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Species loss from land use of oil palm plantations in Thailand

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ABSTRACT

Expansion of oil palm plantation areas in Thailand, the world's third-largest oil palm producer, for food and fuel may sometimes encroach on forest areas, leading to biodiversity loss. Thailand is in the Indo-Burma biodiversity hotspot, which contains high species richness. This study assesses the impacts of oil palm plantations on bird and insect species richness from land use in the five regions of Thailand by using the countryside Species-Area Relationship model. Data from the Global Biodiversity Information Facility (GBIF) and Thailand's Land Development Department (LDD) were used for species occurrence and land use data, respectively. This study focuses on the deforestation for oil palm because it poses the highest risk for wildlife compared to other habitats. The taxon affinity and regional characterization factors show the risk to wildlife (birds and insects) in the formerly natural habitat areas (i.e., deciduous, evergreen, and mangrove forests). The results show that the possibility of animal survival in former mangrove forests is higher than in other forests upon occupation, as demonstrated by the taxon affinity. Likewise, deforestation in the northern region causes the least species loss per area, as demonstrated by the lowest average regional characterization factor, because species densities are lowest. However, the impacts on species richness depend on the taxon and the combination of the region and the forest type. While the overall goal should be to minimize the expansion of oil palm, this study indicates in which forest type and Thai region land occupation causes less regional bird and insect species loss.

1. Introduction

Renewable energy has been recommended for minimizing the environmental impacts of a growing world population and its increasing per-capita consumption. The global renewable energy consumption was around 20 percent of total energy consumption in 2016 and continues rising in most countries (REN21, 2018). Biodiesel is one of the renewable energy options suggested worldwide for on-road transportation. Biodiesel is considered environmentally superior to petrodiesel, with lower emissions of greenhouse gases and particulate matter (Silalertruksa and Gheewala, 2012; EERE, 2017). This has led to a rise in global biodiesel demand, which is forecasted to reach 2.3 million barrels per day in 2040 (Prapaspongsa et al., 2017; OPEC, 2017). Likewise, palm oil demand is rising continuously due to the demand for biodiesel but also, for example, as a vegetable oil in the food industry; this has led to expanding oil palm plantation areas across the world. In 2017, world oil palm production amounted to about 320 million tonnes from 21.37 million hectares, with a trend towards further expansion in the future (OAE, 2018; Khatun et al., 2017). For Thailand, biodiesel consumption is projected to increase from 1.24 billion liters in 2015 to about 5.81 billion liters within 20 years (Preechajan and Prasertsri, 2017). Around 0.81 million hectares in Thailand were under oil palm in 2018, increasing by 60 percent from 2009 (OAE, 2018).

Deforestation for planting oil palm causes various impacts, such as greenhouse gas emissions, water scarcity, soil degradation, biodiversity loss, etc. (OECD/FAO, 2016; Silalertruksa et al., 2017). Biodiversity loss, especially of primary forests in the tropics, raises concern because it does not only affect the local communities but also has implications for the conservation of global biodiversity (Barlow et al., 2007; Vijay et al., 2016; Alroy, 2017). Land use change is the main driver of biodiversity loss (Milà i Canals et al., 2016). It threatens the natural habitat, which can lead to species loss and extinction.

For Thailand, many research studies focus on the monitoring and reporting of plant or animal species in the converted areas. Thailand is a country in the Indo-Burma region, which is one of the world's top ten biodiversity hotspots (Tordoff et al., 2012; IUCN, 2013). The continuing deforestation causes high potential species loss, including endemic species (Sangkaman and Ingkasit, 2013; Gheewala et al., 2014a). Some

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Thai case studies estimated biodiversity loss in terms of mean species abundance (Akber and Shrestha, 2015; Trisurat et al., 2019). Some studies reflected on the cause of the difference between the observed, actual species richness and the simulated, potential species richness. The actual species richness is lower than the potential because species richness is estimated without considering the elevation of the studied site and the construction of plantations (Onishi et al. 2016). The reforestation of disturbed areas was also studied, focusing on the regeneration of plant species (Kitamura et al., 2018; Podong and Krivutthinun, 2018). Tree species richness was compared between plantations, grassland, and forests. The study showed that the planted tree species, the disturbance condition of natural forests adjacent to plantations, and the age of the plantation are the main factors influencing species richness. The forest's regeneration depends on external conditions (e.g., wildfire) and internal conditions (e.g., the construction of a plantation which affects the life's understory). While those case studies provide interesting insights into the biodiversity impacts of oil palm plantations in Thailand, such isolated cases cannot be used for land use planning on a larger scale.

Biodiversity footprints as part of a life cycle assessment (LCA) are a way to assess the land use impacts on species richness. Their potential for environmental product declaration in Thailand was tested and judged as challenging due to the limitation of data availability and the model's suitability for the assessment (Mungkung et al., 2019). Although existing global methods (e.g., Chaudhary et al. 2015) cover the country, they do not fit the land use of interest, i.e., oil palm plantations. Moreover, such global methods do not provide details for Thai regions and are typically limited to vertebrates but disregard invertebrates. Thus, this study aims to estimate the species loss from land use of oil palm plantations in Thailand to support land use planning. To achieve this aim, this study compares the species richness of birds and insects in oil palm plantations to natural forests in five regions of Thailand and identifies the forest type and region where oil palm expansion threatens species the least.

2. Materials and methods

2.1. Goal and scope

This study analyzed the biodiversity impacts from land use of oil palm plantations in five regions of Thailand, i.e., North, Northeast, Central, East, and South. We used species richness as the measure of biodiversity because it is commonly used and recommended for life cycle assessments (Woods et al., 2018). The potential species losses were estimated for the year 2012 relative to the year 2000. The study focuses on three types of forests (i.e., deciduous, evergreen, and mangrove

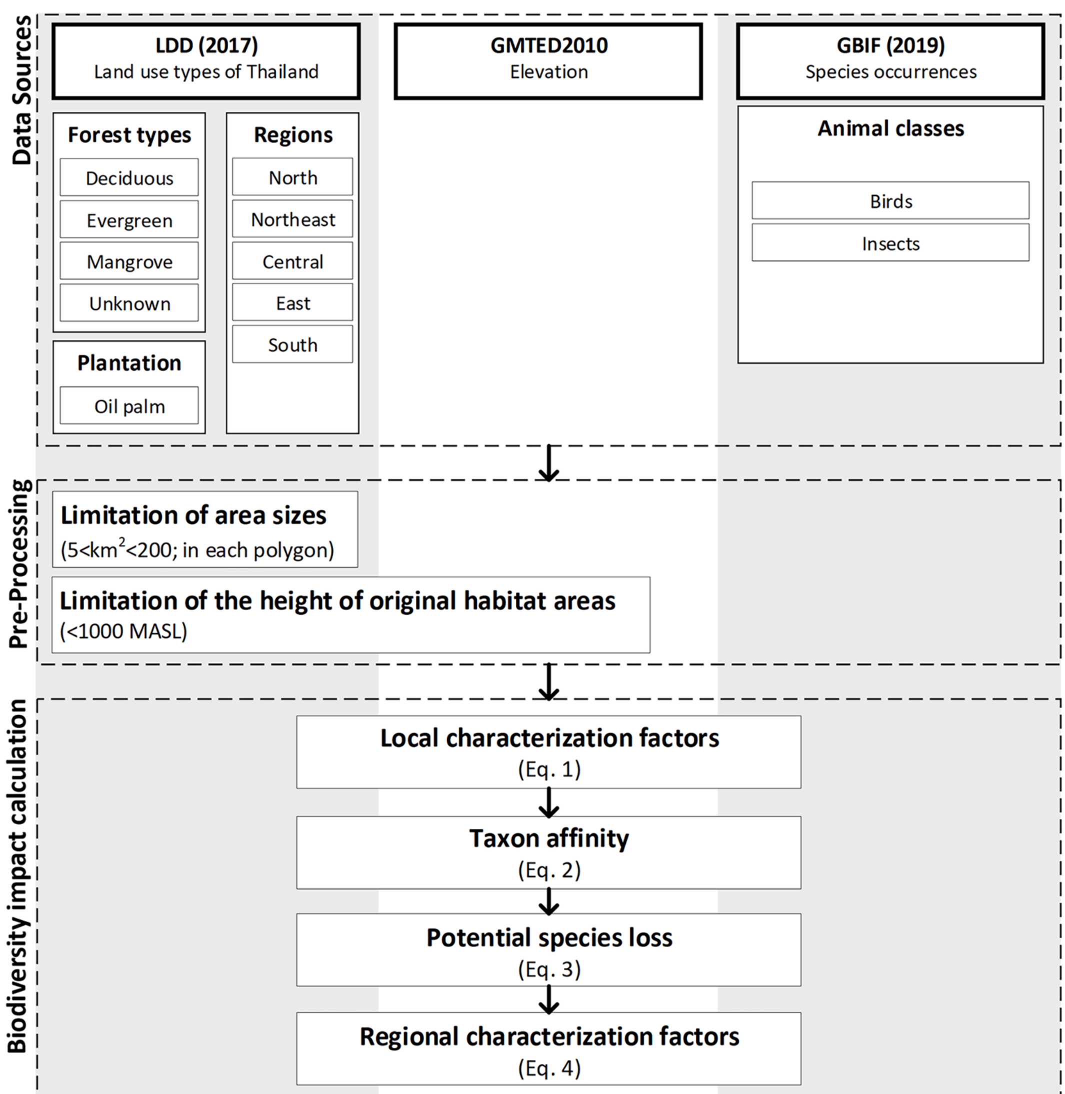

Fig. 1. Framework of this study.

forests) because forests are the most important global sources of terrestrial biodiversity (Liang et al., 2016), as also for Thailand. Additionally, this study considered unknown forest, which represents a forest converted to an oil palm plantation where the specific forest type is unknown. The biodiversity impacts were estimated using local and regional characterization factors. Such characterization factors translate the land use area to impacts on species richness. Local characterization factors based on site comparisons and taxon affinities for specific land use types, on which the regional characterization factors, considering the wider landscape, depend, were estimated for each forest type at the national level. Potential species losses and regional characterization factors were estimated for different land use types and regions (Fig. 1).

2.2. Land use inventory

This study compares the biodiversity of oil palm plantations with that of (quasi-)natural forests within Thailand. The land use data is available as spatial polygons from Thailand's Land Development Department (LDD, 2017). The reference state is a baseline for demonstrating the change in ecosystem quality (Milà i Canals et al., 2016). It can be (1) the potential natural vegetation, (2) the (quasi-)natural land use in a given ecoregion, or (3) the current land use mix. While it is a value choice that also depends on the scope of the study, Koellner et al. (2013) recommended using option (2), the (quasi-)natural land use, as done here.

Although the land use data shows the amount of forest converted to oil palm areas, the start time of the land occupation, which affects the species richness (Matsuura, 2010; Lees et al., 2015; Figueiredo et al., 2019), is not documented in the data of Thailand. This is relevant information, as the species diversity decreases with the plantation age (Lees et al., 2015). Thus, this study distinguished two scenarios for illustrating the possibility of species loss with increasing ages of plantations: only oil palm plantations already existing in 2000, i.e., at least 12 years old called "old", and "all" oil palm plantations in 2012 (Fig. 2).

2.3. Impact assessment using the countryside SAR model

The countryside species-area relationship (SAR) model was integrated by Chaudhary et al. (2015) into LCA to estimate the potential species loss caused by anthropogenic land use. Here, we adopted this model specifically for oil palm plantations in Thailand while defining our own approach to estimating local species losses that feed into the model instead of using existing estimates.

2.3.1. Local species loss

The local species loss was estimated by using local characterization factors ($CF_{loc,g,i,j}$) for each animal class g (i.e., birds and insects) and each natural land use type j (i.e., deciduous forest, evergreen forest, mangrove forest, and unknown forest). Land use type i includes oil palm plantations and other land uses. Other land uses influence the regional impacts of oil palm plantations, which depend on the wider landscape. The $CF_{loc,g,i,j}$ of other land uses was estimated by averaging the local characterization factors for birds presented in Chaudhary et al. (2015) for biomes 1 (Tropical and subtropical moist broadleaf forests) and 2 (Tropical and subtropical dry broadleaf forests) first for each land use type and then across all land use types (i.e., taking the average of the land use type-specific averages) to account for unequal data availabilities across the land use types. Such land use types included annual crops, permanent crops, pasture, extensively used forest, intensively used forest, and urban areas. Meanwhile, the $CF_{loc,g,i,j}$ of oil palm was derived from the species richness per area (species/km^2), in the following called species density, in oil palm plantation areas ($S_{g,i}$) relative to that in natural habitat areas ($S_{nat,g,j}$).

$$CF_{loc,g,i,j} = 1 - \frac{S_{g,i}}{S_{nat,g,j}} \quad (1)$$

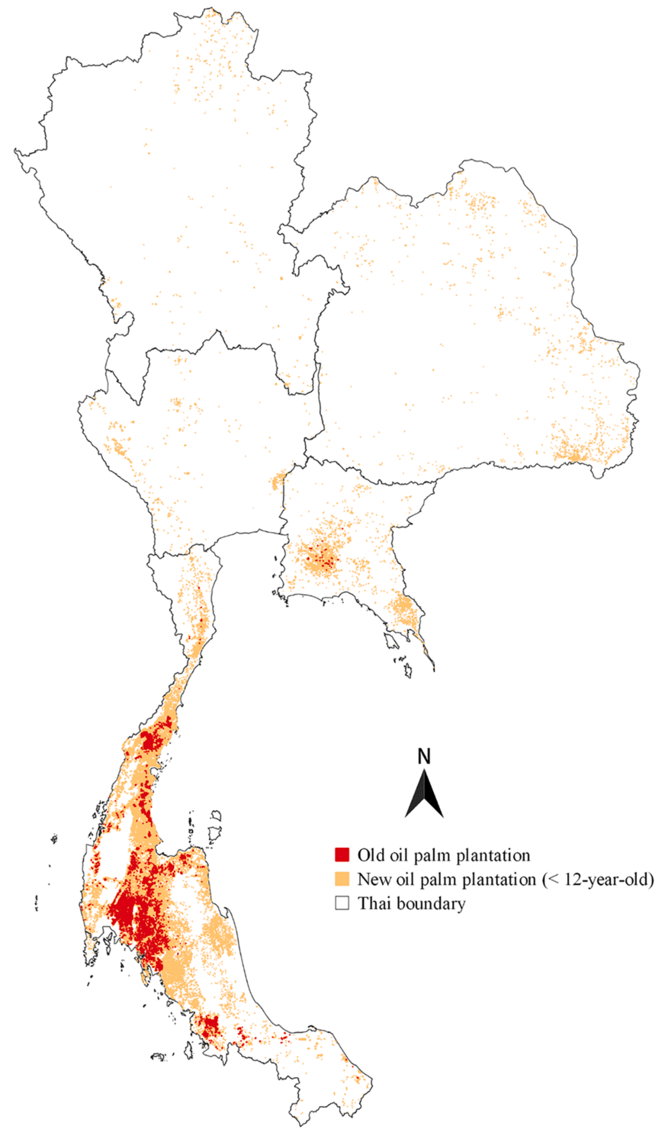

Fig. 2. Oil palm plantations in 2012.

It ranges from 0 to 1 for the occupied land use type fully hosting and losing all animal species, respectively. The $CF_{loc,g,i,j}$ also feeds into the calculation of the taxon affinity ($h_{g,i,j}$).

$$h_{g,i,j} = \left(1 - CF_{loc,g,i,j}\right)^{1/z} \quad (2)$$

where z is the constant from the classic SAR for forests: 0.344 (dimensionless) (Drakare et al. 2006). If the occupied habitat hosts all animal species, $h_{g,i,j}$ equals 1 (i.e., $CF_{loc,g,i,j} = 0$), and if the occupied habitat loses all species, $h_{g,j} = 0$.

This work mainly focuses on the estimation of species density on oil palm and forest areas, which is used to calculate taxon affinity. Both areas are presented separately for each natural habitat and land use area, which is referred to as a "polygon area". For the evaluation of species density, Thai land use data represent the year 2012, and the species richness of the natural habitat and oil palm area represent the years 2009–2013. For species occurrences, we used a period of five years, encompassing the year of the land use data, because of varying sampling efforts over time (Rocha-Ortega et al., 2021). Data of animal and plant occurrences was sourced from the Global Biodiversity Information Facility (GBIF) and grouped to the taxonomic rank "class". The taxonomic rank "class" can be subdivided into orders, families, genera, and species. This study estimated the species density by using the species richness, separately for each class, in each polygon area. We downloaded the species occurrences in Thailand from GBIF (2019) (see the data distribution in Fig. A3). GBIF was selected for this assessment because of its representativeness and comprehensiveness; GBIF data were collected from 98 organizations around the world. For example, GBIF covers globally 21,605 and 990,125 species of bird and insects, respectively. Besides, this database contains 597 species of birds and 105 species of insects in natural habitat and oil palm areas of Thailand. Based on attributes within the GBIF database, the quality of the data was checked to ensure that (1) the taxonomic rank is a species, (2) synonyms of accepted species names do not mistakenly lead to additional species, and (3) the records do not include fossil specimens. The coordinate uncertainty of the occurrence records was not an exclusion criterion to keep a larger sample size. It ranged from 0.2 to 66,430 m for the sample used in the final analysis; however, the uncertainty of over 90% of these records was 1,000 m or lower.

Pre-processing (Fig. 1) involves two steps to ensure the comparability between natural habitat and oil palm areas. Initially, this study intended to include various animal and plant classes and original land use types. Of initially twelve downloaded classes of plants, vertebrates, and arthropods, only the seven classes that have at least 100 species occurrences were selected for further pre-processing: plants (Magnoliopsida and Liliopsida), birds, mammals, reptiles, insects, and arachnids, presented in Table A1 in the Supplementary Information. The species occurrences of each class were overlaid with the land use data to identify the occurrences that are in the natural habitat and oil palm areas of Thailand. Due to an insufficient overlap with both land use types, the classes were further reduced to only birds and insects. The estimated species density revealed some unreasonable values. The estimated species density of disturbed and oil palm areas was higher than of natural habitat areas for all regions and classes, which contradicts expectations (Liang et al., 2016). This misrepresentation could be attributed to differences in polygon area sizes of the land use data, as shown in Figs. A1 and A2 in the Supplementary Information. Initial analysis showed that all polygon sizes of disturbed forests and oil palm plantations were disproportionately smaller than natural habitat forests. Therefore, a restriction of the area was conducted to correct the inflated species density values. The limits were based on approximately overlapping polygon area ranges for each pair of oil palm plantation age and natural forest type so that the minimum and maximum areas were of the same order of magnitude, resulting in comparable average areas (Table A2 in the Supplementary Information). Overall, the considered polygons ranged in size from 0.3 to 178 square kilometers. Due to small sample sizes and incomparable polygon sizes, the relative species density of a few pairs had to be derived from the relationships observed in other pairs, i.e., for the other taxon or another land use pair, instead of directly comparing the species densities of the taxon and land use pair in question. The species density of insects in all oil palm plantations relative to mangrove forests was estimated based on the species density of birds and the ratio between the species density of birds and insects for oil palm plantations relative to evergreen forests, which have a similar relative species density for birds. This assumes that there is some correlation between the species richness of birds and insects, which was indeed found for tropical land-use systems (Schulze et al. 2004), where it is generally higher than in temperate regions (Wolters et al. 2006). Moreover, the relative species density of birds and insects in old oil palm plantations relative to mangrove forests was estimated based on the average reductions for other forest types when compared to old instead of all oil palm plantations. In addition, the elevation of the area was considered in this study because it affects biodiversity. A higher elevation, which leads to a lower temperature, generally relates to lower species richness (Rahbek, 1997; Malsch et al., 2008; Bertuzzo et al., 2016; Onishi et al., 2016). The digital elevation model called "The Global Multi-resolution Terrain Elevation Data (GMTED2010)" was used to extract the area's height. The mean product layer was selected for this assessment, as it is the most suitable for general-purpose processing (Danielson and Gesch, 2011). The spatial resolution is 1 km^2 (30 arcs). The land use (natural habitat and oil palm area) was overlaid with the elevation. The outcome demonstrates the maximum height of oil palm areas in Thailand is around 850 MASL (meters above sea level), while natural habitat areas reach up to 1,800 MASL. Hence, the natural habitat areas higher than 1,000 MASL were excluded from further analysis. The elevation was limited at 1,000 MASL for including the species occurrences as much as possible. Finally, after pre-processing, this study included deciduous forests, evergreen forests, mangrove forests, and oil palm plantations, which contain 336 bird species and 18 insect species.

2.3.2. Regional species loss

The total potential species losses ($S_{lost,g,\ j,k}$ unit: regional species lost) for taxon g, natural land use type j, and Thai region k with the occupied land use areas i were calculated with Eq. (3). In this study, the regional species loss represents average loss from oil palm plantations in Thailand during 2000–2012. Meanwhile, the regional characterization factors represent the marginal loss ($CF_{regional,g,i,j,k}$ unit: regional species lost/m^2) of wildlife in each region of Thailand by differentiation (Eq. (4)). Eqs. (3) and (4) represent total potential species loss and marginal loss from all deforestation (i.e., for other land uses and oil palm).

$$S_{lost,g,j,k} = S_{org,g,j,k}\left[1 - \left(\frac{A_{new,j,k} + \sum_{i=1}^{n} h_{g,i,j}A_{i,j,k}}{A_{org,j,k}}\right)\right]^{z} \tag{3}$$

$$\frac{\partial S_{lost,g,j,k}}{\partial A_{lost,g,j,k}} = \frac{S_{org,g,j,k}}{A_{org,j,k}} \times z\left(\frac{A_{new,j,k} + \sum_{i=1}^{n} h_{g,i,j}A_{i,j,k}}{A_{org,j,k}}\right)^{z-1} \tag{4}$$

The allocation factor, Eq. (5), was used to allocate species loss to the deforestation for oil palm ($S_{lost,g,j,k}$), as demonstrated for marginal loss in Eq. (6).

$$a_{i,j,k} = \frac{p_{i,j,k}CF_{loc,g,i,j}}{\sum_{i=1}^{n} p_{i,j,k}CF_{loc,g,i,j}} \tag{5}$$

$$CF_{regional,g,i,j,k} = \frac{\partial S_{lost,g,j,k}a_{i,j,k}}{\partial A_{lost,g,j,k}p_{i,j,k}} \tag{6}$$

Here $S_{org,g,j,k}$ is the potential species richness in the natural habitat area in 2000 (unit: species), $A_{org,j,k}$ is the natural habitat area in 2000 (unit: m^2), $A_{i,j,k}$ is the oil palm plantation and other land use areas in 2012 (unit: m^2), $A_{new,j,k}$ is the remaining natural habitat area in 2012 (unit: m^2), $p_{i,j,k}$ is the relative area share in the total occupied area as the sum of $A_{i,j,k}$.

While the local characterization factors and the taxon affinity were estimated for both scenarios of old and all oil palm plantations, the potential species losses and regional characterization factors were derived from the species density of old oil palm plantations.

3. Results

3.1. Species density

The species densities of natural habitats are higher than that of oil palm plantations (Fig. 3, Table A2). The differences in species density between forests and old oil palm plantations are higher than between forests and all oil palm plantations. It suggests that species density decreases with the age of plantations. Also, the differences are higher for birds than for insects. However, the latter might be an artifact due to lower data availability for insects.

3.2. Taxon affinity

In line with the species densities, the taxon affinity of old oil palm plantations is lower than of all oil palm plantations, which include new plantations. Hence, the prospect of species loss in oil palm areas rises

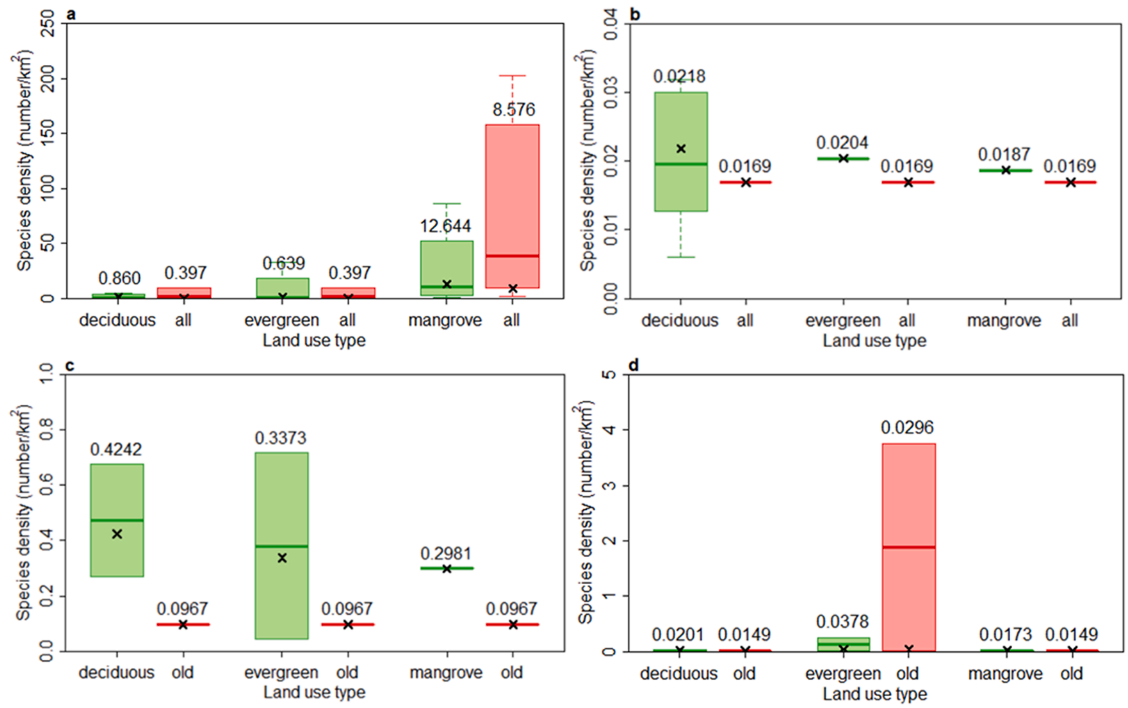

Fig. 3. Species density per land use type for (a) birds and all oil palm plantations, (b) insects and all oil palm plantations, (c) birds and old oil palm plantations, and (d) insects and old oil palm plantations. Green and red represent forests and oil palm plantations, respectively. The crosses represent the species densities of the total areas as opposed to individual polygons, and the values are displayed above the boxes. For better visualization, outliers are not shown. The same land use type can have different species densities in different pair-wise comparisons due to the matching of approximately overlapping polygon area ranges. See also Table A2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

with the increasing age of plantations. Besides, the occupation of originally mangrove forests with oil palms presents the lowest threat to bird and insect species, as illustrated in the highest taxon affinity values. In contrast, the conversion of deciduous forests to oil palm shows the biggest threat to bird and insect species, as demonstrated in the lowest taxon affinity values. This trend between land use types is consistent for both animal classes (Table 1).

3.3. Regional characterization factor

This study shows that fewer animals are affected when occupying former natural forests of the northern region than in other regions of Thailand, i.e. it has, on average, lower CFs (Fig. 4). This can be explained by the lowest species density in the North compared to other regions, which implies that there are fewer species that can potentially get lost. In contrast, the South has the highest species density, thus exposing more species to any threat by deforestation. During 2000–2012, the total area and the share of original habitat forests that converted to oil palm plantations in the southern region were higher than in other regions (Fig. 2). Besides, the remaining forest areas in the southern region are less than in other regions, which makes it difficult for animals to migrate to a suitable environment. Thus, further deforestation for oil palms in the southern region will severely threaten animals, consistent with the highest regional characterization factors.

Table 1
Taxon affinity to oil palm plantations relative to each forest type.

Land use types	Old plantations (≥12 years old)		All plantations	
	Birds	Insects	Birds	Insects
Deciduous forest	0.01	0.41	0.11	0.48
Evergreen forest	0.03	0.49	0.25	0.58
Mangrove forest	0.04	0.65	0.32	0.75
Unknown forest	0.02	0.50	0.13	0.52

The most suitable regions differ by taxa. For birds, the average regional characterization factor (i.e., of an unknown forest) in the northern region is the lowest (Table A3 in the Supplementary Information). It relates to the total remaining forest areas. The total remaining forest in the northeastern, central, eastern, and southern regions is smaller than in the northern region by approximately 68, 74, 90, and 69 percent, respectively (Table A4 in the Supplementary Information). That means animals (e.g., birds) in the northern region have more chance to migrate to the remaining forest areas. In contrast to birds, the average regional characterization factor of insects is lowest in the central region, i.e., it does not relate to the remaining forest areas. When taking the average for both taxa, the northern region performs best overall in terms of losing the least species.

The forest type that would least harm species richness upon occupation with oil palms differs in each region. It depends on the plantation areas and remaining forest areas. Although oil palms on former mangrove forests have the highest taxon affinity (Table 1), they do not perform best in any of the Thai regions. In the eastern region, occupied mangrove forests even cause the highest potential species losses (Table A3). In 2012, the remaining area of mangrove forests was 95 percent lower than of the other two forest types (Table A3). In the northern, northeastern, and central regions, the occupied deciduous forests cause lower impacts on wildlife, although oil palms on former deciduous forests have the lowest taxon affinity. The total remaining deciduous forests in these regions cover 61–82 percent of the total remaining forest areas (Table A4). For the southern and eastern regions, the occupied evergreen forest is estimated to cause the lowest species losses.

3.4. Regional species loss

The regional species loss from the occupied deciduous forests is higher than from the other occupied forests but still similar to that from evergreen forests (Fig. 5**a**). It applies to both taxa and can be explained

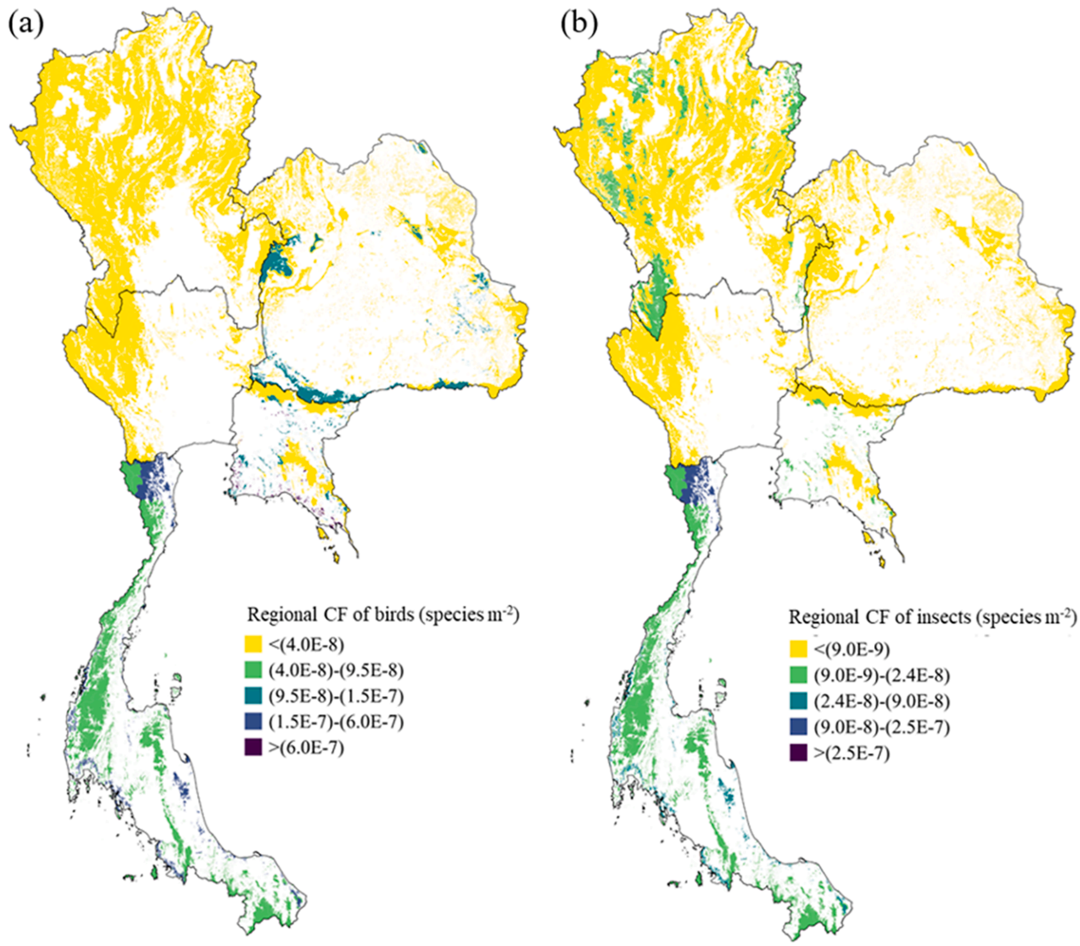

Fig. 4. Regional characterization factors of former or current natural forests in each region of Thailand for (a) birds and (b) insects.

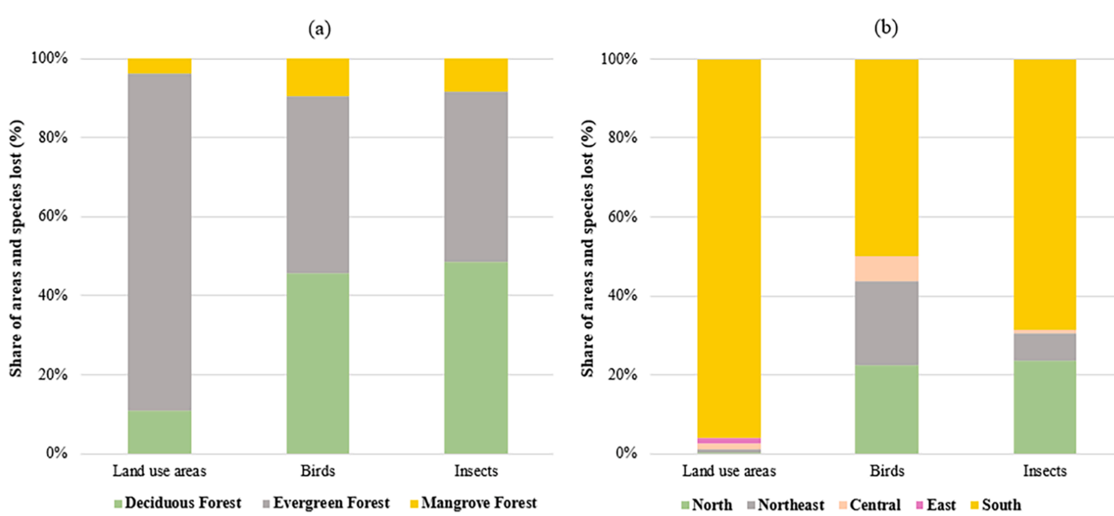

Fig. 5. Share of land use areas and regional species lost for oil palm plantations occupying former forests; (a) distinguishes forest types, and (b) distinguishes regions.

by the taxon affinity and the proportion of deforestation. Although the proportion of deciduous forests occupied with oil palm plantations is almost 8 times lower than of evergreen forests (Table A4), the taxon affinity of oil palms on former deciduous forests is also lower than on former evergreen forests. Thus, the two factors partly compensate for each other.

By far the most deforestation for oil palms occurs in the southern region, which consequently leads to the largest regional species losses of birds and insects in that region (Fig. 5**b**). The share of species loss is less than the share of the occupied area in the South. Conversely, the share of species loss in the North and Northeast are much higher than the share of the occupied area. The North faces the most deforestation, considering both oil palm plantations and other land uses, and the North and Northeast face a higher share of deforestation from deciduous forests where oil palms show the lowest taxon affinity (Table A4).

4. Discussion

The inclusion of multiple taxa in life cycle assessment (LCA) is important, as the environmental pressures, such as land use, can affect them in different ways. This was shown in our own results and is confirmed, for example, by Foster et al. (2011), who also investigated biodiversity in oil palm areas in South East Asia. They found that some taxa even increase in species richness or abundance, although most of them decrease in both aspects.

Because of limited data available in this study, the choice of taxa was narrowed down to two animal classes, i.e., birds and insects. Both taxa are of special interest for biodiversity impact assessments. The loss of bird species has received a lot of concern worldwide, including in Thailand (Waltert et al., 2005; Aratrakorn et al., 2006; Dyer et al., 2017; Erniwati and Santosa, 2019; Schumm et al., 2020). In 1989, the recorded data showed that Thailand contained more than 916 bird species, which is very high compared with the country area (Treesucon and Round, 1989). The expansion of deforestation for agricultural activities, including oil palm plantations, strongly affects the bird species richness, especially for endemic species (Aratrakorn et al., 2006). Besides birds being easy to survey (Irwin et al., 2014), they have been extensively studied, leading to high data availability (Larsen et al., 2012), and are congruent with many other taxa (Irwin et al., 2014). That is why they are often used as biodiversity surrogates. Still, the use of birds as a single taxon for surrogacy is criticized, and their effectiveness can be improved by adding another taxon (Larsen et al., 2012; Irwin et al., 2014), here insects. Insects cover more than 50 percent of all animal species in the world (Foster et al., 2011; Roskov et al., 2019) and play the most important role in maintaining ecosystem functions (Stork, 2018). The inclusion of insect species is an important contribution of this study. For biodiversity impact studies with LCA, invertebrates are rarely considered because of limited data availability, with a few exceptions (Tendall et al., 2014). Thus, the joint consideration of birds and insects seems to be a reasonable proxy for species diversity in Thailand, although we faced limited data availability of invertebrates, too, as shown in the much fewer occurrences for insects than birds (Table A1). Also, as the study of Chaudhary and Brooks (2018) excludes insects, this study could only compare the taxon affinities and regional characterization factors for birds with their results (Table 2, Table 3).

The estimated species densities on old and all oil palm plantations in this study conform to the research of Lees et al. (2015). They found that bird species richness in old oil palm plantations (>10 years old) is about half that in new oil palm plantations (≤10 years) (Lees et al., 2015), which corresponds to our results. Delayed species extinction explains the reduction of species density with the age of plantations and is driven by two factors: (1) the life-history traits help to extend the species survival, and (2) the population and metapopulation dynamics maintain populations under degraded habitat conditions (Figueiredo et al., 2019). Immediate and local species extinctions (a part of metapopulation dynamics) normally occur due to land use and land use change, while longevity, long-distance dispersal ability, and asexual reproduction (related to life-history traits) lead to delayed extinctions. Excessive asexual reproduction will appear in the long run and lead to delayed species extinctions because it decreases the genetic diversity and ability of species to adapt to environmental stress (Matsuura, 2010). Thus, this study calculated the taxon affinities and regional characterization factors from the species densities of old oil palm plantations to illustrate the worse (conservative) effects of land use on animals.

Table 2
Taxon affinity of birds.

Original land use	Old oil palms	All oil palms	Reference
Deciduous forest	0.01	0.11	This study
Evergreen forest	0.03	0.25	
Mangrove forest	0.04	0.32	
Unknown forest	0.02	0.13	
	Permanent crops in biomes 1 and 2		
Natural habitat	0.09		Chaudhary et al. (2015)
	Plantations with intense use, global		
Natural habitat	0.01		Chaudhary and Brooks (2018)

Table 3
Regional characterization factors for birds (unit: regional species lost/m^2).

This study					Chaudhary et al. (2015)*	
North	Northeast	Central	East	South	Thailand	Global range
1.46E-08	4.77E-08	3.77E-08	1.07E-07	1.17E-07	5.14E-09	3.22E-11–1.78E-07

*The median of countries for permanent crops is taken for the comparison.

This study showed that the taxon affinity of deciduous forest replaced by old oil palms is similar to the taxon affinity presented by Chaudhary and Brooks (Table 2). The taxon affinity estimated from this study is compared with the taxon affinity of plantations with intense use from Chaudhary and Brooks (2018). Normally, oil palm plantations in Thailand represent monoculture plantations, where chemical fertilizers, pesticides, and irrigation water are applied. Accordingly, they can be classified as intense use. Besides, oil palm plantations in Thailand are replanted around every 25–30 years, which is supposed to be non-crop rotation (Gheewala et al., 2014a; Silalertruksa et al., 2017).

For the regional characterization factors of this study, all values are within the global range of country medians for permanent crops, as presented by Chaudhary et al. (2015). Considering the large variation among the factors of the five regions, it is important to distinguish them instead of using one factor for the entire country. However, the estimated regional characterization factors of each region are higher than the overall regional characterization factor for Thailand from Chaudhary et al. (2015) (Table 3). The possible reasons for this difference are manifold. While our study is more specific for oil palm plantations in Thailand, it is less specific for other deforestation. Besides, we focused on forests as natural habitats, which have higher species densities than other natural habitats.

This study added spatial details by providing regional characterization factors separately for each Thai region that can support agricultural zoning. Although almost 95 percent of oil palm plantations in Thailand lie in the southern region because of land and climate suitability (Karnjanalai et al., 2009; OAE, 2018; TMD, 2019; Jaroenkietkajorn and Gheewala, 2020), the plantation areas have expanded in all regions to support the increasing demand (OAE, 2018). Whereas land and climate suitability are the main criteria for agricultural zoning, environmental impacts such as water scarcity and biodiversity loss should be included in the consideration (Silalertruksa and Gheewala, 2012; Gheewala et al., 2014a; Gheewala et al., 2014b; Vijay et al., 2016; Silalertruksa et al., 2017). Several studies reported the land use change of the various land cover types to oil palm plantations during the previous 25 years; these include primary forest, logged forest, tree cropland, rubber plantation, shrubland, paddy field, fruit orchard, food cropland or annual cropland, and grassland. At times, protected forests were also converted to oil palm plantations, which are mostly in the southern region of Thailand related to the expansion of oil palm areas (Gheewala et al., 2014a; Silalertruksa et al., 2017). Hence, agricultural zoning of oil palm plantations in other regions should be conducted to reduce the stress on wildlife from the plantation in the southern region. In contrast to deforestation for oil palms, reforestation on wastelands should be promoted to improve biodiversity.

Biodiversity goes well beyond local and regional species loss. Here, we give just a few possible examples and focus on those already used within LCA. Some assessed global species loss by considering the species' range size and threat level (e.g., Chaudhary and Brooks, 2018). While global loss leads to extinctions, local and regional losses remain important for providing ecosystem functions (Hooper et al., 2012). Others have assessed functional diversity loss (Scherer et al., 2020), but this approach is still in its infancy and requires further research before it becomes operational.

Data availability is a major challenge for biodiversity impact assessments worldwide (Souza et al., 2015), including in Thailand. Most studies used observation data, which do not cover all Thai regions. Likewise, some studies cover all of Thailand, but only at a coarse resolution. The values of taxon affinity and regional characterization factors were previously only reported for ecoregions or countries and for aggregated land use types (Chaudhary et al., 2015; Chaudhary and Brooks, 2018), but these do not correspond to Thai regions and the land use of interest (oil palm plantation). The taxon affinities presented by Chaudhary and Brooks (2018) are averaged from terrestrial ecoregions, which only partly overlap with Thailand (Fig. A4 in the Supplementary Information). Thailand intersects with six ecoregions, i.e., Northern Thailand-Laos moist deciduous forests, Northern Khorat Plateau moist deciduous forests, Chao Phraya freshwater swamp forests, Chao Phraya lowland moist deciduous forests, Tenasserim-South Thailand semi-evergreen rain forests, and Central Indochina dry forests for the northern, northeastern, central, eastern, and southern regions. This study used species densities for the calculation of taxon affinities, regional characterization factors, and regional species losses for each natural forest area (i.e., deciduous forest, evergreen forest, mangrove forest, and unknown forest). GBIF data was used for the calculations because it is more comprehensive, but it has rarely been used in LCA studies so far (e.g., Tendall et al., 2014; Crespo-Mendes et al., 2019). GBIF data covers 1.6 million species, including both threatened and non-threatened species of birds, insects, other animals, fungi, and plants. It contains around 60 percent and 99 percent of the world's bird and insect species reported by the Catalogue of Life. The Catalogue of Life has the most comprehensive global species richness data and includes about 32,176 bird and 998,650 insect species (Roskov et al., 2019). Globally, GBIF data includes approximately 18,400 bird species (GBIF, 2019), while the study of Chaudhary and Brooks (2018) included around 10,140 species. However, occurrence records in GBIF may suffer from inconsistency among observers using different sampling methods (Takashina and Economo, 2021). Additionally, the records are biased towards Europe and North America and are particularly sparse in Asia (Rocha-Ortega et al., 2021). Moreover, this study restricted the elevation and polygon sizes for each land use pair to make the biodiversity data of different land use types more comparable and thereby our analysis more reliable. However, other factors, like the climate and soil conditions, can also influence species richness. For the same reason, Scherer et al. (2020) conducted a natural experiment in which they matched biodiversity samples for each land use pair based on environmental covariates. Their approach is more systematic but also requires a larger data set. Both studies confirm that such a pre-processing and a selection of an appropriate subset of samples is essential.

The regional species losses on various land use types can also be examined for suggesting areas where oil palm expansion is less harmful to biodiversity. This study demonstrates the species richness impacts from deforestation for oil palms in five regions of Thailand, which presents the worst effects of land use on wildlife (species losses). The expansion of oil palms in mangrove forests seems to have a lower impact on species, compared to deciduous and evergreen forests. However, it should be noted that data availability was more limited for mangroves, and the estimation of local characterization factors required additional assumptions for old plantations and insects, as indicated in section 2.3.1. Meanwhile, various types of land use without natural habitat forests, such as rice paddy fields, have been occupied with oil palm plantations during the last three decades (Gheewala et al., 2014a; Silalertruksa et al., 2017). Occupied lands or degraded forests may be an appropriate option for further oil palm expansion. For example, oil palm trees can store more carbon compared to rice paddies, leading to lower greenhouse gas emissions (Gheewala et al., 2014a). Furthermore, the government of Thailand also uses the Roundtable on Sustainable Palm Oil (RSPO) manual for sustainable oil palm plantations through the support and cooperation among related associations of the palm oil industries and oil palm farmers. The principles and criteria include the avoidance of deforestation for oil palms (RSPO: TH-NI, 2012). Some alternative sustainability initiatives were established relating to the RSPO criteria, e.g., the International Federation of Organic Agriculture Movements (IFOAM), Good Agricultural Practices (GAP), etc. Some oil palm plantations in Thailand adhere to GAP principles (i.e., water source, planting area, pesticides, pre-harvest quality, harvest and post-harvest handlings, transportation, personal health, and record-keeping). In 2015, almost 800 oil palm farmers in Thailand were GAP-certified by the Department of Agricultural Extension. However, certified oil palm plantations represent only 0.4 percent of all oil palm plantations in Thailand. The Thai government aims to push the GAP certification to be a minimum condition for oil palm plantations. This certification can guarantee fresh fruit bunch quality and plantation sustainability (Obertreis, 2012; Willems, 2015). Hence, a comparison of biodiversity impacts between GAP-oil palm plantations and non-GAP-oil palm plantations is interesting for future studies.

5. Conclusions

During the last decade, expansion of oil palm plantations in Thailand may have led to some encroachment even into protected forests, contributing to species loss. This study used species occurrence data from GBIF (2019) and the latest land use data from LDD (2017) to quantify this loss. The strength of this study is the local and regional species loss estimated specifically for oil palm plantations in Thailand. Bird and insect species were analyzed and are considered as an adequate representation for other animal species affected by oil palm plantations in Thailand. The local relative species loss of the occupied forest areas (i.e., deciduous, evergreen, and mangrove forests) forms the basis for calculating taxon affinity. Regional characterization factors distinguish five regions of Thailand. The results illustrate that the species density in the occupied area (oil palm plantation) is lower than in the natural forests. The age of oil palm plantations also affects species loss. The species density in all oil palm plantations is higher than in old oil palm plantations for both birds and insects. The taxon affinity to oil palms on former mangrove forests is higher than for other forests. Together with much less deforestation of mangrove forests, these forests are least affected by new oil palm plantations between 2000 and 2012. The regional characterization factors demonstrate that fewer animals are affected per area unit in the northern region of Thailand because of lower species densities. However, the impacts on species depend on the taxon and the combination of the region and the forest type. For example, insects perform better in the central than the northeastern region. Moreover, in the South and East, evergreen forests are best suited, and in the north, northeast, and central regions, deciduous forests are best suited, despite the lowest taxon affinity. While it is obvious that deforestation for oil palms should be avoided as much as possible, the different risks for birds and insects by forest type and Thai region, presented in this study, can guide decision-making regarding new oil palm plantations or the restoration of old ones.

CRediT authorship contribution statement

Ukrit Jaroenkietkajorn: Formal analysis, Visualization, Writing – original draft. **Shabbir H. Gheewala:** Conceptualization, Writing – review & editing. **Laura Scherer:** Methodology, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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