Lampang | FIO report (2013) | Yes |
| Mae Li Forest Park, Li District | Lamphun | FIO report (2016) | Yes |
| Ban Khilek, Mae Rim District | Chiang Mai | THNHM16101 (1970) | Yes |
| Doi Suthep-Pui National Park, Maeung Chiang Mai District* | Chiang Mai | Local report (2017) | Yes |
| Mae Chaem Forest Park, Mae Chaem District | Chiang Mai | FIO report (2015) | Yes |
| Doi Wiang La Wildlife Sanctuary, Khun Yuam District* | Mae Hong Son | Local report (2018) | Yes |

* = protected area

survey technique (VES). Most surveys were situated in forest parks and national parks with some localities located on private property and school grounds. The observers walked along existing trails in those localities in order to minimize disturbance and carefully searched for butterfly lizards. The surveys were carried out during 9:00 to 15:00 h on sunny days during the dry season from October 2017 to May 2018. To increase the probability of detection, we conducted 3–5 surveys for each locality on separated days. Coordinates of present localities were recorded. Two points of detection located < 1 km in distance apart were considered the same point.

**Environmental variables**

All bioclimatic variables (Supplementary -Table S1) were downloaded from WorldClim database (www.worldclim.org) at a resolution of 30 sec (~1 km2) under monthly average conditions for 1970-2000 (Fick and Hijmans, 2017). This resolution approximately corresponded with the estimated home range of *Leiolepis* (approximately 800 m2; Arunyavalai, 2003). In Thailand, the initial prediction of Maxent showed that distribution of *L. ocellata* did not appeared in other regions but northern Thailand. We thus presented only the map of northern Thailand. The climate layers were clipped to the north of Thailand using QGIS. All layers were then converted into ASCII files.

**Species distribution modeling**

Presence data and environmental layers were used to generate probability maps predicting the potential distribution of *L. ocellata* in Maxent v.3.4.1 (Phillips et al., 2006). Presence data was obtained from our field surveys and specimen data (four localities with authenticated museum specimens). To select the most suitable predictor variables, 19 bioclimatic variables were initially considered in the first modeling using default setting of the Maxent (regularization multiplier = 1, max number of background points = 10000, and 1 replicate with cross-validate replicated run type). The selection was based on percent contribution (>10%), permutation importance (>10%), and Pearson correlation (coefficient $|r| < 0.80$; e.g. Khanum et al., 2013). After the initial model was evaluated, only three variables, isothermality (bio3), temperature annual range (bio7), and precipitation seasonality (bio15), were extracted and used for further analyses. Isothermality (bio3), which determines day-night temperature oscillation relative to annual temperature oscillations (summer-winter, O'Donnell and Ignizio, 2012), was calculated to percent. A value of 100% indicated equality of day-night temperature range and annual temperature range, while values < 100% indicated that day-night temperature oscillations were smaller than annual temperature oscillations. Temperature annual range (bio7) was calculated by subtracting the minimum temperature of the coldest month from the maximum temperature of the warmest month (O'Donnell and Ignizio, 2012). Precipitation seasonality (bio15) is a measure of variation in monthly precipitation totals over the course of the year (O'Donnell and Ignizio, 2012).

Twenty models were generated using different combinations of these three variables and different regularization multiplier values (1-3). These experiments were run under 10 replications of cross-validation replicated run type, the output format as "Cloglog", 10 percentile training presence as threshold rule, and other parameters at its default setting. Model performance was evaluated from areas under the curve (AUC) of a receiver operating characteristic (ROC) plot. The experiment with the highest average test AUC was considered as the most optimal model. The contribution of each environmental variable was then assessed by two methods: 1) percent contribution and permutation importance and 2) the jackknife method. Response curves were also generated to observe how each environmental variable affects Maxent prediction. The most optimal model was projected with presence data of *L. ocellata*. Further, the raster results were polygonized to calculate a total area and the area located within protected areas. Projection and polygonization were generated using QGIS.

## RESULTS

*Leiolepis ocellata* were highly active in the mornings of sunny days but less active and usually remained in their burrows on rainy days. Habitat types of the surveyed sites consisted of bare grounds, agricultural areas, and dry dipterocarp forests. The areas were encompassed by mountain ranges and covered with loose soil, across an elevation range of 140 to 646 meters above sea level. We detected *L. ocellata* at 35 points in 15 discrete localities (Table 1). Of these, there were five localities located in protected areas. We also detected additional *L. ocellata* populations at four sites that had never been documented but were informed by local people, which were Mae Peum National Park (Chiang Rai Province), Mae Chai District (Phayao Province), Doi Pha Klong National Park (Phrae Province) and Khun Yuam District (Mae Hong Son Province). The only locality where we failed to detect *L. ocellata* was in Mae Sod District, Tak Province. Nevertheless, we included this locality based on a museum specimen (THNHM15653, collected in

**TABLE 2.** Model selection summary of *L. ocellata*. (Grey bar represents the most optimal model.)

| Combination of variables | Number of variables | Regularization multiplier value | Average test AUC |
|---|---|---|---|
| bio3, bio7, bio15 | 3 | 1 | 0.872±0.095 |
| bio3, bio7, bio15 | 3 | 1.5 | 0.875±0.085 |
| bio3, bio7, bio15 | 3 | 2 | 0.875±0.081 |
| bio3, bio7, bio15 | 3 | 2.5 | 0.875±0.081 |
| bio3, bio7, bio15 | 3 | 3 | 0.875±0.076 |
| bio3, bio7 | 2 | 1 | 0.854±0.077 |
| bio3, bio7 | 2 | 1.5 | 0.857±0.073 |
| bio3, bio7 | 2 | 2 | 0.858±0.070 |
| bio3, bio7 | 2 | 2.5 | 0.857±0.068 |
| bio3, bio7 | 2 | 3 | 0.855±0.067 |
| bio3, bio15 | 2 | 1 | 0.844±0.062 |
| bio3, bio15 | 2 | 1.5 | 0.848±0.060 |
| bio3, bio15 | 2 | 2 | 0.851±0.062 |
| bio3, bio15 | 2 | 2.5 | 0.854±0.066 |
| bio3, bio15 | 2 | 3 | 0.855±0.068 |
| bio7, bio15 | 2 | 1 | 0.869±0.106 |
| bio7, bio15 | 2 | 1.5 | 0.871±0.104 |
| bio7, bio15 | 2 | 2 | 0.871±0.101 |
| bio7, bio15 | 2 | 2.5 | 0.872±0.098 |
| bio7, bio15 | 2 | 3 | 0.862±0.092 |

1967) as a confirmed site for our model prediction. As a result, a total of 39 points of *L. ocellata*— 35 points from field surveys and four points from museum records— were used in model prediction.

Optimization of Maxent generated 20 distribution models supported by average test AUC values (Table 2). The model with a combination of three variables (bio3, bio7, bio15) showed the highest AUC (0.875) when regularization multiplier values were 1.5–3. Thus, the most optimal model with lowest standard deviation (0.875±0.076) was used as a representative model for predicting the potential distribution of *L. ocellata* (Table 2; Fig1).

The areas with high probability of occurrence were predicted in northern Thailand, especially in the middle of the region (Fig. 1), and absent from other regions in the country as predicted by initial modeling. The distribution modeling mostly corresponded with surveyed localities and museum records with the sole exception of the record from Mae Sod District, Tak Province (Fig. 1). This locality specified by one museum specimen was neither predicted by this model nor detected during field surveys. Percent mutation, permutation importance, and jackknife procedure showed that isothermality (bio3) was the most important predictor variable (Table 3; Fig. 2) followed by temperature annual range (bio7) and precipitation seasonality (bio15). The probability of occurrence decreased with increasing of isothermality and precipitation seasonality (Fig. 3A, C) but increased with increasing temperature annual range (Fig. 3B).

After polygonization, the most optimal model estimated 10,710 km2 as a total potential distribution area of *L. ocellata* suitable (Fig. 4). Of this, 2,879 km2 located across 32 protected areas in northern Thailand (ca. 27% of total predicted area).

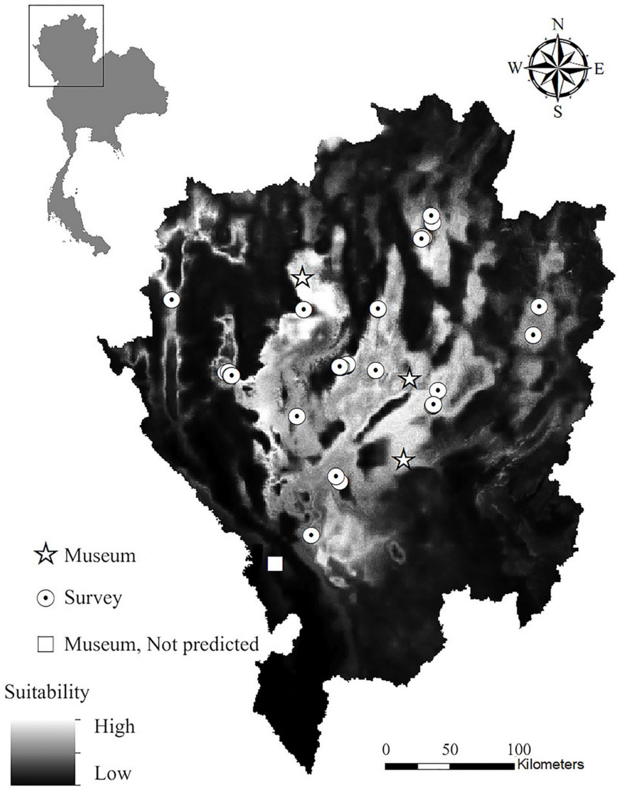


**FIGURE 1.** Predicted distribution model based on three selected predictor variables (bio3, 7, and 15) and presence information based on surveys (⦿) and museum specimens (stars☆) of *L. ocellata*. Mae Sod District, Tak Province, was a locality obtained from museum specimen, but not found in predicted map and survey (□).

## DISCUSSION

Improved and more detailed information on distribution of poorly known or endemic species is fundamental for conservation (Burgman et al., 2005; Gül, 2015; Javed et al., 2017). Field surveys and museum records enabled us to generate the first species distribution modeling for *L. ocellata*. The use of presence-only data should be interpreted with caution since an imperfect prediction may result from limited algorithms of the model (Elith and Graham, 2009). Nevertheless, we reduced this imperfection by optimization to find the most reliable model with the average AUC > 0.8 (Eskildsen et al., 2013; Manel et al., 2001; Swets, 1988). The most optimal model (AUC = 0.875±0.076) revealed the areas with high probability of occurrence of *L. ocellata* in northern Thailand and absent from other region in the country. Of the three predictor variables selected for performing the model, isothermality (bio3) had the strongest influence on *L. ocellata* distribution. Isothermality indicating fluctuation of monthly temperature ranges throughout the year was negatively

**TABLE 3.** Estimated relative contributions of each environmental variable. The values are average over 10 replications.

| Variable | Percent contribution | Permutation importance |
|---|---|---|
| Isothermality (bio3) | 64.4 | 61.1 |
| Temperature annual range (bio7) | 24.2 | 15.1 |
| Precipitation seasonality (bio15) | 11.4 | 23.9 |

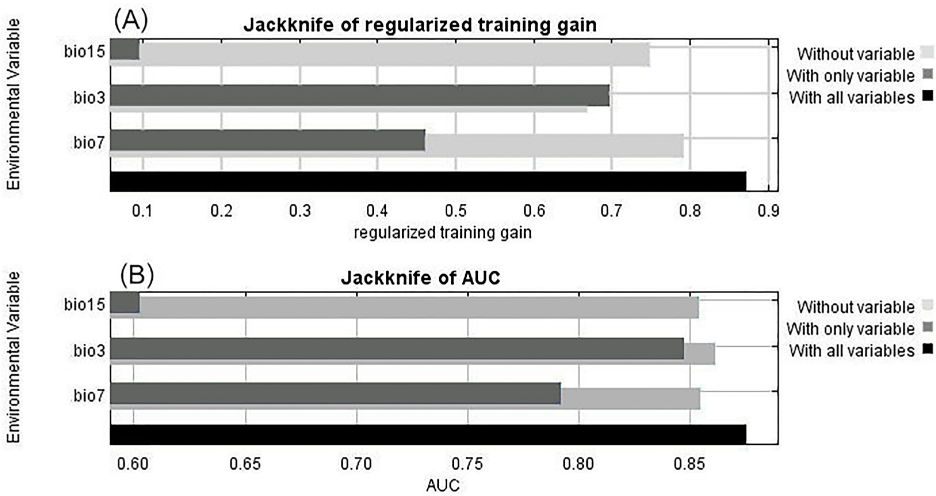


**FIGURE 2.** Jackknife test of the final model presenting environmental variable contributions to (A) regularized training gain and (B) AUC of *L. ocellata*. The values are average over 10 replications.

correlated with the probability of occurrence of *L. ocellata*. This suggested *L. ocellata* may prefer habitats with fluctuated temperature throughout the year as found in northern Thailand.

Within northern Thailand, low probability of occurrence was mostly found in the areas along mountain ranges in which the temperature is low throughout the year (occasionally dropping below 2 °C; www.tmd.go.th). As environmental temperature is vital for ectotherms (Angilletta et al., 2002; Lutterschmidt and Hutchison, 1997), this temperature may be lower than the critical thermal minimum of lizards (approximately 2.2 - 9.8 °C; Spellerberg, 1971) and could limit distribution of *L. ocellata*. Moreover, the highest mountain range in Thailand, Thanon Thong Chai Range, isolates the lowland in Mae Hong Son Province in the extreme westernmost part from other areas. Mae Hong Son Province is a poorly explored area in which biological information on butterfly lizards and others reptile species is still lacking. Our first report and model prediction of *L. ocellata* in this region suggested the possibility of many more unexplored reptiles that may exist and require comprehensive investigation.

The model prediction well corresponded with historical records and field surveys except for one locality obtained from a

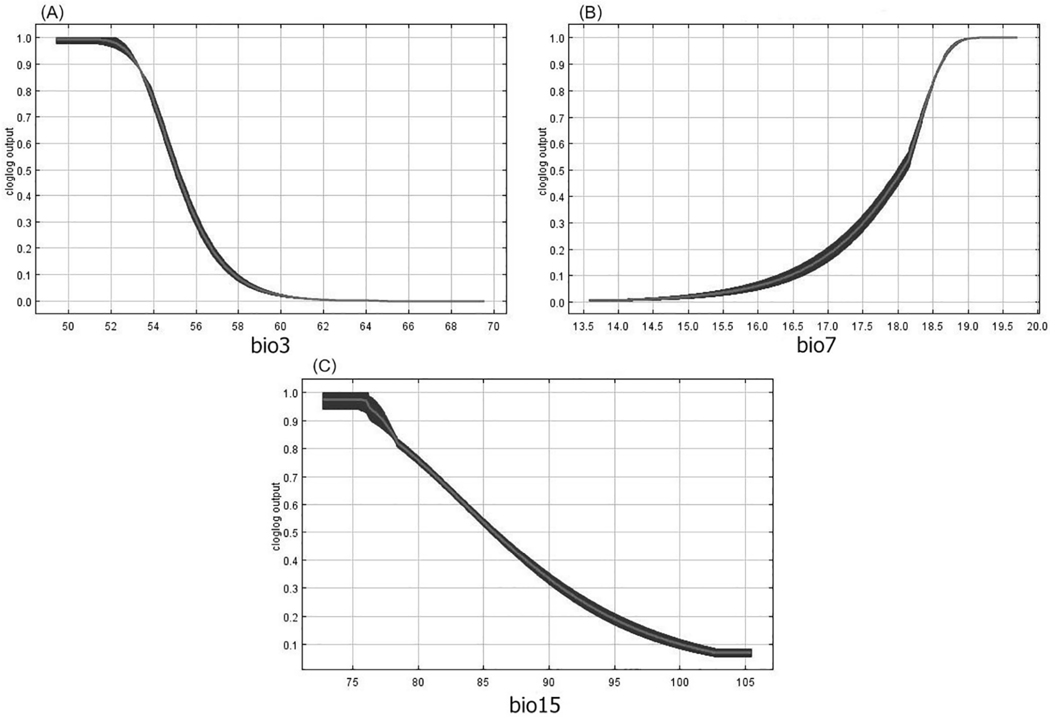


**FIGURE 3.** Response curves presenting relationships between selected environmental variables (x axis) and probability of presence of *L. ocellata* (y axis). (A) isothermality (bio3), (B) temperature annual range (bio7), and (C) precipitation seasonality (bio15). Each curve represents a different Maxent model created using only the corresponding variable.

museum specimen (THNHM15653) collected in Mae Sod District in 1967. Mae Sod District was not suitable for *L. ocellata* as predicted by the model and confirmed from field surveys. We carefully conducted field surveys and did not find the butterfly lizards nor their burrows in this and adjacent areas. Because important information such as name of the collector was missing, it was possible that mislabeling of a document might have occurred for Mae Sod District.

Baseline knowledge on species distribution in Thailand is imperative but usually unorganized. In this study, we gathered several sources of information for predicting potential distribution of *L. ocellata*. The model created a useful insight on the species biogeography and conservation. We found that predicted range of *L. ocellata* mostly located outside protected areas such as in private agricultural fields and urban zones, which are highly modified. Their populations in those areas are, thus, potentially threatened by land modification. For instance, in Mueang Chiang Mai District, Chiang Mai Province, we found *L. ocellata* only in a small part of Doi Suthep foothill despite its predicted suitable habitat covered most part of the district. Urban expansion in Chiang Mai Province may relegate its habitats preventing population establishment. Furthermore, the protected areas containing predicted range were mostly dry deciduous

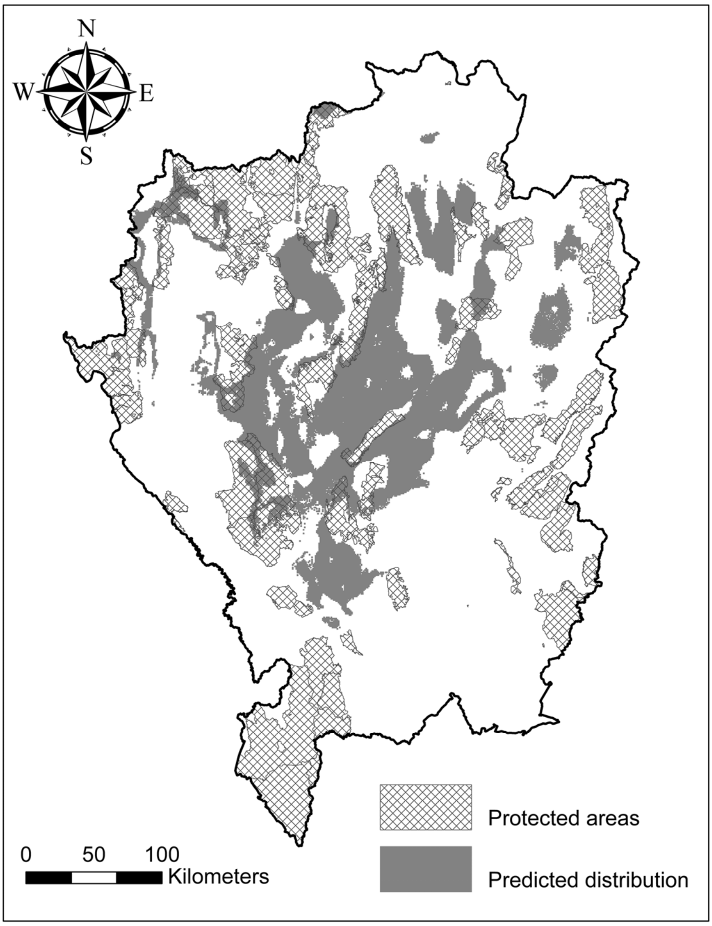


**FIGURE 4.** Predicted distribution model covered by protected areas in northern Thailand.

forests and currently have been severely devastated by wildfire. We strongly suggested species distribution modeling could be applied for conservational purposes of *L. ocellata* including the establishment of additional protected areas and prevention of those areas from urbanization and wildfire. We also recommend that organized and updated species distribution data could be useful for conservation planning of others threatened/endemic species, which will require consistent and careful monitoring.

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## Supplementary material

**SUPPLEMENTARY TABLE S1**. Bioclimatic variables used in modeling

| **Name** | **Code** |
|---|---|
| Annual mean temperature | bio1 |
| Mean diurnal range (mean of monthly (max temp – min temp)) | bio2 |
| Isothermality (bio2/bio7) (*100) | bio3 |
| Temperature seasonality (standard deviation *100) | bio4 |
| Max temperature of warmest month | bio5 |
| Min temperature of coldest month | bio6 |
| Temperature annual range (bio5-bio6) | bio7 |
| Mean temperature of wettest quarter | bio8 |
| Mean temperature of driest quarter | bio9 |
| Mean temperature of warmest quarter | bio10 |
| Mean temperature of coldest quarter | bio11 |
| Annual precipitation | bio12 |
| Precipitation of wettest month | bio13 |
| Precipitation of driest month | bio14 |
| Precipitation seasonality (coefficient of variation) | bio15 |
| Precipitation of wettest quarter | bio16 |
| Precipitation of driest quarter | bio17 |
| Precipitation of warmest quarter | bio18 |
| Precipitation of coldest quarter | bio19 |