sustainability

MDPI

Article

Predicting the Global Extinction Risk for 6569 Species by Applying the Life Cycle Impact Assessment Method to the Impact of Future Land Use Changes

Runya Liu [1,*], Haruka Ohashi [2], Akiko Hirata [2], Longlong Tang [3], Tetsuya Matsui [2], Kousuke Terasaki [4], Ryuzo Furukawa [1] and Norihiro Itsubo [5]

[1] Graduate School of the Environmental Information Studies, Tokyo City University, Yokohama 224-0015, Japan; ryuzofkw@tcu.ac.jp
[2] Forestry and Forest Products Research Institute, Forest Research and Management Organization, Tsukuba 305-8687, Japan; harukaohashi@affrc.go.jp (H.O.); hirataa@affrc.go.jp (A.H.); tematsui@affrc.go.jp (T.M.)
[3] Institute for Agro-Environmental Sciences, National Agriculture and Food Research Organization, Kannondai 3-1-3, Tsukuba 305-8604, Japan; tanglonglong@naro.affrc.go.jp
[4] MS&AD InterRisk Research & Consulting, Inc., Tokyo 101-0063, Japan; kousuke.terasaki@ms-ad-hd.com
[5] Department of Resources and Environment Engineering, School of Creative Science and Engineering, Waseda University, Okubo Shinjuku-Ku, Tokyo 169-8555, Japan; itsubo-n@waseda.jp
* Correspondence: g2193107@tcu.ac.jp; Tel.: +81-03-5286-3326

Abstract: Land use change is considered to be one of the key direct drivers of ecosystem erosion and biodiversity loss. The Life Cycle Impact Assessment (LCIA) serves as a robust tool for environmental impact assessment, featuring an advanced framework and indicators for assessing global biodiversity loss. In this research, we utilized the Species Distribution Model (SDM) to evaluate 6569 species across five taxonomic groups. We simulated habitat change and losses induced by land use changes under sustainable future scenarios from the present to 2100. This enables us to assess spatial extinction risks based on shifts in the global distribution of species. Our findings reveal a global biodiversity extinction risk of approximately 4.9 species/year, equivalent to an extinction rate of 745.9 E/MSY. Notably, higher-risk hotspots have been identified in regions such as South America, South Australia, and New Zealand. Although future sustainable scenarios involving land intensification may mitigate the biodiversity extinction rate, the objective of reaching 10 E/MSY by the end of this century remains a distant goal. By providing a more rational basis for biodiversity loss, the indicators of spatial extinction risk demonstrate the advantage of effectively reflecting regional characteristics.

Keywords: biodiversity; extinction risk; land use change; LCIA; future scenarios

check for updates

Citation: Liu, R.; Ohashi, H.; Hirata, A.; Tang, L.; Matsui, T.; Terasaki, K.; Furukawa, R.; Itsubo, N. Predicting the Global Extinction Risk for 6569 Species by Applying the Life Cycle Impact Assessment Method to the Impact of Future Land Use Changes. *Sustainability* **2024**, *16*, 5484. https://doi.org/10.3390/su16135484

Academic Editor: Irene Petrosillo

Received: 1 April 2024
Revised: 23 June 2024
Accepted: 24 June 2024
Published: 27 June 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The consensus reached after the establishment of the Kunming–Montreal Global Biodiversity Framework and IPBES is that anthropogenic activities are one of the most significant drivers of global biodiversity loss and degradation through land use and land use change [1]. Continuous economic growth and an increasing population, along with the large demand for consumption from the global supply chain, have intensified the impact of land use [2–4]. Maintaining current intensive land use practices will further accelerate the sixth mass extinction. The IUCN Red List shows that more than 44,000 (44,000/157,100) species are currently threatened with extinction [5]. In the last century, the average rate of extinction for vertebrate species was up to 100 times higher than 2 E/MSY. The current extinction rate is not positively known; previous research conservatively set the value to as high as 100 E/MSY [6]. Additionally, some other future projection-based estimations of extinction risk vary between scenarios; Abhishek Chaudhary et al. 2018 estimated the future land use (2015~2100) impact–induced extinction rate for three taxa by applying the Species–Area Relationship (SAR) model and found that the total mean extinction rate

was in the range of 105~412 E/MSY, with RCP2.6 SSP-1 leading to the lowest biodiversity loss [7]. However, the currently widely recognized controlled variables for the global extinction rate range from 100 to 1000 E/MSY [8–10].

Life Cycle Assessment (LCA) is a promising tool for evaluating the environmental impact related to global supply chain consumption [11]. The UNEP-SETAC Life Cycle Initiative has expanded the scope of assessment to include ecosystem quality, this being further subcategorized into global biodiversity loss [12]. Numerous studies have focused on developing factors for global biodiversity loss that extend beyond terrestrial environments to aquatic and even marine environments [13–15]. To assess biodiversity damage, the most prevalent and recommended method is to implement various SAR (Species–Area Relationship) models in combination with the PDF (Potentially Disappeared Fraction) to describe changes in species richness within certain spatial and temporal boundaries [11]. However, this methodology still falls short due to various limitations. (1) It is controversial that, in terms of the species richness concept, the larger the survey area, the more species are likely to be expected. This consequence is closely related to the only uncertainty considered in the SAR model (z-value) [7,16]. (2) Some research remarked that using species richness as an indicator of global conservation area allocation results in substantial decreases in biodiversity coverage [17]. (3) It is important to note that within most LCIA models and frameworks to date, there is a deficiency in addressing biodiversity extinction. To halt global biodiversity degradation, it is important to determine both species richness loss and species extinction [18].

In a recent review, only a few studies were shown to have expanded their fundamental aspects to encompass global species extinction [19]. Except for the indicator of PDF, the Global Extinction Probability (GEP) was assessed by considering species richness, species' habitat ranges, and IUCN threat levels to assess various ecosystems [15,19]. The research assessed more than 98,000 species across marine, terrestrial, and freshwater ecosystems. They found that high GEP was present in tropical islands, and some other distinct regions like northwest South America, Madagascar, the Himalayas, and Southeast Asia. Additionally, Extinction Species Indicators (EINES), developed via the Life Cycle Impact Assessment Method based on the Endpoint model (LIME3), are defined as the inverse of the waiting time (t) to extinction for each species [20]. Previous research has greatly progressed in assessing extinction risk concerning the impact of CO_2 emissions on terrestrial biodiversity by incorporating SDM (Species Distribution Modeling) to predict potential changes in species habitats. Extinction risk was defined as the change in the potential number of extinct species in each taxon due to additional emissions of CO_2 [21]. Previous research has examined the species extinction risk of vascular plants under the impact of six types of land use change in Japan [20]. However, it has become increasingly important to obtain a more inclusive global-scale extinction risk, which could be facilitated by obtaining more detailed species information. Moreover, to tackle global biodiversity loss, policymakers and stakeholders are seeking a long-term indicator database that provides longer temporal insight.

According to previous research, SDM is expected to contribute to the field of LCIA. SDM is characterized by predicting a potential species' habitat according to species presence-only data coupled with environmental shift. Applying one of the SDM approaches, Max Entropy (MaxEnt) was used to predict diversity changes in bird species under the impact of wind power [22,23]. It was also used to assess the impact of global warming impact on Japanese vascular plants. Moreover, SDM was used to estimate marine species richness under the impact of marine eutrophication [24]. Although SDM is a promising and flexible approach, there are limited instances of its application to the LCIA endpoint stage compared with other methods thus far.

While the trend of using Species Distribution Models (SDMs) in ecological studies is on the rise [25], the applications in Life Cycle Impact Assessment (LCIA) are also increasing. Nevertheless, there remains an insufficiency of practices that address long-term projections based on potential habitat loss at the species level [26]. Although previous studies have developed the indicator of extinction risk in the model of LIME, there is great demand

for more precise and long-term coverage of extinction risk indicators in Life Cycle Impact Assessment (LCIA). For the first time, we will develop a spatial extinction risk indicator derived from loss in species-level potential habitat distributions caused by land use changes.

This research aims to estimate the spatial global extinction risk under the impact of future land use change by considering the LCIA method and validating the impact of a sustainable future land use placement scenario on global biodiversity extinction. To avoid the inherent limitations of species richness, we tried to apply the biodiversity extinction risk indicator developed in the Life Cycle Impact Assessment Method based on the Endpoint model (LIME3) [27]. We used MaxEnt to model the potential habitat for each of the 6569 species in five taxonomic groups, both at baseline and future time points (the species list is available in the Supporting Information). The potential habitat predicted at 0.25 arc-degrees was based on the impact of baseline and future land use combination changes. The potential habitat change was used to estimate the extinction risk from the species level to the global level. The global risk of extinction was derived by summing up the extinction risks of 6569 biological species, and likewise, the extinction risks of each taxonomic group were obtained.

2. Methodology

2.1. Calculation of Global Extinction Risk

To be able to formulate the extinction risk, we first modeled each species' potential habitat in MaxEnt ('dismo' R package) [28]. All calculations were processed under the R version 4.1.1 environment [29]. The global Expected Increase in Number of Extinct Species (EINES) (species/grid) was defined as the extinction of species during the assessment period and further gridded into each grid cell (c), which was equal to the time interval (int) multiplied by the sum of all targeted species' extinction risks (ER) (species/year/grid), as shown in Equation (1). Meanwhile, the taxon-specific extinction risk was generated in the same way by summing up the taxon species extinction risk in each grid (species/year/grid). The extinction risk calculations initially followed previous research [20,21,27].

$$EINES_{c,global} = int \cdot \sum_{taxon} ER_{c,taxon} \quad (1)$$

$$ER_{c,taxon} = \sum_{sp \to taxon} ER_{sp \to taxon,c} \quad (2)$$

2.2. Calculation of Species-Level Extinction Risk

The MaxEnt model assessed the baseline (2015) and future (2100) habitats for all species at the same time. We determined each species' risk of extinction by analyzing the change ratio (R) of baseline ($C_{sp,baseline}$) and future ($C_{sp,future}$) potential habitat areas, as in Equation (3):

$$R_{sp} = C_{sp,future} / C_{sp,baseline} \quad (3)$$

The habitat area was represented by grid-based spatial data, and the habitat area was represented by counting the number of grid cells (C). Extinction risk (ER_{sp}) was defined as the inverse of each species' time to extinction ($ER_{sp} = 1/t_{sp},\ R \neq 0$); see Equation (4):

$$\begin{cases} ER_{sp} = 0,\ R = 0 \\ ER_{sp} = 1/t_{sp},\ R \neq 0 \end{cases} \quad (4)$$

To determine the time to extinction (t_{sp}), three cases must be considered. If one species' habitat area vanishes when comparing the baseline and future estimated potential habitat, this species is regarded as becoming extinct in 85 years (int), and its extinction risk ($1/t_{sp}$) equals 0.01; see Equation (5). However, when the habitat of a species remains unchanged, we assume that its extinction risk over the next 85 years is 0 ($ER_{sp} = 0,\ R = 0$). If the

habitat changes but does not vanish, the extinction risk can be calculated using Equation (5) based on a method used in previous research [21]:

$$0.01 = \sum_{sp} C_{sp,baseline} \cdot R^{t_{sp}/int} \quad (5)$$

After calculating each species' extinction risk, we allocated the risk onto the map. The extinction risk for each species was allocated to a changed potential habitat grid cell, valued as ($ER_{sp,c}$) for each grid cell, as shown in Equation (6):

$$ER_{sp,c} = ER_{sp}/(C_{sp,baseline} - C_{sp,future}) \quad (6)$$

2.3. Model and Data Used in Extinction Risk Calculation

The land use data were sourced from Land-Use Harmonization (LUH2 v2f), which is the future harmonized land use coupled dataset for CMIP6 [30]. To fit the model efficiently, land use types were reclassified into the resulting integrated types of cropland, urban land, grazing land, primary forested land, primary non-forested land, secondary forested land, and secondary non-forested land. The dataset employed in this research contains baseline (2015) information for each land use type; as a comparison, contrast data with temporal coverage extending to the future (2100s) were selected. As a sustainable and biodiversity-protecting scenario, we selected the SSP1-RCP2.6 IMAGE model to validate whether the biodiversity conservation level was sufficient [31]. The data were characterized by the relatively high resolution of 0.25 arc-degrees. Land use data were incorporated as variables into the MaxEnt model to predict the potential habitats of species [32].

In the SSP1-RCP2.6 scenario, we compared the changes in seven reclassified land uses between 2015 and 2100. The spatial distribution can be seen in the Supplemental Materials (Figure S3). This scenario assumes a future of green growth, where temperature rise does not exceed 2 degrees by 2100 under sustainable development [33]. The changes in urban land are the most moderate, with changes ranging from −154.6 to 324.8 km^2 per grid cell. This is partly due to the assumption of moderate population growth trending towards stability by the mid-century [34]. Significant areas of growth are concentrated in North America, sub-Saharan Africa, South Asia, and small parts of Indonesia. Globally, grazing land shows a significant decrease, ranging from −715.4 to 277.8 km^2 per grid cell. This is attributed to intensified livestock farming, reduced food waste, and decreased demand for meat products leading to the large-scale abandonment of pastures, this being especially pronounced in Central America. Additionally, bioenergy plays a significant role in this scenario, contributing to a decrease in biomass prices to some extent via the abandonment of large-scale pastures [35]. Regions experiencing an increase in cropland share are concentrated in South America, sub-Saharan Africa, southern China, and parts of Southeast Asia, this being closely linked to population growth. Furthermore, there is a notable decrease in primary forested land and a corresponding increase in secondary forested land in North Asia, indicating a trade-off, aligned with the policy of forest conservation and restoration in this scenario.

The species occurrence data were applied from the Global Biodiversity Information Facility (GBIF), including the 5 taxonomic groups (birds, reptiles, vascular plants, mammals, and amphibians), with about 6569 species being finally integrated into the model results [36]. The current climatic variables were selected to be modeled with land use data in SDM, which included the standard 19 bioclimatic variables for the baseline incorporated from WorldClim version 2 [37]. Finally, one of the Species Distribution Models (SDMs), MaxEnt, was applied to carry out the modeling work. We extended the model; the details of the procedure are available in a previous study [32]. The initial difference in this research is that we modeled the individual impact of land use by maintaining the climatic variables and substituting only the future scenario's land use input. Moreover, the updated GBIF species occurrence data were applied to obtain the latest insights into the potential habitat estimations for the species. By carrying out prediction using MaxEnt, the potential habitats

in the baseline scenario and future scenarios were used to calculate the change ratio of potential habitats for each species, which is described in Equation (3).

3. Results

3.1. Global Extinction Risk

The global extinction risk map was generated based on the prediction from 2015 to 2100, with a spatial scale of 0.25 arc-degree grid cells (Figure 1). It is estimated that approximately 4.9 species will go extinct every year out of the total of 6569 due to the land use change impact under the SSP1-RCP2.6 scenario. Due to the fact that this extinction risk prediction was only made for 6569 randomly selected species, we used this extinction rate for further expanded assessments. We expanded the assumption from 6569 species to 100,000 species, reaching an extinction rate of approximately 745.9 E/MSY. A similar previous study estimated the future climate change impact for 8428 species across 5 taxonomic groups under the RCP2.6 scenario, with respect to the results of ER, the average value of which equals 5.12 species/year. After converting this into the extinction rate, this value is approximately 607.5 E/MSY [21]. Although the comparison of two studies revealed different numbers of target species, indicating varying extinction risks, the values were still very close. Furthermore, when values were converted into extinction rates, the extinction rate due to land use surpassed that caused by climate change. This finding is consistent with some research findings, where land use is identified as the most significant driver among the top five drivers influencing biodiversity [38,39]. From a spatial perspective, our findings identify several regions with high extinction risk, from Mesoamerica to the Tropical Andes, the coastal areas of southern Australia, and New Zealand. Additionally, regions such as East Africa, Madagascar, and an area from Southeast Asia to Oceania also exhibit higher extinction risks compared with other locations. These regions significantly overlap with global biodiversity hotspots, characterized by high levels of endemic species and facing significant habitat degradation. They are also widely recognized as priority areas for conservation to prevent large-scale extinctions [40]. The importance of geographic regions in these high-risk areas is corroborated by other studies. Research focusing on areas based on the Species Threat Abatement and Restoration (START) metric shows that these regions align closely with our projected high-risk extinction zones. This also underscores these areas' critical role in biodiversity conservation [41]. This also validates the accuracy of our predictions regarding the distribution of extinction risks. In some past studies, different assessment methods have been applied to assess the extinction rate of endemic species over the same time frame. When compared with other scenarios, the SSP1-RCP2.6 scenario has the least impact on biodiversity, with an estimated extinction rate of around 100 E/MSY. However, this assessment method uses the conventional SAR model to calculate endemic species results, which are more likely to indicate extinction [7]. Our study focuses on evaluating the number of extinct species, not only the number of species extinct due to land use changes but also the species that may potentially become extinct due to a loss of habitat area. Previous research has estimated that typical rates of background extinction are around 0.1 E/MSY [42]. However, some research analyzing historical data indicates that the extinction rates of island-dwelling species are significantly higher than those of continental-dwelling species. This study also reveals that, based on historical data, the extinction rate for birds is the highest at approximately 177.2 E/MSY, while mammals have a maximum extinction rate of 147.4 E/MSY [43]. Additionally, numerous studies have indicated that the current extinction risk of terrestrial species ranges between 0.1 and 100 E/MSY [8,44]. The future rates are predicted to be 10,000 times higher, approximately 1000 E/MSY [10,42]. The estimated extinction rate in this research was lower than 1000 E/MSY, which may be because of the consideration of sustainability and biodiversity conservation scenarios. This demonstrates that reducing the intensity of land use in line with the sustainability scenario could potentially slow the pace of extinction in the future, albeit falling far short of the aspirational goal of 1~10 E/MSY [45].

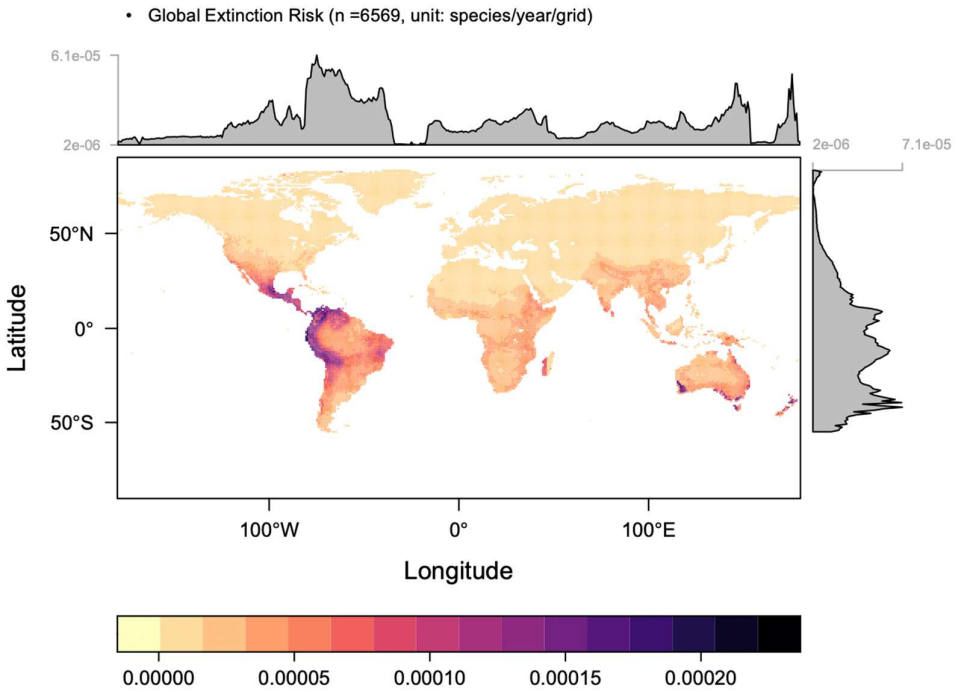


Figure 1. Estimated global extinction risk for 6569 species from 2015 to 2100 under the scenario of SSP1-RCP2.6 coupled with land use change impact. (Unit: species/year/grid).

3.2. Regional Extinction Risk

The assessment of global extinction risk identified several noteworthy high-risk hotspot areas (Figure 2). By examining the frequency of extinction risk values assigned to each grid within various regions, we further explored the characteristics of extinction risk occurrences in different zones. In the graph, the X axis represents the values of each grid within the region, while the Y axis indicates the frequency of occurrence for each value range. The Latin American regions exhibited relatively high levels of extinction compared with other regions on the same continent. The extinction risk in South America is predicted to be 1.63 species/year, which is the highest compared with that in other regions of the globe. This is largely attributed to the future land use change in the SSP1-RCP2.6 scenario. By the 2100s, the grazing land under this scenario is projected to significantly decline worldwide due to the intensified livestock sector and reduced food loss, leading to decreased demand for meat and the abandonment of grazing land. Additionally, bioenergy plays a significant role in SSP1, due to the abandonment of grazing land, which leads to a reduction in biomass prices and further confirms that significant grazing land transformation will lead to a high risk of biodiversity extinction [46]. The other regions with the highest extinction are Asia, Africa, North America, Australia, and South America, with extinction risks of 0.96 species/year, 0.95 species/year, 0.76 species/year, and 0.46 species/year. On one hand, these regions have a wider area and thus cover more species, while on the other hand, future land use change occurs within these regions, leading to a special high risk of extinction.

The potential for extinction is expected to be greater in the West Australia, coastal Australia, and Oceania regions. Aside from the aforementioned reasons, other land use changes may also potentially lead to a high risk of extinction in these regions. In the Northern California coast and east of the Gulf of Mexico within the North American region, the area of secondary forested land is rapidly expanding worldwide, while some areas in the southeast of the American region are experiencing decreases. Furthermore, urban land expansion is projected from the east to the west of America due to the increase in urbanization in the predictions of the future scenario [46,47].

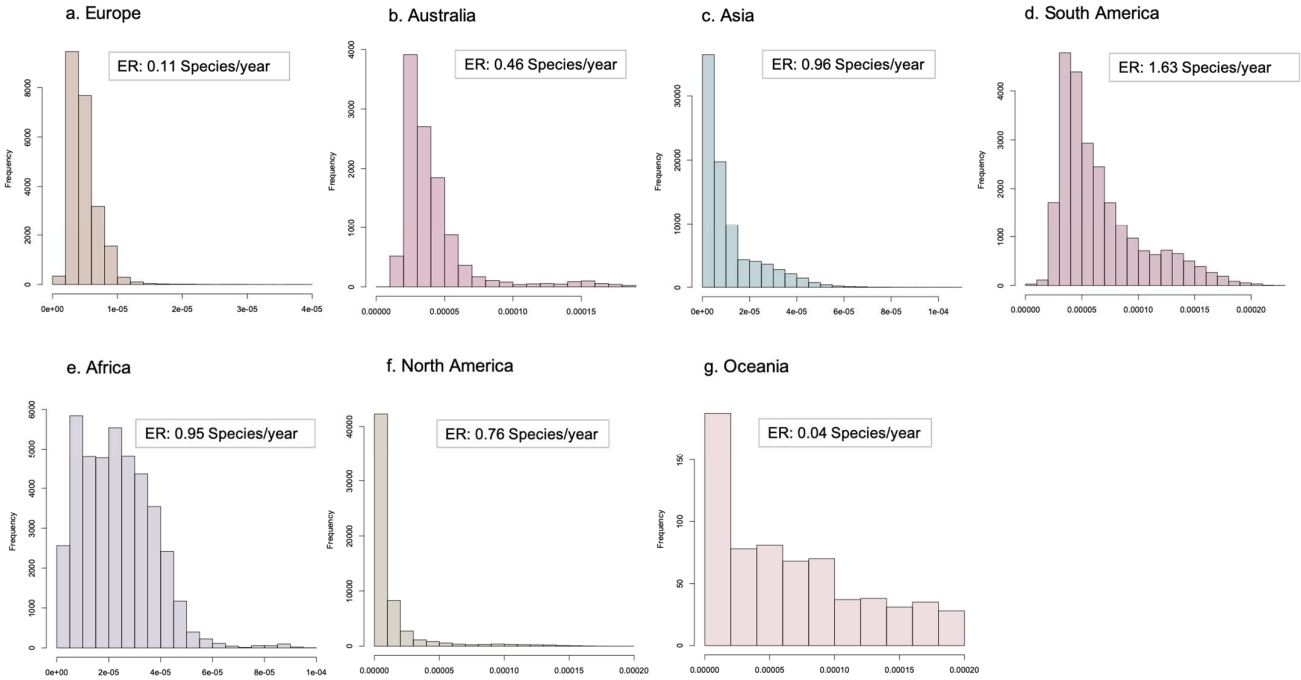


Figure 2. The histogram of each grid within each region and ER (extinction risk). (**a**) The frequency of ER estimated in each grid in Europe; the ER was calculated by summing all ER-assigned grids. (**b**) The frequency of ER in Australia. (**c**) The frequency of ER in Asia. (**d**) The frequency of ER in South America. (**e**) The frequency of ER in Africa. (**f**) The frequency of ER in North America. (**g**) The frequency of ER in Oceania (Australia was assessed separately and excluded).

3.3. Taxon-Based Extinction Risk

After estimating the global extinction risk, we analyzed the extinction risk for each taxon individually (Figure 3). The intensity of taxon-based extinction risk varies geographically. The total extinction risk for birds is the highest at around 4.38 species/year (n = 3791), followed by vascular plants at around 0.22 species/year (n = 1296), mammals at about 0.21 species/year (n = 937), amphibians at about 0.089 species/year (n = 447), and reptiles at 0.012 species/year (n = 98). The extinction rate for each group was converted, and the mean extinction rate across five taxa was estimated to be 374.16 E/MSY. These results were largely influenced by an imbalance in the sample quantity attributed to each taxon, which resulted in bird species occupying over 57.7% of the total samples, leading to a high cumulative risk, responsible for 89.8% of global extinction risk. Of the 3791 bird species, over 59.6% of them will lose over half of their habitats by 2100 compared with the current scenario. A high intensity of distribution is evident in the South American region, with the values predominantly covering the Southern Hemisphere due to the lengthy migratory capabilities of birds. We analyzed bird species that are expected to lose more than 50% of their habitat in the future, and found that South America had the highest proportion of about 14.9%; extinction risk in this region is estimated to be 0.99 species/year, which is responsible for 22.5% of the total extinction risk for bird species. For these species, the average habitat loss in South America is predicted at about 71%, which implies a great impact resulting from future land use change in South America. Through confirmation in Meso-America of future land use changes in South America, we can observe that the land use changes with significant impacts on bird species are not singular, especially in regions where the reduction in grazing land and secondary forested land overlaps significantly with high-risk bird areas. In the Meso-American region, three of the four major trans-regional migratory bird routes in the Western hemisphere converge. South America, being a hotspot region, harbors over 3000 species of land birds, with a greater number of endemic species than that in any other region [48]. The reduction in forests plays a crucial role in bird habitats, while the replacement and decrease in grassland directly impact bird diversity [49].

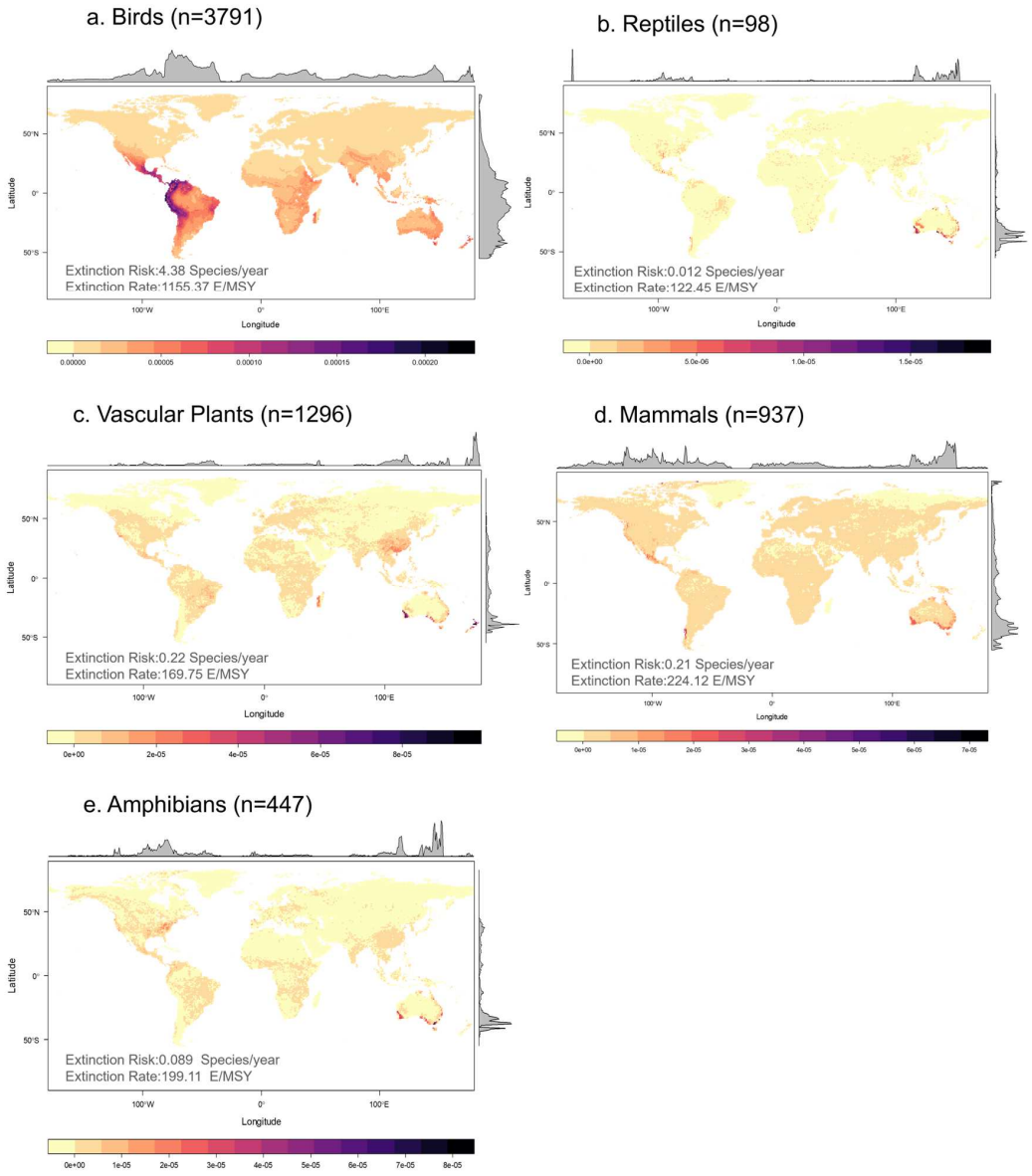


Figure 3. Extinction risk based on taxonomic groups refers to the analysis of extinction risk at a global level. The measurement unit for each map is defined as species/year/grid. (**a**) The extinction risk for the bird group, containing 3791 bird species in total. (**b**) The extinction risk for reptiles, comprising 98 species in total. (**c**) The extinction risk for mammals, comprising 937 species in total. (**d**) The extinction risk for vascular plants, comprising 1296 species in total. (**e**) The extinction risk for amphibians, encompassing 447 species in total.

The extinction risk for vascular plant species was estimated to be the second highest, partly due to the large number of species samples collected in this research. The migration ability of vascular plant species is generally seen as a great source of uncertainty in terms of their adaptation to environmental changes in their habitat [50]. The average habitat loss of vascular plants is about 10%, and species with more than 10% habitat loss account for about 31% (406/1296) of the total. The total extinction risk for these species is about 0.18 species/year, which is about 81% of the overall extinction risk for plants. Species with habitat loss exceeding 10% were mostly distributed in Asia and Oceania, and the extinction risk of the former was about 0.0498 species/year, accounting for 22.6% of the total vascular plant extinction risk, while species with more than 10% habitat loss found in Oceania had an extinction risk of 0.042 species/year, accounting for 19% of the total extinction risk. By comparing future land use changes in Oceania and Asia, we observed a significant

reduction in primary forested land, particularly in Tasmania and New Zealand, as well as in Southeast Asia. This closely aligns with the distribution of high-risk plant areas in these regions, explaining the significant impact of primary forested land on plant species extinction. In addition, the increase in cropland share in Madagascar, southern China, and South America has resulted in a decrease in plant biodiversity in these regions.

Due to the limited reptile species fitted to the model, the areas with high extinction rates were also low compared with those of areas with other taxa. The high-risk regions were predominantly found in the coastal areas of Australia, North America, and the Meso-America region. The loss of habitat for more than 10% of reptile species accounted for 23% of the total in this study, with high-risk hotspots in Oceania and North America. The extinction risk in Oceania is approximately 0.0059 species per year, which represents almost half (49%) of the overall extinction risk, with an average habitat loss of about 25.6%. After analyzing the high-risk areas of reptilian species, it was found that South Australia exhibits characteristics of highly extensive crop and grazing activities. Comparing the characteristics of future land use changes in this region, it was discovered that areas with a decrease in cropland share highly coincide with areas at high risk for reptiles. Especially in the southwest region, reptilian species are abundant, even leading globally. The reduction in cropland size, due to its extensive and warm conditions serving as an essential shelter for reptiles, also profoundly impacts the local reptilian population.

4. Discussion

4.1. Global Extinction Risk (EINES) and Global Potentially Disappeared Species (PDS)

Our modeling outcome is characterized by high flexibility, which allows other indicators, such as Potentially Disappeared Species (PDS), to be compared with the results of Extinction Species (EINES) (Figure 4). The PDS was derived from the Potential Disappeared Fraction (PDF), which generally represents the species richness loss ratio. Using the different dimensions of the PDF, we transformed the PDF into PDS, which is valued as a unit of species/grid on the global scale. Here, we aimed to assess the biodiversity changes in a random sample of 6569 species. Therefore, we did not adopt the SAR model approach to quantify the PDF indicator but overlaid the predicted habitats of species to define the potential species richness in each grid, and finally compared the differences between the two time points to obtain the potential loss of richness.

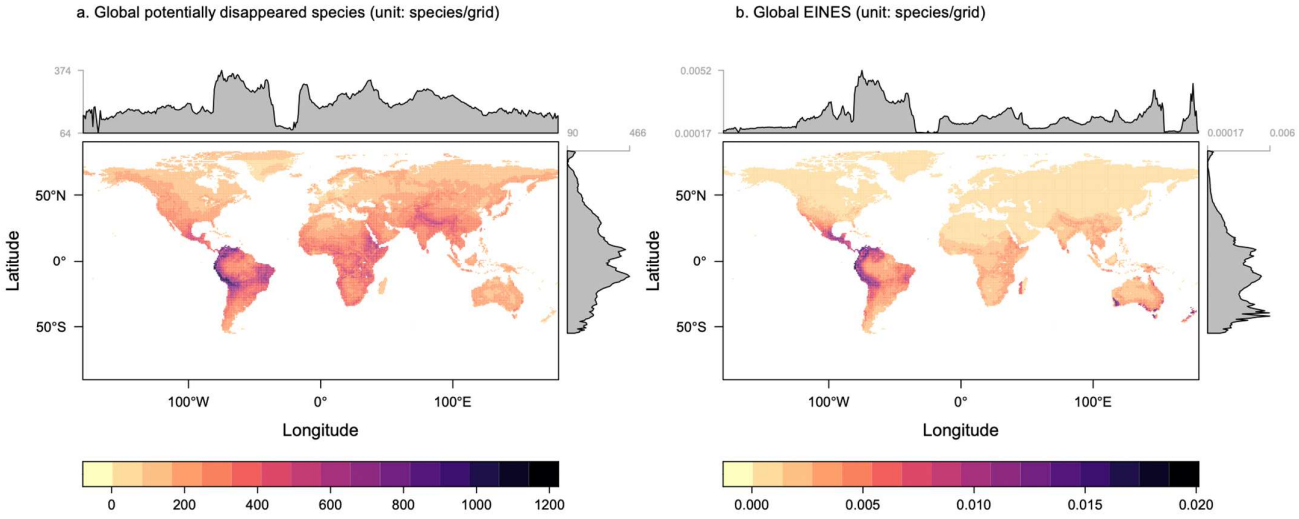


Figure 4. (**a**) Global Potentially Disappeared Species (PDS) compared with (**b**) global EINES (global Expected Increase in Number of Extinct Species). The results for both were generated from the outcome of the MaxEnt model for 6569 species. The PDS value was derived from the outcome of the PDF results for comparison using a unified dimension scale. The calculation procedure for PDS is provided in the Supporting Information. The EINES calculation refers to the methodology.

Overall, the two results exhibit similarities in their global distribution, such as the distribution of weight and high-risk areas in the northern and southern hemispheres, where there are similar trends in hotspot regions. However, the two indices exhibit a significant difference in numerical terms. This difference arises from the inherent distinctions in the indicators, with the former focusing on the quantity of species richness loss and the latter on the potential number of extinctions. The potential disappearance of species richness in a specific area does not necessarily indicate the extinction of species, as the species' migratory and adaptive abilities may allow them to survive in other regions [51]. In addition, some differences also manifest in geographical scales. This further confirms and corroborates some of the previous research findings that indicate a higher extinction risk for island-dwelling species compared with that for continental species due to adaptive escape from habitat loss, and therefore leading to islands becoming hotspots for the current biodiversity crisis [52].

Various indicators have corresponding research significance for different research scopes and fields. As a widely used biodiversity indicator, the PDF has been noted by some researchers to have inherent shortcomings such as unclear definitions, assessment scales, and interpretations [53,54]. The most crucial aspect is how to define the significance of species disappearance and extinction on a spatial scale [55]. Nonetheless, the PDF is currently one of the most advanced indicators being developed, with related studies aiming to further improve the PDF to derive Global Extinction Probabilities (GEP) [14,55]. In GEP research, expanding the assessment scope to cover more types of ecosystems and species numbers has led to a deeper exploration of extinction possibilities. However, for the current species extinction probabilities, it is important to emphasize in research the long-term future warnings about the crises that biodiversity may face. This is also represents the significance of and improvements achieved in our study; we expanded the research scope in both spatial and temporal scales.

4.2. Limitations

Some limitations occur when applying this methodology to the estimation of the future extinction risk under the impact of land use change. The estimation of high bird extinction risk in this study resulted from the number of species sampled, while the opposite scenario resulted in the risk of reptile extinction being the lowest. The selection of species to fit the model filtered a large number of species that possess abnormal distribution records. Thus, this ultimately caused an unbalanced species record for each taxonomic group and even for the final spatial risk distribution. This may have led to the overestimation/underestimation of certain regions. In future work, such problems could be alleviated by expanding the currently low numbers of species to realize a more balanced estimation. The predicted extinction rate in this study is based on the assumption of a range expansion due to extinction risk, and therefore the unbalanced bird data undoubtedly resulted in an estimation of high extinction rates.

Focusing on the changing status of land use to explain the impact of land use transformation on biodiversity is not sufficient alone. A more accurate understanding of the reasons for biodiversity loss can be achieved using a dynamic transformation pattern of land use. The current research results only focus on land use status at the starting and ending time points, and only certain land use transformations. Therefore, in future research, it is very important to integrate dynamic, phased land use transformations to interpret the resulting loss of biodiversity.

Due to the model and the prediction of a large number of species-level habitats based on land use variables in this study, it is challenging to analyze how specific environmental factors unique to each species interact or respond to changes in species habitat. Therefore, in future research, retrieving the factors specific to each species to analyze sensitivity and changes in variables is a crucial topic. Additionally, as a future research direction, the development of damage factors applicable to LCIA can further analyze how different land use changes affect the process of species extinction in specific regions.

5. Conclusions

In this study, we primarily contributed to the development of existing biodiversity indicators on a spatial scale and tried to verify the effectiveness of using this method for future long-term land use scenarios in biodiversity conservation.

Due to land use being the greatest and most direct driver of biodiversity, spatial analysis methods that assess the impact of land use change are crucial [39]. When emphasizing the impact of land use on biodiversity loss, at the assessment level, species' survival exhibits unique responses to specific ecosystems, requiring a more accurate species-level assessment [12]. From a user perspective, while considering factors leading to species disappearance, it is also necessary to contemplate species extinction to develop more scientific actions for biodiversity conservation, such as determining whether or not afforestation in specific areas outweighs the effects of land restoration [56]. Therefore, the importance of land in specific areas requires quantitative data support for standardization. Here, we identified the shortcomings in assessing extinction risks and addressed future needs for enhancement and further development. This allowed us to visualize the extinction risks for the first time. In comparison with previous studies where researchers applied extinction risk to evaluate global biodiversity loss due to global warming, we still provide estimates for species-level extinction risk and taxon-group assemblages [21]. Additionally, we leveraged extinction risk assessment, taking it from a regional overall characteristic to a location-based level [20]. This approach enables users to assess the impact of specific location land use changes more easily, by incorporating local ecosystem characteristics for timely adjustment and validation of regional policies. This is also makes it easier to identify the reasons for some high extinction consequences by connecting extinction with future land use changes in certain areas.

While many future scenarios have been very systematic, featuring cutting-edge strategies to tackle climate change, not all climate change mitigation policies benefit biodiversity simultaneously [56]. Therefore, even though some sustainable future scenarios have reduced biodiversity loss to some extent, the reduction in loss needs to be further quantified and verified. Despite the extensive consideration given to biodiversity conservation in many future scenarios, the target of 1~10 E/MSY is still far from being met. Several studies also indicate that further interdisciplinary research is needed to verify whether the sixth mass extinction under anthropogenic influence has already begun [57].

In future research, these results will be further utilized to develop a global land use-based LCIA damage factor database, benefiting more user demands, such as by supporting the global location-based assessment in the TNFD's LEAP framework, to provide more accurate assessments for disclosure and easily interpretable results for taking mitigation measures.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16135484/s1. Figure S1. Accumulative Species distribution map; Figure S2. The Potentially Disappeared Fraction. The PDF is defined in this research as the species richness change; Figure S3. The changes in land use status between 2015 and 2100, unit for each grid cell km^2/grid.

Author Contributions: R.L. conducted the research; H.O. and A.H. guided the modeling and provided species data input; L.T., N.I. and R.L. guided the indicators; T.M., R.F. and K.T. provided advice on the paper. All authors have read and agreed to the published version of the manuscript.

Funding: This study was partly funded by the Environment Research and Technology Development Fund (JPMEERF20202002, JPMEERF23S12108) of the Environmental Restoration and Conservation Agency of Japan, and the Ministry of Environment of Japan, JST SPRING (Grant Number JPMJSP2118, JPMEERF20241001) and JSPS KAKENHI (Grant Number JP21H04944).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data and code will be provided upon request.

Acknowledgments: In this research work we used the supercomputer of AFFRIT, MAFF, Japan.

Conflicts of Interest: K.T. is affiliated to MS&AD InterRisk Research & Consulting, Inc. The rest of the authors declare no conflicts of interest.

References

1. Jaureguiberry, P.; Titeux, N.; Wiemers, M.; Bowler, D.E.; Coscieme, L.; Golden, A.S.; Guerra, C.A.; Jacob, U.; Takahashi, Y.; Settele, J.; et al. The Direct Drivers of Recent Global Anthropogenic Biodiversity Loss. *Sci. Adv.* **2022**, *8*, eabm9982. [CrossRef] [PubMed]
2. De Vos, J.M.; Joppa, L.N.; Gittleman, J.L.; Stephens, P.R.; Pimm, S.L.; Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; et al. Where to Put Things? Spatial Land Management to Sustain Biodiversity and Economic Returns. *Int. J. Life Cycle Assess.* **2017**, *23*, 1505–1524. [CrossRef]
3. Marques, A.; Martins, I.S.; Kastner, T.; Plutzar, C.; Theurl, M.C.; Eisenmenger, N.; Huijbregts, M.A.J.; Wood, R.; Stadler, K.; Bruckner, M.; et al. Increasing Impacts of Land Use on Biodiversity and Carbon Sequestration Driven by Population and Economic Growth. *Nat. Ecol. Evol.* **2019**, *3*, 628–637. [CrossRef] [PubMed]
4. Moran, D.; Kanemoto, K. Identifying Species Threat Hotspots from Global Supply Chains. *Nat. Ecol. Evol.* **2017**, *1*, 0023. [CrossRef] [PubMed]
5. IUCN Background & History. Available online: https://www.iucnredlist.org/about/background-history (accessed on 5 March 2024).
6. Richardson, K.; Steffen, W.; Lucht, W.; Bendtsen, J.; Cornell, S.E.; Donges, J.F.; Drüke, M.; Fetzer, I.; Bala, G.; von Bloh, W.; et al. Earth beyond Six of Nine Planetary Boundaries. *Sci. Adv.* **2023**, *9*, eadh2458. [CrossRef] [PubMed]
7. Chaudhary, A.; Mooers, A. Terrestrial Vertebrate Biodiversity Loss under Future Global Land Use Change Scenarios. *Sustainability* **2018**, *10*, 2764. [CrossRef]
8. Pimm, S.; Raven, P.; Peterson, A.; Şekercioğlu, Ç.H.; Ehrlich, P.R. Human Impacts on the Rates of Recent, Present, and Future Bird Extinctions. *Proc. Natl. Acad. Sci. USA* **2006**, *103*, 10941–10946. [CrossRef] [PubMed]
9. Lamkin, M.; Miller, A.I. On the Challenge of Comparing Contemporary and Deep-Time Biological-Extinction Rates. *Bioscience* **2016**, *66*, 785–789. [CrossRef]
10. De Vos, J.M.; Joppa, L.N.; Gittleman, J.L.; Stephens, P.R.; Pimm, S.L. Estimating the Normal Background Rate of Species Extinction. *Conserv. Biol.* **2015**, *29*, 452–462. [CrossRef] [PubMed]
11. Verones, F.; Bare, J.; Bulle, C.; Frischknecht, R.; Hauschild, M.; Hellweg, S.; Henderson, A.; Jolliet, O.; Laurent, A.; Liao, X.; et al. LCIA Framework and Cross-Cutting Issues Guidance within the UNEP-SETAC Life Cycle Initiative. *J. Clean. Prod.* **2017**, *161*, 957–967. [CrossRef]
12. de Baan, L.; Alkemade, R.; Koellner, T. Land Use Impacts on Biodiversity in LCA: A Global Approach. *Int. J. Life Cycle Assess.* **2013**, *18*, 1216–1230. [CrossRef]
13. Tendall, D.M.; Hellweg, S.; Pfister, S.; Huijbregts, M.A.J.; Gaillard, G. Impacts of River Water Consumption on Aquatic Biodiversity in Life Cycle Assessment—A Proposed Method, and a Case Study for Europe. *Environ. Sci. Technol.* **2014**, *48*, 3236–3244. [CrossRef] [PubMed]
14. Verones, F.; Kuipers, K.; Núñez, M.; Rosa, F.; Scherer, L.; Marques, A.; Michelsen, O.; Barbarossa, V.; Jaffe, B.; Pfister, S.; et al. Global Extinction Probabilities of Terrestrial, Freshwater, and Marine Species Groups for Use in Life Cycle Assessment. *Ecol. Indic.* **2022**, *142*, 109204. [CrossRef]
15. Jolliet, O.; Antón, A.; Boulay, A.M.; Cherubini, F.; Fantke, P.; Levasseur, A.; McKone, T.E.; Michelsen, O.; Milà i Canals, L.; Motoshita, M.; et al. Global Guidance on Environmental Life Cycle Impact Assessment Indicators: Impacts of Climate Change, Fine Particulate Matter Formation, Water Consumption and Land Use. *Int. J. Life Cycle Assess.* **2018**, *23*, 2189–2207. [CrossRef]
16. Schmidt, J.H. Development of LCIA Characterisation Factors for Land Use Impacts on Biodiversity. *J. Clean. Prod.* **2008**, *16*, 1929–1942. [CrossRef]
17. Veach, V.; Di Minin, E.; Pouzols, F.M.; Moilanen, A. Species Richness as Criterion for Global Conservation Area Placement Leads to Large Losses in Coverage of Biodiversity. *Divers. Distrib.* **2017**, *23*, 715–726. [CrossRef]
18. Damiani, M.; Sinkko, T.; Caldeira, C.; Tosches, D.; Robuchon, M.; Sala, S. Critical Review of Methods and Models for Biodiversity Impact Assessment and Their Applicability in the LCA Context. *Environ. Impact Assess. Rev.* **2023**, *101*, 107134. [CrossRef]
19. Kuipers, K.J.J.; Hellweg, S.; Verones, F. Potential Consequences of Regional Species Loss for Global Species Richness: A Quantitative Approach for Estimating Global Extinction Probabilities. *Environ. Sci. Technol.* **2019**, *53*, 4728–4738. [CrossRef] [PubMed]
20. Yamaguchi, K.; Ii, R.; Itsubo, N. Ecosystem Damage Assessment of Land Transformation Using Species Loss. *Int. J. Life Cycle Assess.* **2018**, *23*, 2327–2338. [CrossRef]
21. Tang, L.; Ohashi, H.; Matsui, T.; Hirata, A.; Tanaka, N.; Itsubo, N. Characterization Factor Estimation Based on a Species-Specific Extinction Risk Approach for Determining CO2 Emission Impact on Terrestrial Biodiversity. *Ecol. Indic.* **2023**, *154*, 110556. [CrossRef]
22. May, R.; Jackson, C.R.; Middel, H.; Stokke, B.G.; Verones, F. Life-Cycle Impacts of Wind Energy Development on Bird Diversity in Norway. *Environ. Impact Assess. Rev.* **2021**, *90*, 106635. [CrossRef]

23. Laranjeiro, T.; May, R.; Verones, F. Impacts of Onshore Wind Energy Production on Birds and Bats: Recommendations for Future Life Cycle Impact Assessment Developments. *Int. J. Life Cycle Assess.* **2018**, *23*, 2007–2023. [CrossRef]
24. Cosme, N.; Jones, M.C.; Cheung, W.W.L.; Larsen, H.F. Spatial Differentiation of Marine Eutrophication Damage Indicators Based on Species Density. *Ecol. Indic.* **2017**, *73*, 676–685. [CrossRef]
25. Booth, T.H.; Nix, H.A.; Busby, J.R.; Hutchinson, M.F. BIOCLIM: The first species distribution modelling package, its early applications and relevance to most current MAXENT studies. *Divers. Distrib.* **2014**, *20*, 1–9. [CrossRef]
26. Urban, M.C. Accelerating extinction risk from climate change. *Science* **2015**, *348*, 571–573. [CrossRef]
27. Inaba, A.; Itsubo, N. Preface. *Int. J. Life Cycle Assess.* **2018**, *23*, 2271–2275. [CrossRef]
28. Hijmans, R.J.; Phillips, S.; Leathwick, J.; Elith, J.; Dismo: Species Distribution Modeling. R Package Version 1.3-14. 2023. Available online: https://CRAN.R-project.org/package=dismo (accessed on 18 August 2023).
29. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2021; Available online: https://www.R-project.org/ (accessed on 18 August 2023).
30. Hurtt, G.C.; Chini, L.; Sahajpal, R.; Frolking, S.; Bodirsky, B.L.; Calvin, K.; Doelman, J.C.; Fisk, J.; Fujimori, S.; Klein Goldewijk, K.; et al. Harmonization of Global Land Use Change and Management for the Period 850–2100 (LUH2) for CMIP6. *Geosci. Model Dev.* **2020**, *13*, 5425–5464. [CrossRef]
31. Stehfest, E.; van Vuuren, D.; Bouwman, L.; Kram, T. *Integrated Assessment of Global Environmental Change with IMAGE 3.0: Model Description and Policy Applications*; Netherlands Environmental Assessment Agency (PBL): Hague, The Netherlands, 2014.
32. Ohashi, H.; Hasegawa, T.; Hirata, A.; Fujimori, S.; Takahashi, K.; Tsuyama, I.; Nakao, K.; Kominami, Y.; Tanaka, N.; Hijioka, Y.; et al. Biodiversity Can Benefit from Climate Stabilization despite Adverse Side Effects of Land-Based Mitigation. *Nat. Commun.* **2019**, *10*, 5240. [CrossRef]
33. Van Vuuren, D.P.; Stehfest, E.; Gernaat, D.E.; Doelman, J.C.; van den Berg, M.; Harmsen, M.; de Boer, H.S.; Bouwman, L.F.; Diaoglou, V.; Edelenbosch, O.Y. Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. *Glob. Environ. Chang.* **2017**, *42*, 237–250. [CrossRef]
34. van Vuuren, D.P.; Edmonds, J.; Thomson, A.; Riahi, K.; Kainuma, M.; Matsui, T.; Hurtt, G.C.; Lamarque, J.-F.; Meinshausen, M.; Smith, S.; et al. The Representative Concentration Pathways: An overview. *Clim. Chang.* **2011**, *109*, 5–31. [CrossRef]
35. Doelman, J.C.; Stehfest, E.; Tabeau, A.; van Meijl, H.; Lassaletta, L.; Gernaat, D.E.H.J.; Hermans, K.; Harmsen, M.; Diaoglou, V.; Biemans, H.; et al. Exploring SSP land-use dynamics using the IMAGE model: Regional and gridded scenarios of land-use change and land-based climate change mitigation. *Glob. Environ. Chang.* **2018**, *48*, 119–135. [CrossRef]
36. GBIF. GBIF Occurrence Download. 2020. Available online: https://www.gbif.org/ (accessed on 25 August 2020).
37. Fick, S.E.; Hijmans, R.J. WorldClim 2: New 1km spatial resolution climate surfaces for global land areas. *Int. J. Climatol.* **2017**, *37*, 4302–4315. [CrossRef]
38. IPBES. *Global Assessment Report on Biodiversity Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity Ecosystem Services*; Brondizio, E.S., Settele, J., Díaz, S., Ngo, H.T., Eds.; IPBES Secretariat: Bonn, Germany, 2019; 1148p. [CrossRef]
39. Jetz, W.; Wilcove, D.S.; Dobson, A.P. Projected impacts of climate and land-use change on the global diversity of birds. *PLoS Biol.* **2007**, *5*, e157. [CrossRef] [PubMed]
40. Myers, N.; Mittermeier, R.A.; Mittermeier, C.G.; Da Fonseca, G.A.; Kent, J. Biodiversity hotspots for conservation priorities. *Nature* **2000**, *403*, 853–858. [CrossRef]
41. Mair, L.; Bennun, L.A.; Brooks, T.M.; Butchart, S.H.; Bolam, F.C.; Burgess, N.D.; Ekstrom, J.M.; Milner-Gulland, E.J.; Hoffmann, M.; Ma, K.; et al. A metric for spatially explicit contributions to science-based species targets. *Nat. Ecol. Evol.* **2021**, *5*, 836–844. [CrossRef]
42. Pimm, S.L.; Russell, G.J.; Gittleman, J.L.; Brooks, T.M. The future of biodiversity. *Science* **1995**, *269*, 347–350. [CrossRef] [PubMed]
43. Loehle, C.; Eschenbach, W. Historical bird and terrestrial mammal extinction rates and causes. *Divers. Distrib.* **2012**, *18*, 84–91. [CrossRef]
44. Millennium Ecosystem Assessment (MEA). *Ecosystems and Human Well-Being*; Island Press: Washington, DC, USA, 2005; Volume 5, p. 563.
45. Rounsevell, M.D.A.; Harfoot, M.; Harrison, P.A.; Newbold, T.; Gregory, R.D.; Mace, G.M. A Biodiversity Target Based on Species Extinctions. *Science* **2020**, *368*, 1193–1195. [CrossRef]
46. Jiang, L.; O'Neill, B.C. Global Urbanization Projections for the Shared Socioeconomic Pathways. *Glob. Environ. Chang.* **2017**, *42*, 193–199. [CrossRef]
47. He, W.; Li, X.; Zhou, Y.; Shi, Z.; Yu, G.; Hu, T.; Wang, Y.; Huang, J.; Bai, T.; Sun, Z.; et al. Global Urban Fractional Changes at a 1 Km Resolution throughout 2100 under Eight Scenarios of Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). *Earth Syst. Sci. Data* **2023**, *15*, 3623–3639. [CrossRef]
48. Long, A.J.; Crosby, M.J.; Stattersfield, A.J. Towards a global map of biodiversity: Patterns in the distribution of restricted-range birds. *Glob. Ecol. Biogeogr. Lett.* **1996**, *5*, 281–304. [CrossRef]
49. Isacch, J.P.; Maceira, N.O.; Bo, M.S.; Demaría, M.R.; Peluc, S. Bird-habitat relationship in semi-arid natural grasslands and exotic pastures in the west pampas of Argentina. *J. Arid Environ.* **2005**, *62*, 267–283. [CrossRef]
50. Thuiller, W.; Albert, C.; Araújo, M.B.; Berry, P.M.; Cabeza, M.; Guisan, A.; Hickler, T.; Midgley, G.F.; Paterson, J.; Schurr, F.M.; et al. Predicting Global Change Impacts on Plant Species' Distributions: Future Challenges. *Perspect. Plant Ecol. Evol. Syst.* **2008**, *9*, 137–152. [CrossRef]

51. Tang, L.; Higa, M.; Tanaka, N.; Itsubo, N. Assessment of global warming impact on biodiversity using the extinction risk index in LCIA: A case study of Japanese plant species. *Int. J. Life Cycle Assess.* **2018**, *23*, 314–323. [CrossRef]
52. Fernández-Palacios, J.M.; Kreft, H.; Irl, S.D.H.; Norder, S.; Ah-Peng, C.; Borges, P.A.V.; Burns, K.C.; de Nascimento, L.; Meyer, J.-Y.; Montes, E.; et al. Scientists' warning—The outstanding biodiversity of islands is in peril, Global Ecology and Conservation. *Glob. Ecol. Conserv.* **2021**, *31*, e01847. [CrossRef] [PubMed]
53. Côté, S.; Beauregard, R.; Margni, M.; Bélanger, L. Using naturalness for assessing the impact of forestry and protection on the quality of ecosystems in life cycle assessment. *Sustainability* **2021**, *13*, 8859. [CrossRef]
54. Curran, M.; de Baan, L.; De Schryver, A.M.; Van Zelm, R.; Hellweg, S.; Koellner, T.; Sonnemann, G.; Huijbregts, M.A. Toward meaningful end points of biodiversity in life cycle assessment. *Environ. Sci. Technol.* **2011**, *45*, 70–79. [CrossRef] [PubMed]
55. Woods, J.S.; Damiani, M.; Fantke, P.; Henderson, A.D.; Johnston, J.M.; Bare, J.; Sala, S.; de Souza, D.M.; Pfister, S.; Posthuma, L.; et al. Ecosystem quality in LCIA: Status quo, harmonization, and suggestions for the way forward. *Int. J. Life Cycle Assess.* **2018**, *23*, 1995–2006. [CrossRef] [PubMed]
56. Hua, F.; Bruijnzeel, L.A.; Meli, P.; Martin, P.A.; Zhang, J.; Nakagawa, S.; Miao, X.; Wang, W.; McEvoy, C.; Peña-Arancibia, J.L.; et al. The biodiversity and ecosystem service contributions and trade-offs of forest restoration approaches. *Science* **2022**, *376*, 839–844. [CrossRef]
57. Barnosky, A.D.; Matzke, N.; Tomiya, S.; Wogan, G.O.; Swartz, B.; Quental, T.B.; Marshall, C.; McGuire, J.L.; Lindsey, E.L.; Maguire, K.C.; et al. Has the Earth's sixth mass extinction already arrived? *Nature* **2011**, *471*, 51–57. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.