Distribution of Amphibians and Reptiles in Agricultural Landscape Across Europe

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Abstract

Context

To understand the herpetofauna decline in agricultural landscapes with herpetofauna presence and evaluating the species-specific and species richness patterns in response to their features.

Objectives

This work aimed to explore how different crop categories (i.e. agroforestry, irrigated, dry and woody crops and pastures), crop extent and heterogeneity affect herpetofauna distribution and diversity patterns at two different spatial resolutions, UTM 50km^2 and UTM 10km^2.

Methods

We documented the occurrence of European amphibians and reptiles in crops and quantify crop extent and heterogeneity in 50km^2 and 10km^2 grid cells.

Results

We recorded 72 amphibian and 142 reptile species at UTM 50 km^2 and UTM 10 km^2 grids. The geographic location of peaks and troughs of crop extent and of species richness at UTM 50km^2 did not coincide with those at UTM 10km^2. Our results showed that amphibian and reptile species presence and richness are influenced by crop category, extent and heterogeneity and that spatial patterns were scale dependent. Species richness of both amphibians and reptiles was generally negatively correlated with crop extent but was enhanced by crop heterogeneity.

Conclusions

Our results provide useful information for future risk assessment studies of herpetofauna, such as to identify candidates (i.e. “representative species”) for pesticide effect field studies or for studies of risk refinement though radio-tracking.

Introduction

Herpetofauna (amphibians and reptiles) is the most threatened group of vertebrates in the world (Gibbons et al. 2000). Pollution, often pesticide-related, is recognised as a major driver leading to population declines in both amphibians and reptiles (Mann et al. 2009; Todd et al. 2010). This is particularly evident in agricultural areas, that have become one of the largest terrestrial biomes on Earth, occupying more than 40% of the land surface (Foley et al. 2005). For example, croplands receive three quarters of all pesticides which are employed in agricultural production. Agricultural areas include essential habitats for amphibians and reptiles. Thus, pesticide exposure could play a key role in the observed amphibian and reptile declines in agricultural landscapes (Todd et al. 2010; Mingo et al. 2016;

Arntzen et al. 2017). Moreover, both amphibians and reptiles are also exposed to pesticides in habitats adjacent to agricultural landscapes. For example, amphibians are exposed to pesticide during migrations to and from spawning waters (Fryday and Thompson 2012). Pesticides can be transported as well via spray drift or run-off to water bodies used by amphibians for breeding or to sites with habitats suitable for reptiles (Ockleford et al. 2018; Adams et al. 2021). Yet, neither amphibians nor reptiles have been included in regulations concerning the environmental risk assessment (ERA) of pesticides and the available data for their risk evaluation is limited (Brühl et al. 2011).

To fill this knowledge gap and provide scientifically sound and robust information for including amphibians and reptiles within the ERA, it is necessary to gather solid data on herpetofauna occurrence in agricultural landscapes and on amphibian and reptile species-specific responses to their features (i.e. crop type and crop diversity). Moreover, the substitution of natural areas by croplands and the agriculture intensification (Tscharntke et al. 2012) affects species richness (Scales and Marsden 2008) and cause shifts in species composition (Newbold et al. 2016). It is acknowledged that less is known about the response of amphibian and reptile diversity to land use change than other groups, i.e. mammals and birds (Palacios et al. 2013; Newbold et al. 2014). Thus, it becomes evident that documenting how agricultural systems impact amphibian and reptile diversity patterns should receive priority.

Finally, the spatial pattern of biodiversity is scale dependent (Levin 1992). The resolution and the overall size of the study area can affect the observed biodiversity spatial pattern (Rahbek 2005). Few studies have investigated the agro-biodiversity at a continental scale (Billeter et al. 2008; Wilson et al. 2020; Mupepele et al. 2021). Small-scale studies may lead to suboptimal management of the agricultural landscape, if applied more generally (Billeter et al. 2008; Ekroos et al. 2016). In Europe, agricultural landscapes host a wide range of land use types, different sizes and shapes, and semi-natural elements that vary in abundance and pattern. These agricultural landscapes, but in particular those with a fine-grained landscape mosaics and low-intensity forms of agricultural production were formerly characterised by high biodiversity (Edwards et al. 1999). However, in the last decade, the biodiversity in agricultural landscapes has markedly decreased with the decline in semi-natural elements and the change of production systems towards a predominantly intensive agricultural mode (Krebs et al. 1999; Robinson and Sutherland 2002). Thus, updated scientific knowledge on land use change and species diversity in agricultural landscapes across Europe, especially for endangered species such as amphibians and reptiles, is urgently needed.

In this study we document the distribution of amphibian and reptile species in agricultural landscapes across Europe to: (i) investigate their occurrence in crops, (ii) quantify the proportion of crops extent in 50km^2 (UTM 50km × 50km) and in 10km^2 (UTM 10km × 10km) grid cells, and (iii) explore how different crop categories affect herpetofauna distribution and diversity patterns at two different landscape resolutions, i.e. 50km^2 and 10km^2.

Material And Methods

Data sources

We compiled distributional data for amphibian species and reptile species native to Europe from the Atlas of European amphibians and reptiles (Sillero et al. 2014), and species occurrence data sources including Global Information Facility (GBIF: www.gbif.org), iNaturalist (inat: www.inaturalist.org), and VertNet (vertnet.org). We homogenised the databases by deleting all other information except species names, coordinates, and data source. We used the standard geographic coordinate system WGS84. We cleaned the data by removing records with coordinates accuracy below 100 m and duplicated records. To avoid mismatches due to differences in the species nomenclature between the databases we followed the taxonomy from Sillero et al. (2014).

We used the European CORINE Land Cover 2018 (version v.2020_20u1) from the European Environment Agency (EEA, 2018) as base land-cover map for Europa, which covers 39 European countries. CORINE land-cover data consist of 44 land-cover types in raster format, with a spatial resolution of 100 m. From the 44 CORINE land-cover types we selected eleven land-cover types and reclassified them in five crop categories, as follows: irrigated crops (codes 212, 213 and 242), dry crops (codes 211 and 241), woody crops (codes 221, 222 and 223), pastures (code 231), and agroforestry crops (243 and 244). Based on crop category and proportion of each crop category within 50km × 50km (UTM 50 km^2) and 10km × 10km (UTM 10 km^2) grid cells, we calculated a Shannon index of diversity using the vegan package in R (Oksanen et al. 2020) as an indication of crop heterogeneity.

Data analysis

We calculated the proportion of each of the five crop categories within UTM 50 km^2 and UTM 10 km^2 grid cells. These datasets were used to derive maps of proportion of each crop category, of the most abundant eight species, and of amphibian and reptile species richness. To test the effect of crop category on the occurrence of amphibian and reptile species, we modelled the presence/absence of each species using a logistic regression (General Linear Model, GLM), with binary response and binomial distribution of errors and a logit link function. Then, we calculated the proportion of species for each crop category with a significant effect. To explain species richness patterns, we used a generalized additive model (GAM), with a Gaussian error distribution and an identity link function (Zuur et al. 2009) with regression splines (Wood 2003). We ran both GLM and GAM using the proportion of a crop category within 50 km^2 and 10 km^2 grid cell, respectively, as continuous fixed effects and subject to smoothing for GAM. Models for UTM 10 km^2 resolution included a purely spatial term to account for spatial autocorrelation. The normality of residuals was tested using Q-Q plots (Sokal and Rohlf 1995). We report total deviance (%) and adjusted R^2 for the coefficient of determination as indicators of the explained variation of the full model. We performed all analyses using R 4.1.1 (R Core Team 2021) software.

Results

Distribution patterns of amphibians and reptiles and crops

We recorded 72 amphibian and 142 reptile species at UTM 50 km^2 and UTM 10 km^2 grids (Fig. 1). At 50 km^2 spatial resolution, amphibian species richness in crops was higher in Western-Central Europe, while for reptiles it was higher in the southern peninsulas, particularly the Iberian Peninsula and Greece. At 10 km^2 spatial resolution, the pattern is less continuous. Presence/absence maps of the eight most abundant amphibian and reptile species in agricultural landscapes across Europe at UTM 50km^2 and UTM 10km^2 resolutions are presented in the Online Resource 1 (EMS1_1, EMS1_2, EMS1_3 and EMS1_4).

The relative extent of each crop category varied depending on the spatial resolution (Fig. 2). At the spatial resolution of 50 km^2, the crops do not occupy the whole grid square extent: 0.37–0.49, agroforestry crops; 0.66–0.88, dry crops; 0.44–0.59, irrigated crops; 0.62–0.82, pastures; and 0.52–0.70, woody crops. At the spatial resolution of 10 km^2, some crop categories occupy all the grid square extent: 0.7–1, agroforestry crops; 0.7–1, dry crops; 0.7–0.9, irrigated crops; 0.7–0.9, pastures; and 0.7–0.9, woody crops. Both spatial resolutions obtained a similar value of Shannon diversity index (H) as an indicator of crop heterogeneity: 1.4–1.59. However, crop heterogeneity was higher towards southern Europe, namely at 50 km^2 spatial resolution (Fig. 2).

Crops extents in grid cells occupied by amphibians and reptiles

At UTM 50km^2, the most extended crop category with occurrences of amphibians and reptiles was the dry crop (Fig. 3a and 3b) while at UTM 10km^2, the most extended one was agroforestry crop (Fig. 3c and 3d). However, the differences between crop categories at 10km^2 presented less variability (Fig. 3). The GLMs on the presence/absence of each species indicated that at both resolutions all crop categories had a significant effect on more than 20% of the species: thus, both amphibian and reptile species are selecting specific crop categories (Online Resource 2, EMS2_1). The species presence in agroforestry crops was significantly more likely than would be expected by chance for more than 60% of species at UTM 50km^2 spatial resolution, whilst at UTM 10km^2, woody crops had a significant effect on more than 45% of the species (Online Resource 2, EMS2_1). When considering separately the proportion of species positively or negatively affected by crop categories, agroforestry crops affected positively the highest proportion of species at UTM 50km^2 spatial resolution (Fig. 4). Woody crops positively affected the highest proportion of species at both UTM 10km^2 (Fig. 4) while pasture negatively affected the highest proportion of species at both UTM 50km^2 and UTM 10km^2 spatial resolutions (Fig. 4).

The species richness of amphibians and reptiles was significantly correlated with the extent of crop categories at UTM 50km^2 and 10km^2 spatial resolutions, except with pasture and woody extent at UTM 10km^2 spatial resolution for amphibians (Table 1). Species richness generally decreased with the increase in the crop extent both at UTM 50km^2 and 10km^2 spatial resolutions, with some exceptions (Fig. 5). Amphibian species richness increased with the increase of agroforestry crop extent at UTM 50km^2, while reptile species richness showed a significant positive relationship with the extent of irrigated crops both at UTM 50km^2 and 10km^2 resolution, and the extent of woody crops at UTM 50km^2. Also, reptile species richness showed an initial decline with the increase of agroforestry crop extent to 0.3%, followed by an abrupt decrease to higher agroforestry crop extent at UTM 50km^2 (Fig. 5). Species richness increased significantly with crop heterogeneity for amphibians (at UTM 50km^2 spatial resolution, edf = 8.246, F = 296.6, P < 0.001; at UTM 10km^2 spatial resolution, edf = 5.996, F = 26.61, P < 0.001) and reptile (at UTM 50km^2 spatial resolution, edf = 7.884, F = 475.3, P < 0.001; at UTM 10km^2 spatial resolution, edf = 8.743, F = 3.16, P < 0.001).

Table 1
Generalized Additive Model results for effect of crop categories on species richness of amphibians (SR amp) and reptiles (SR rep) at UTM 50 km^2 and UTM 10 km^2 spatial resolutions; edf = the effective degrees of freedom; test statistics are either chi-square (for models with Poisson distribution) or F (for models with Gaussian distribution); agfr = agroforestry crops; dry = dry crops, irr = irrigated crops; past = pastures; wood = woody crops. Models for UTM 10 km^2 resolution included a spatial term to account for spatial autocorrelation.

50km × 50 km resolution						
SR amp (R^2 = 0.412; total deviance = 41.6%)				SR rep (R^2 = 0.528; total deviance = 53.2%)		
	edf	Statistic	P	edf	Statistic	P
agfr	8.007	12.607	< 0.001	8.458	14.505	< 0.001
dry	8.763	23.522	< 0.001	8.661	28.923	< 0.001
irr	10.238	7.086	< 0.001	9.928	6.494	< 0.001
past	8.422	13.241	< 0.001	19.641	19.116	< 0.001
wood	2.077	3.179	0.031	8.762	69.719	< 0.001
10km × 10 km resolution						
SR amp (R^2 = 0.411; total deviance = 43.7%)				SR rep (R^2 = 0.435; total deviance = 45.5%)		
agfr	5.018	1.729	0.100	3.159	6.302	< 0.001
dry	5.371	3.114	0.004	7.561	5.334	< 0.001
irr	10.344	5.074	< 0.001	10.900	9.462	< 0.001
past	1.955	0.447	0.547	5.106	7.656	< 0.001
wood	5.127	1.204	0.289	7.683	18.464	< 0.001
spatial	1572.872	14.475	< 0.001	1216.524	16.971	< 0.001

Discussion

Our study indicated that the species presence and richness of amphibians and reptiles are influenced by crop extent and crop category in agricultural landscapes across Europe. Moreover, we found that the observed spatial patterns of species richness and of crop extent were scale dependent. More specifically, although the number of species occurring in crops did not differed between scales, the geographic location of peaks and troughs of species richness and of crop extent at coarse scale (grain size $50km^2$) did not coincide with those at finer scale ($10km^2$). At coarse spatial resolution, amphibian species richness in crops was higher in Western-Central Europe, while for reptiles it was higher in the southern peninsulas. This was in general agreement with the distribution and geographic patterns of amphibians and reptiles of Europe (Sillero et al. 2014). The analysis at a finer scale led to less obvious hotspots and cold spots of species richness, due to the lack of homogeneous distribution data at that spatial resolution. In the case of crop extent, the smaller the areas, the lesser the crop categories, thus increasing the dominance of one crop category, especially on islands.

Our results showed that species presence may be affected by crop extent and crop category. Although all crop categories contributed significantly to explain species presence, our results revealed some scale-dependent contrasts in crop influence on species presence. For example, while agroforestry crop extent had a significant positive effect on most species at UTM $50km^2$, at UTM $10km^2$ woody crop category positively affected the highest number of species. Agroforestry crop in our study includes land principally occupied by agriculture with significant areas of natural vegetation and agroforestry areas (like the typical montados and dehesas in the Iberian Peninsula; CORINE Land Cover 2018, version v.2020_20u1). Previous studies have shown that the combination of agriculture and forestry enhances the persistence of amphibian and reptile species (Brüning et al. 2018; Warren-Thomas et al. 2020; Fulgence et al. 2021), being in general beneficial for biodiversity (Hartley 2002; Harvey et al. 2007; Torralba et al. 2016). Agroforests are important for biodiversity as they provide a more diverse habitat than a conventional agricultural system and can serve as corridors between habitats (Harvey et al. 2007). Woody crops in our study included vineyards, fruit trees and berry plantations, olive and chestnut groves and walnut groves shrub orchards. Reptile species, such as lizards, can be widespread in vineyards (Biaggini and Corti 2021). Traditionally cultivated olive plantations host an exceptionally high proportion of specialist reptiles (Kazes et al. 2020, but see Carpio et al. 2016). Furthermore, when herbaceous cover exist woody crops may harbour a diverse community of reptiles (Carpio et al. 2017). All above explanations assume that landscape has a hierarchical structure, i.e. regions consist of a mosaic of smaller habitat patches which occur within larger habitat patches (Kotliar and Wiens 1990). Habitat patches vary depending on an organism's perception (Wiens and Milne 1989) which involves the spatial resolution and the concept of contrast (i.e. "the magnitude of differences in measures across a given boundary between adjacent patch types", Wiens and Milne 1989). The response of species to a mosaic of habitat patches depends on both spatial scale and contrast levels (Chust et al. 2003). Thus, a multi-contrast levels and scales approach would help to evaluate properly effect of different crop categories on species occurrence and biodiversity and explain the different patterns we found at different resolutions.

Our results provided evidence that the species richness of amphibians and reptiles is in general negatively correlated with crop extent. However, the results also highlighted scale- and group-dependent richness patterns in response to crop extent and crop categories. This emphasises the importance of considering the context specificity of scale- and taxa-dependent responses to crop types when investigating these patterns. Previous studies have indicated that agricultural lands are often not optimal habitats for amphibians and reptiles (e.g. Loman and Lardner 2006, 2009; Ribeiro et al. 2009), both groups being particular sensitive to agricultural activities (Dürr et al. 1999), such as the use of pesticides (Brühl et al. 2013). Further, agricultural lands may even serve as ecological traps (Rotem et al. 2013).

The extent of dry crops may be the main threat to amphibian species diversity in agricultural landscape. Both at coarse and finer spatial resolutions, amphibian species richness was negatively affected by the extent of dry crops. Pond-breeding amphibians are dependent on availability of aquatic habitats, being strongly related to aquatic habitats characteristics (e.g. surface, hydroperiod, water chemistry, predators and cover vegetation) (Skelly et al. 1999; Skelly 2001) and vegetation around them for migratory events and other terrestrial activities (Mazerolle and Desrochers 2005; Prevedello and Vieira 2010). The low spatial and temporal availability of aquatic habitats in drylands, subject to human activities altering their characteristics and the vegetation around them, most likely affect negatively the amphibian species diversity (Gardner et al. 2007).

Species richness of amphibians was also negatively affected both at coarse and finer spatial scale by irrigated crops, possibly due to higher use of pesticides or alteration of aquatic habitats in this crop category. Similarly, at the coarse spatial scale, agroforestry crops had also a positive effect on amphibians richness, probably due to the higher landscape heterogeneity in those crop categories than in monoculture lands (Brüning et al. 2018; Fulgence et al. 2021). Agroforestry crops have less intensive agricultural modes and contain patches of natural vegetation and hedges, providing shelter and food resources. Indeed, ponds are very abundant in the Spanish dehesas and Portuguese montados agroforests, for providing water to cattle. Reptile species richness responded significantly to all five crop categories, decreasing with the extent of all crop categories except irrigated and woody crops at coarse spatial resolution. Previous studies have shown that non-irrigated crops adversely affect reptiles (Atauri and de Lucio 2001). Grazing is an important anthropogenic disturbance on pastures and can have negative and positive effects on biodiversity (Schieltz and Rubenstein 2016). The response of reptile species to grazing has been found to be influenced by arboreality (Neilly et al. 2018). Terrestrial reptiles were generally negatively affected by increasing grazing pressure, unlike arboreal reptiles (Howland et al. 2014). Research work on agroforests indicated that, although agroforests and monocultures contain different reptile assemblages, the species richness is similar (Wanger et al. 2010; Warren-Thomas et al. 2020).

Crop heterogeneity enhances species richness of both amphibians and reptiles. Crop heterogeneity affects positively a wide range of taxa, including amphibians (Collins and Fahrig 2017). Yet, evidence of biodiversity benefits from crop diversity was claimed to strongly depend on spatial resolution. Our results provided support for an increase in the species richness of amphibians and reptiles with crop heterogeneity at both coarse and finer spatial resolutions. However, we measured the compositional heterogeneity (Fahrig et al. 2011), that describes the diversity of crops grown in a landscape, as the Shannon diversity index of crop categories. Configurational heterogeneity (Fahrig et al. 2011) describing the spatial arrangement of fields and measured as mean field size or density of field borders, might play an important role on amphibian and reptile species richness. Therefore, further studies are needed to understand whether crop heterogeneity could be an effective way to increase the diversity of amphibians and reptiles in agricultural landscape.

Conclusions

Harnessing agricultural landscapes for conservation of biodiversity, in particular by appropriate environment risk assessment of pesticide for amphibians and reptiles is a priority. Our study provides solid data on amphibian and reptile species occurrence and richness patterns in agricultural landscape across Europe and how they are mediated by crop type, extent and heterogeneity at different spatial resolutions, from large (e.g., UTM $50km^2$) to small (e.g., UTM $10km^2$) ones. Thus, we recommend using this information in risk assessment studies for amphibians and reptiles, for instance in studies designed to identify candidates, e.g. so-called “representative species”, for field effect studies, or studies of risk refinement though radio-tracking.

Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Data collection was done by Neftalí Sillero, Raluca Ioana Băncilă, and Matteo Lattuada, and analyses were performed by Raluca Ioana Băncilă and Matteo Lattuada and supervised by Neftalí Sillero. The first draft of the manuscript was written by Raluca Ioana Băncilă and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability

Part of the dataset generated and analysed during the current study is available from the corresponding author on reasonable request and another part from GBIF (GBIF.org (15 September 2021) GBIF Occurrence Download https://doi.org/10.15468/dl.fuwc5a and https://doi.org/10.15468/dl.qxet2m).

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Figures

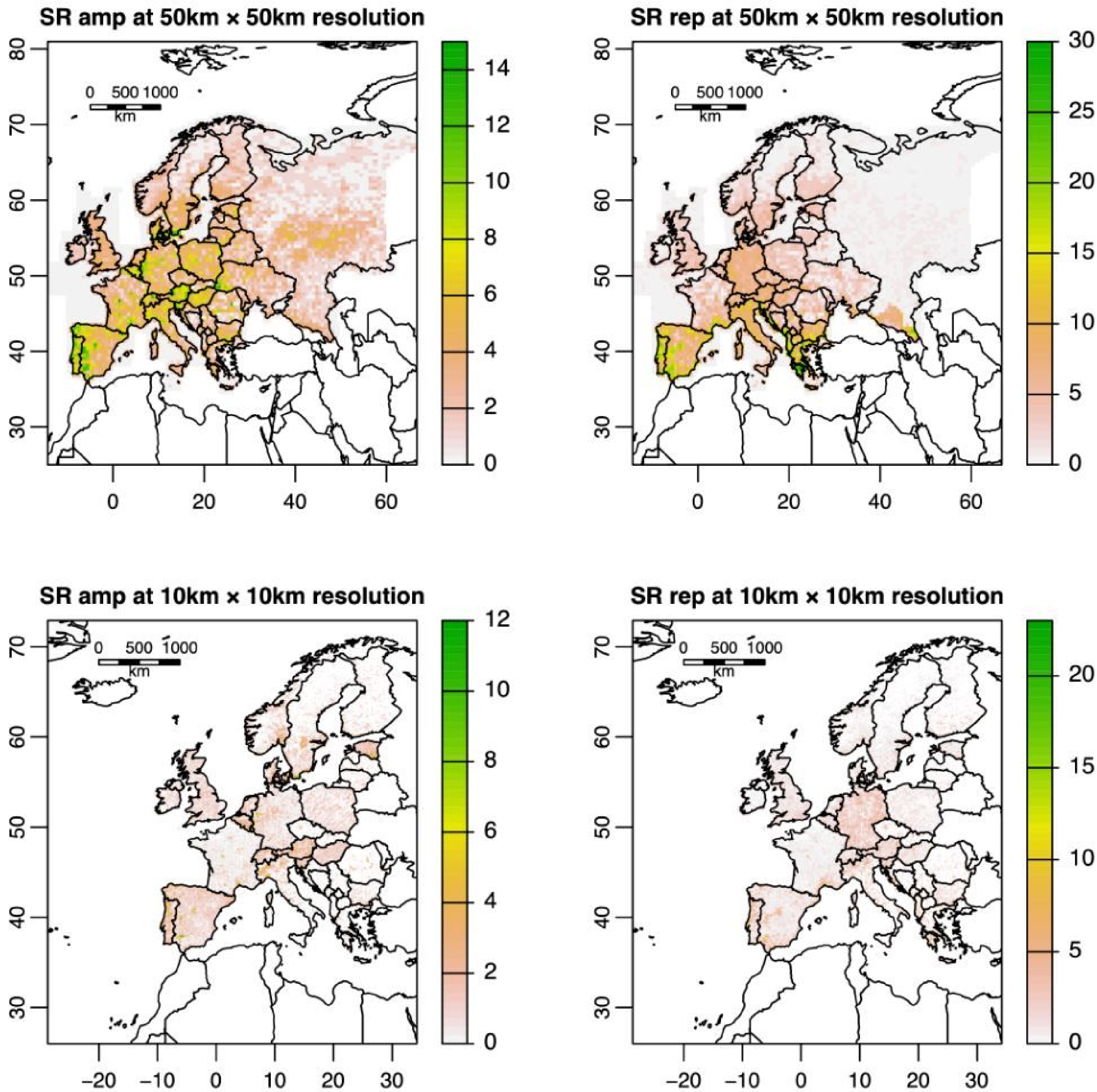

Figure 1

Maps of species richness of amphibians (SR amp) and reptiles (SR rep) in agricultural landscape across Europe for UTM 50km^2 and UTM 10km^2 spatial resolutions. Light red colours represent low richness while dark green colours represent high species richness (i.e. 11-15 amphibian species and 22-30 reptile species present within a 50km^2 grid cell, and 9-12 amphibian species and 17-23 reptiles species present within a 10km^2 grid cell).

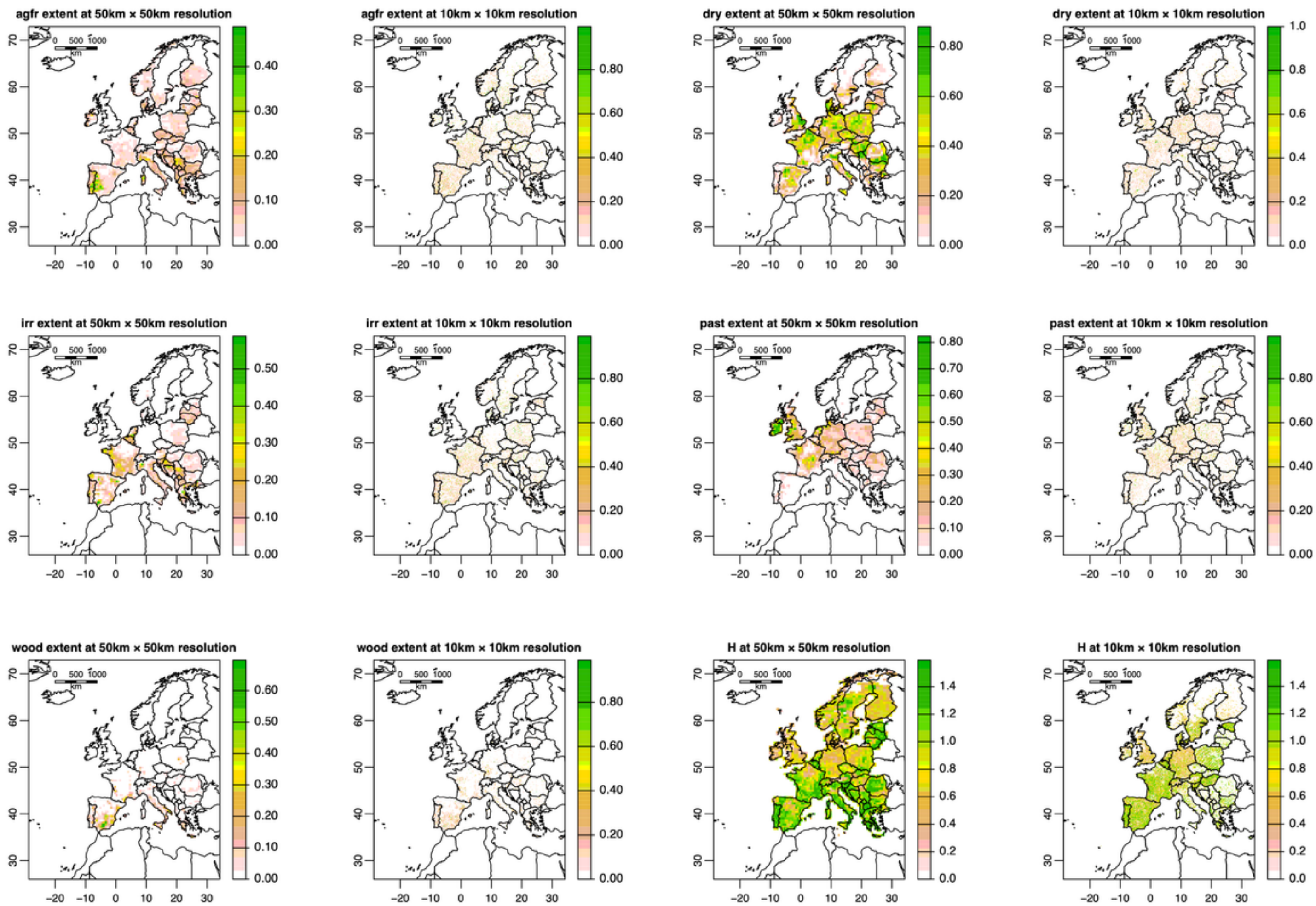

Figure 2

Maps of the relative extent of each crop category for within UTM 50km^2 and UTM 10km^2 spatial resolutions. Crop extent increases from light red to dark green colours agfr = agroforestry crops; dry = dry crops, irr = irrigated crops; past = pastures; wood = woody crops; H = Shannon diversity index, as an indicator of crop heterogeneity.

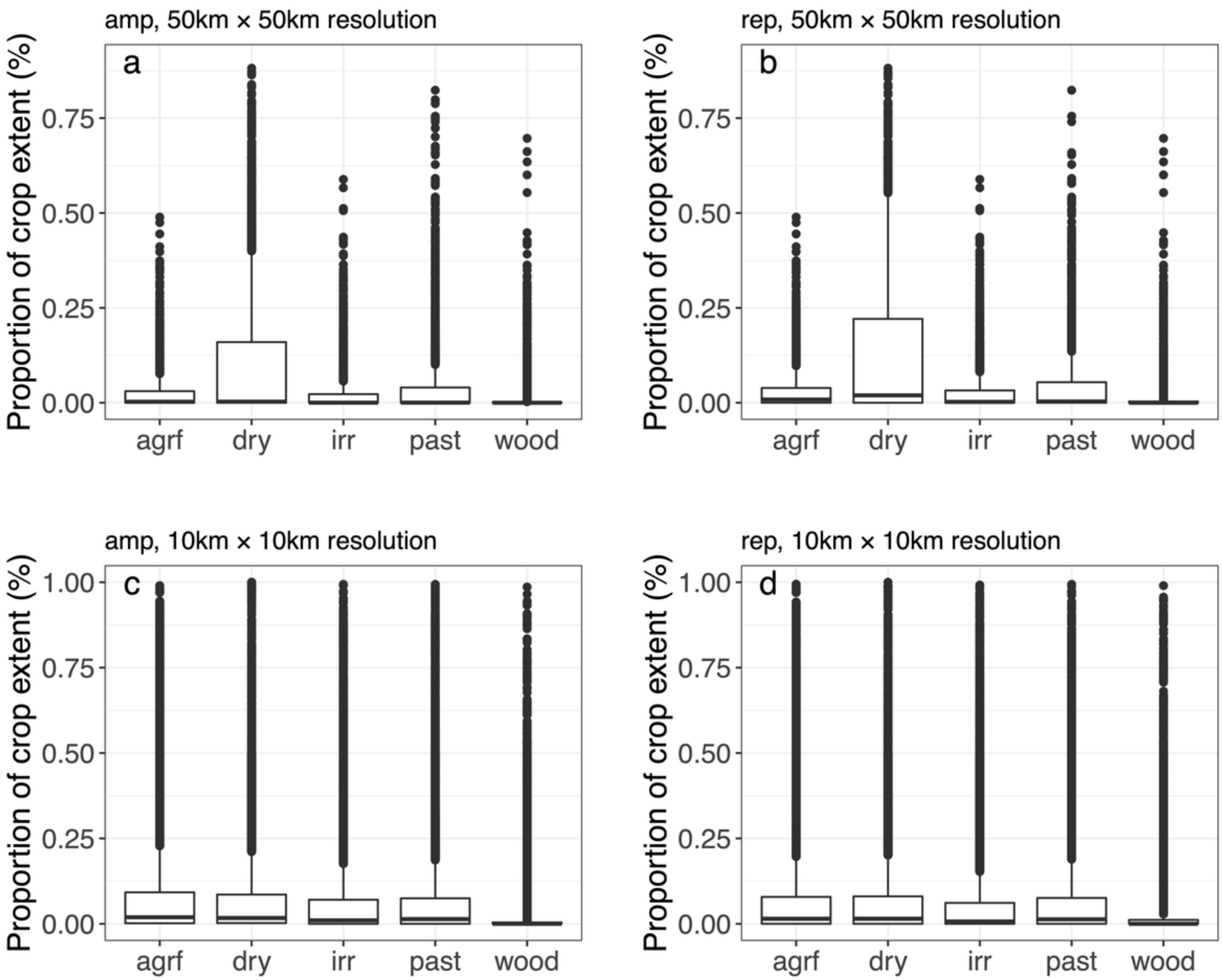

Figure 3

Crop extent for amphibians (amp) and reptiles (rep) within UTM $50km^2$ and UTM $10km^2$ spatial resolutions.

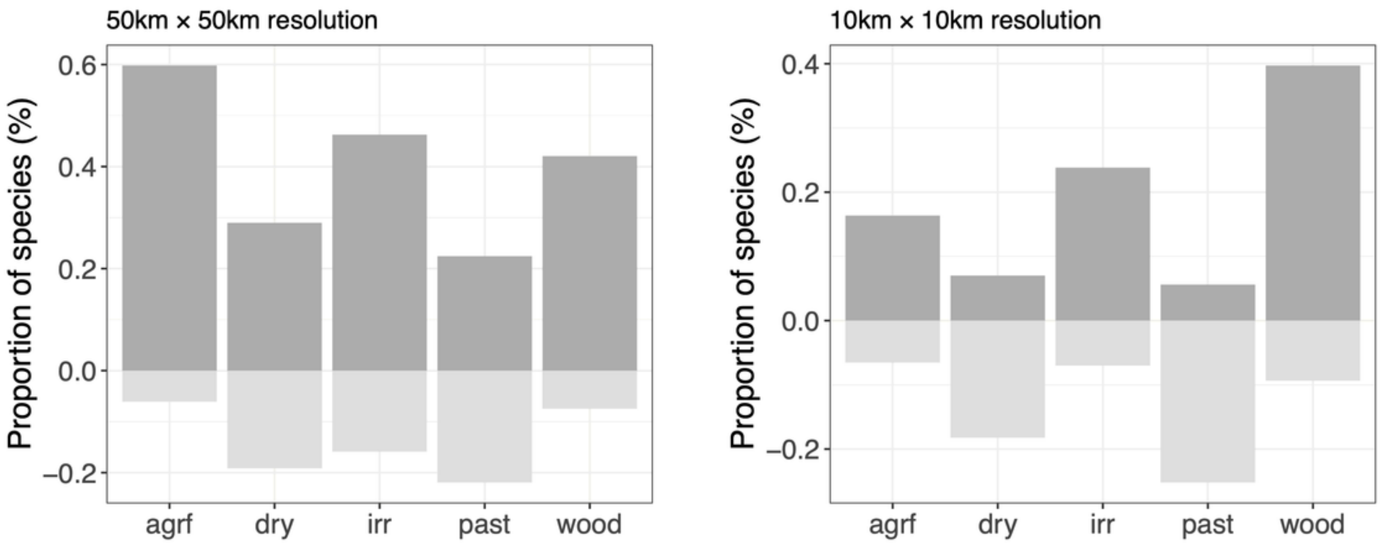

Figure 4

Proportion of species with a significant positive and negative relationship with crop category at UTM 50km^2 and UTM 10km^2 spatial resolutions; agfr = agroforestry crops; dry = dry crops, irr = irrigated crops; past = pastures; wood = woody crops.

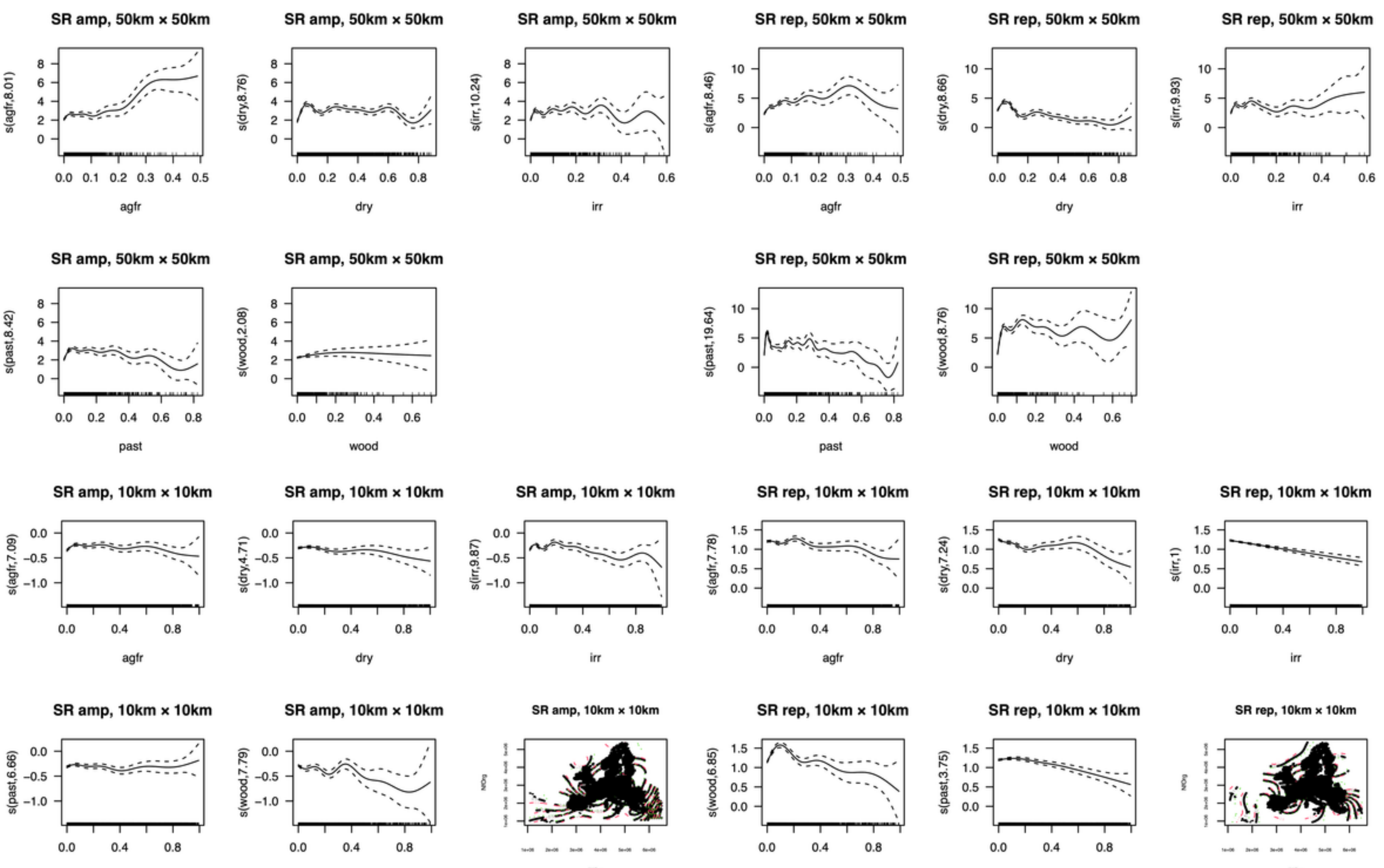

Figure 5

Results of Generalized Additive Models for amphibian and reptile species richness at UTM 50km^2 and UTM 10km^2 spatial resolutions. Dashed lines are ± standard errors of the partial effect term combined with the standard errors of the model intercept. Rug plot on the X axis shows density of data points. Y axis shows smooth values of dependent variable and the effective degrees of freedom (edf). The figures were made by shifting the scale by the value of the intercept to help interpretation; agfr = agroforestry crops; dry = dry crops, irr = irrigated crops; past = pastures; wood = woody crops.

Supplementary Files

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