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Habitat Suitability of European Land Systems for Terrestrial Vertebrates

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ABSTRACT

Motivation: Accurate estimates of species distributions are crucial for biogeography, spatial conservation, and for assessing the impacts of human activities on species. However, existing approaches to estimate species distributions have typically neglected the influence of land use intensity, potentially overlooking the negative impacts of high-intensity land uses on biodiversity. Here, we build a dataset documenting the habitat suitability of European land systems for terrestrial vertebrate species, based on a novel land system map of Europe that factors in land use intensity. Our database offers refined and up-to-date information on terrestrial vertebrate distributions in Europe by explicitly considering land use intensity.

Main Types of Variables Contained: We created a table defining the suitability of land use classes as habitats for each species. We then built Area of Habitat (AOH) maps for each species by filtering out unsuitable habitat from the latest available estimates of species ranges. AOH maps were then compared with occurrence records from the Global Biodiversity Information Facility (GBIF). Processed datasets and R scripts are publicly available online, facilitating the use of our approach to refine expert-based distributions for other taxa, land system classifications and regions worldwide.

Spatial Location and Grain: The AOH maps cover the spatial extent of the European Union (EU) with the United Kingdom, Norway, Switzerland, and the Western Balkans. The AOH maps are at a 1 km^2 resolution.

Time Period and Grain: The dataset uses information published during the last 10 years.

Major Taxa and Level of Measurement: Habitat suitability was documented for 1155 terrestrial vertebrate species known to occur in Europe: 279 mammals, 520 birds, 251 reptiles and 104 amphibians.

Software Format: We provide the habitat suitability table in a comma-separated values (csv) format. The AOH maps are available as raster files. R scripts are publicly accessible on GitHub.

1 | Introduction

Accurately estimating species distributions is central to biogeography and to conservation planning, but it presents significant challenges. Expert-based range maps alone tend to overestimate the biodiversity present in a given location, while observation records are limited by sampling effort and are highly spatially and taxonomically biased (Nori et al. 2023). The concept of Area of Habitat (AOH) was developed as a solution to this conundrum and is defined as suitable habitat within the geographic range of a species (Lumbierres et al. 2022). AOH maps are essential for biogeography and to explore the consequences of land use change scenarios for species habitat-suitable ranges. For example, Powers and Jetz (2019) used AOH to quantify the impacts of a set of land use scenarios on global distributions of 19,400 species of mammals, birds and amphibians, and highlighted areas in need of conservation planning. AOH is particularly relevant for conservation planning, as it documents the suitable habitats that are known to be required for the survival of a species, and can be mapped at a large geographical extent and high resolution.

So far, the habitat suitability information underlying AOH maps has been based on land cover, and land use intensity level has generally been overlooked (Dou et al. 2021). Yet, it is well established that highly intensive land uses have more negative impacts on biodiversity than low-intensity land uses (Etard et al. 2021; Newbold et al. 2015; Beckmann et al. 2019). The same land cover class can have very different impacts on biodiversity depending on the land use intensity level. For example, intensively managed forests are ecologically very different from primary and old-growth forests, and intensive croplands (with large fields, no hedgerows and high pesticides input) have drastically higher impacts on biodiversity compared with extensive agriculture (Botella et al. 2024; O'Connor et al. 2024). Therefore, land use intensity needs to be integrated in AOH maps, particularly in Europe where intensive land use is widespread (Dou et al. 2021). So far, progress has been limited due to the lack of a habitat classification that includes land use intensity. Fortunately, a novel land system map for Europe (Dou et al. 2021) has recently addressed this gap by including land use intensity levels (low, medium and high) for each land system (e.g., settlements, forests, grasslands and croplands).

Here, we harness the novel land system classification for Europe incorporating land use intensity (Dou et al. 2021) to build AOH maps for terrestrial vertebrate species. We first built a table documenting the habitat suitability of each land system for each species. We then filtered the most recent estimates of species geographic ranges with the European land system map. Finally, we validated the database by comparing the AOH maps with Global Biodiversity Information Facility (GBIF) occurrence records. Our database improves on previous estimates of terrestrial vertebrate distributions in Europe by including land use intensity and combines the latest sources of data available for these species.

2 | Methods

2.1 | Creating the Habitat Suitability Table for European Land Systems

Land cover characterises the physical and biological cover on the land, including different vegetation types and water bodies. Land use (in the context of Dou et al. 2021) instead refers to the human use and the intensity of management of the land and its resources, such as for agricultural activities, urban development and forestry. A land system represents the integration of land cover and land use. We identified suitable habitat types within the European land systems (Dou et al. 2021), which include 8 land systems subdivided in 26 land use intensity classes, by combining different expert-based datasets on species habitat requirements and sensitivity to threats (Tables S1 and S2). We proceeded in two stages.

First, we determined the suitability of the land cover types of the different land use classes. We used existing datasets of species habitats preferences and established a crosswalk between these habitat classifications, and the European land systems classification:

1. We used the habitat preference table built by Maiorano et al. (2013), where the habitat suitability for each species and each land cover class was based on the land cover classification from GlobCover V2.2, which included 46 different land cover classes (Maiorano et al. 2013; Bicheron et al. 2008). We built a crosswalk between the European land systems classification (Dou et al. 2021) and the GlobCover classes, in terms of land cover (Table S1). The habitat suitability table developed in Maiorano et al. (2013) distinguishes three levels of habitat suitability: optimal or typical habitat (score of 2), occasional or secondary habitat (score of 1) and unsuitable habitat (score of 0). Using the crosswalk, we created a habitat suitability matrix for the land cover types of European land systems classes, keeping the same suitability scores as determined by Maiorano et al. (2013).

2. We retrieved known species habitat preferences from the European IUCN Red List dataset (European Environment Agency 2018). We searched for keywords in the habitats column that were related to land cover classes (Table S2). Classes that were documented as suitable were assigned a suitability score of 2; unsuitable were assigned a score of 0.

3. We then extracted species habitat preferences from the global IUCN database. We retained 39 habitat classes that are relevant for the terrestrial European ecosystem (excluding subantarctic, subtropical, tropical, savannah and marine habitats). We then performed a crosswalk between the IUCN habitat classification scheme, and the land system classification (Dou et al. 2021) in terms of land cover. Finally, we retained only the habitats that were noted to be suitable (i.e., we excluded marginal and unknown). With this information, we created a third habitat suitability matrix for the land cover types of the European land systems classes. Classes that were documented as suitable were assigned a suitability score of 2; unsuitable were assigned a suitability score of 0.

We combined the three matrices above by averaging their habitat suitability scores, and rounding to the closest integer. The resulting matrix documented the suitability of land use classes based on land cover only and did not distinguish between different intensity levels of land use classes. This is because land cover types are the primary driver of the suitability of land systems, which we then refined based on the known sensitivity of species to different management intensity levels in a given land system.

Second, we determined the suitability of different levels of intensity within each land system.

1. We extracted the data on species habitat requirements detailed in the European red list dataset. We searched for keywords in the habitats column that were related to low-intensity levels in a land system (Table S2). We synthesised this information in the form of a binary matrix, where elements were equal to 1 when the low-intensity level of a given land system is known to be preferred by the species. We refined the habitat suitability matrix with this information: for species known to prefer low-intensity levels in a given land system, we subtracted 1 to the suitability scores of the medium intensity level and we subtracted 2 from the habitat suitability score of the high-intensity level. Consequently, if the land cover is optimal habitat, but the species is known to prefer low intensity, then medium intensity is assigned a score of 1 and high intensity a score of 0; if the land cover is secondary habitat and the species is known to prefer low intensity, both medium and high intensity are unsuitable.
2. We used data on threats to species detailed in the European red list dataset (European Environment Agency 2018). We searched for unsuitable land use classes in the form of character strings in the threats column in the European red list dataset (O'Connor et al. 2024). If a species was known to be threatened by intensity of management (e.g., 'agricultural intensification'), then the corresponding intensive land use classes were assumed to be unsuitable (Table S2). We thus refined the habitat suitability scores with this information: when the land use intensity of the land system was listed as a threat to species, we subtracted 2 to the habitat suitability score of high-intensity levels in the land system, and we subtracted 1 to the habitat suitability score of medium intensity levels in the same land system. This implies that, if the land cover type is an optimal habitat but the species is threatened by intensive management, then the corresponding medium intensity is assigned a score of 1 and high intensity a score of 0. If the land cover type is a secondary habitat and the species is threatened by intensive management, both medium intensity and high intensity are assumed unsuitable. Negative elements of the resulting matrix were set to zero.

Another important aspect of the European land systems dataset built by Dou et al. (2021) is the inclusion of mosaic systems, which are 1 km^2 grid cells that are not dominated by a single land cover class but instead are composed of several land use–land cover classes, each covering at least 30% and up to 70% of the grid cell. We assumed that a 1 km^2 grid cell made of a mosaic system was suitable if at least one of the land use–land cover classes within the mosaic was a suitable habitat for the species (e.g., a forest/grassland mosaic was considered suitable for both grassland- and forest-dwelling species).

The final habitat suitability table thus documents the habitat suitability scores of each land use class for each species: elements are equal to 0 if the land use class is unsuitable habitat for the species; 1 if it is occasional habitat; and 2 if it is optimal habitat. The table of habitat suitability for terrestrial vertebrates in Europe is provided in csv format, where habitats are in columns, and species are in rows, is openly accessible online (O'Connor 2023).

2.2 | Creating AOH Maps for European Vertebrates

We collected species extent of occurrence (EOO) data for mammals, amphibians, reptiles (IUCN Red List 2022) and birds (Birdlife 2020), retaining the 'extant' and 'possibly extant' ranges for resident and breeding birds. 1 km^2 species distribution maps were generated by filtering EOO data with habitat preferences based on the land system map, extracted from Dou et al. (2021), and which was also at a 1 km^2 resolution (Figure 1). In the resulting AOH maps, grid cell values equalled 1 if within the species EOO and contained suitable habitat; otherwise, the value was 0.

3 | Comparison with GBIF Observation Records

We extracted GBIF observations that had a spatial accuracy (or precision) value of maximum 1000 m, to match the resolution of the AOH maps. We then computed the percentage of observations that fell within a grid cell where the species was estimated to be present in the AOH maps, and compared it with a previous version of the AOH without land use intensity (Figure 2).

Overall, there was high overlap between the presences estimated through the 1 km^2 AOH maps and GBIF observations for all taxonomic groups. To evaluate whether including land use intensity improved the AOH maps, we also compared this with the previous version of the AOH maps at the same resolution (1 km^2), which did not account for land use intensity, for European terrestrial vertebrates (Maiorano et al. 2013) (Figure 2). A Welch's two-sample t-test revealed a significantly higher agreement with GBIF observations when the AOH maps included land use intensity, compared with a previous version of AOH maps that only considered land cover, for all species. The mean percentage overlap between GBIF and AOH maps was significantly lower in the AOH with only land cover (46.3%) compared with the AOH with both land cover and land use intensity (72.2%) ($p < 2e{-16}$, 95% CI [−28.5, −23.3]). This result was consistent for all taxonomic classes (Figure 2 and Appendix 2).

It should be noted that for 104 species, more than half of GBIF observations fell outside of the AOH constructed here (Figure 2 and Table S3). There are three limitations inherent to the AOH maps developed here, which may explain this. First, our AOH maps did not include caves or subterranean habitats. Hence, some species with mismatches between GBIF and AOH are

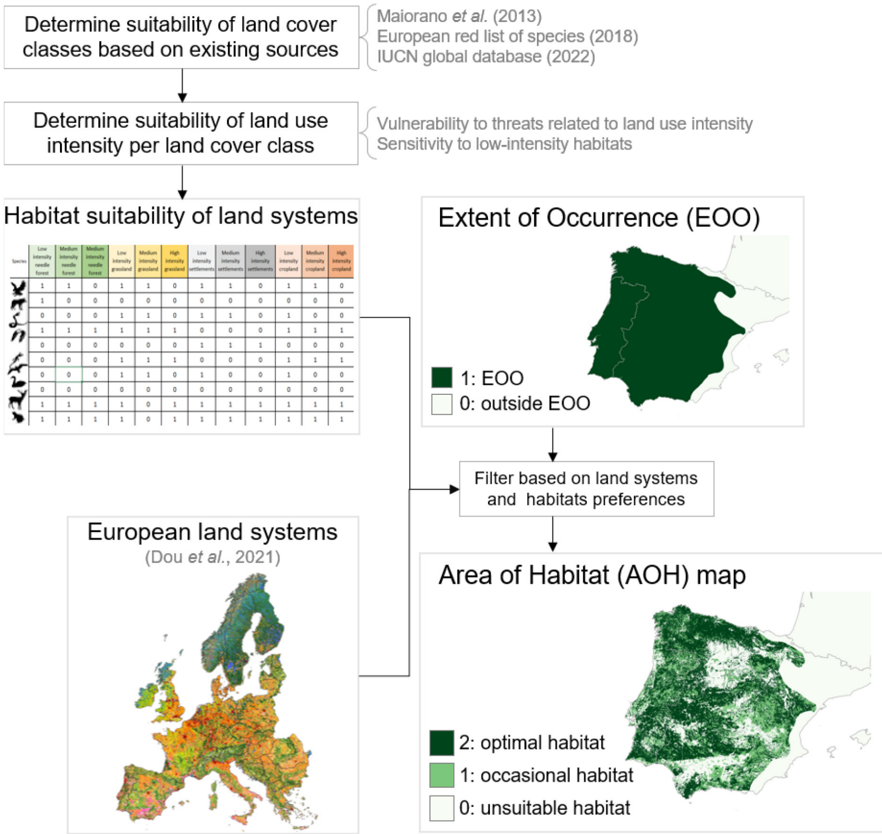

FIGURE 1 | Workflow to create AOH maps for terrestrial vertebrates in Europe. The species shown as an example is the Iberian painted frog (*Discoglossus galganoi*). It is found in Portugal and Spain (as shown on the maps) and lives in a range of habitats (open areas, meadows, thickets, woodland verges, swamps, traditional farmland) (European Environment Agency 2018).

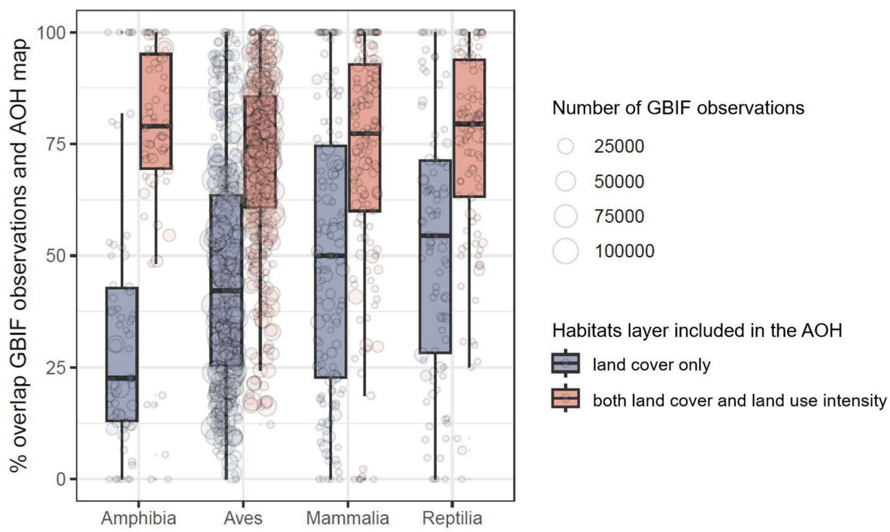

FIGURE 2 | Congruence between GBIF observations and presences estimated in the AOH maps, with and without land use intensity. Box plots for each taxonomic class represent the quartiles of the percentage of GBIF observations for each species that fall into a grid cell where the species is estimated to be present according to the AOH. The colour of the boxes compare the AOH with (red) and without (blue) land use intensity in addition to land cover. Each dot represents a species, the size of which reflects the number of GBIF observations for each species.

cave-dwelling or subterranean species (e.g., *Chiroptera* spp.; *Proteus anguinus*). Second, we did not account for distance to water requirements for species due to a lack of suitable data on wetlands and water availability (see Appendix 1). Third, forest structure (open/dense) and mixed forests were not considered in the land system classification. This may explain why AOH maps for some woodpeckers and for *Rana dalmatina* (which specifically prefers mixed forests) have a low overlap with GBIF observations. Therefore, the AOH maps in our dataset may poorly describe the actual distributions of some species, although they still improve on previous versions of AOH (see Appendix 2). Another possible reason for the mismatches between GBIF observations and the AOH maps for some species is inherent to occurrence records datasets. While we used records of GBIF observations as a means to evaluate the resulting AOH, it should be noted that there are some inherent limitations to GBIF (Troudet et al. 2017). One of the challenges associated with GBIF data is spatial biases, due to spatial variations in human density and accessibility (Hughes et al. 2021; Bowler et al. 2022). There are also some taxonomic biases within GBIF: charismatic species that are diurnal and large-bodied are more likely to be observed. However, in the case of the four classes considered here (Aves, Reptilia, Amphibia and Mammalia), these four classes are overrepresented in terms of occurrences compared with other classes that are underrepresented (e.g., insects), and thus, we assume biases to be homogenous across the four vertebrate classes (Troudet et al. 2017). Another challenge of GBIF observations is that individuals may be observed outside of the habitats that they depend on. For example, birds can be observed flying outside their suitable habitats (Table S3) as they may venture far to find food. Many of the birds with GBIF observations outside of their estimated AOH are migratory species and thus could have been observed outside of their suitable breeding range habitats while migrating. Other factors may also be at play: erroneous identification of the species on GBIF due to confusion with similar species (Table S3). Finally, some of the species with a poor agreement with GBIF are partly domesticated or used by humans, and could be observed outside of suitable habitats due to human uses (e.g., hunting, falconry and aviculturists).

4 | Conclusions

We showed that including land use intensity leads to a significant improvement compared with previous versions of the AOH that only included land cover. The habitat suitability table and the AOH maps can be useful for applications in biogeography and in conservation, such as for identifying and prioritising conservation efforts. Overall, we conclude that the AOH maps developed here accurately reflect the current distribution and habitat preferences for the majority of birds, mammals and reptiles, and amphibians in Europe.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The dataset is openly available on Zenodo at https://doi.org/10.5281/zenodo.8407593. The script to produce the data is publicly available on the GitHub repository maintained by the author: https://github.com/lmjoconnor/LandUse_Habitats_EU_Tetrapods.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.