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RESEARCH PAPER

Most habitat's and species' assessments in German Natura 2000 sites reflect unfavourable conservation states

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ABSTRACT

The Convention on Biological Diversity aims to protect 30 % of the Earth's land and marine surface to promote biodiversity. In the European Union, conservation areas are mainly placed under protection through the Habitats Directive. These so-called Natura 2000 sites currently cover 18.6 % of Europe's land area. Obligatory status reports enable a broad-scale analysis of conservation states to investigate if biodiversity is in the favourable conservation status demanded by the directive and which factors may be inhibiting. With focus on Germany, we evaluated the conservation states of habitat types and species groups as assessed in standard data forms and related it to drivers commonly reported for the sites, e.g., land-use practices, protected area size and time since designation. Our results are based on assessments from 23 % (1049) of Germany's Natura 2000 sites protected under the Habitats Directive and show that only 6 % of habitats' and 4 % of species' assessments report a favourable conservation status. A review of the reported drivers showed that most negative influences on Natura 2000 sites were attributed to agricultural and forestry activities, as well as natural system modifications, while for both land-use types also practices with positive impact were listed. For habitats, conservation status was better in Natura 2000 sites that were established earlier than later. For both habitats and species, more favourable conservation states were overall related to larger area sizes and the absence of direct land use (agriculture, forestry). Our results highlight that a high proportion of protected areas alone does not suffice to infer successes for biodiversity conservation when land-use activities continue to affect target species or their habitats. Increased conversation efforts for Natura 2000 areas will be required to meet the goals of the recently implemented EU Nature Restoration Law.

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Introduction

Protected areas are a key approach to maintain and improve local biodiversity (UNEP-WCMC & IUCN, 2025; Gray et al., 2016). Currently, they cover >16 % of the world's terrestrial surface and 8 % of the marine surface, a share which is planned to be enlarged to 30 % each by 2030 (COP, 2022; UNEP-WCMC & IUCN, 2025). In the European Union (EU), the designation and implementation of protected areas is primarily promoted by the Birds (79/409/EEC) and Habitats Directive (92/43/EEC), together forming the so-called Natura 2000 network, aiming at preserving natural habitats and wild species (EEA, 2020). As of 2023, there were 23,771 Natura 2000 sites based on the Habitats Directive, which make up 87.5 % of all Natura 2000 sites (EEA, 2025).

For effective biodiversity conservation, impact evaluations of implemented conservation measures are essential to enable evidence-based decision making (Baylis et al., 2016; Sutherland et al., 2019). Therefore, when the Habitats Directive was issued in 1992, it included the obligation for member states to regularly report on the conservation status of their protected assets with the aim to evaluate the effectiveness of the Natura 2000 network. To this end, all member states use a standard data form to report on each Natura 2000 site based on best expert judgement (EU, 2011). Assets are classified as either in favourable, inadequate or bad conservation state based on their structure, prospects and restoration possibilities for habitats as well as population size and degree of isolation for species, with results being published every six years by the EU (EC, 2013). Although the Habitats Directive can be considered a success in increasing the proportion of area protected by Natura 2000 sites in Europe to 18.6 %, more than thirty years after its implementation most sites are not in a good state, as only 15 % of habitats and 27 % of species were of favourable conservation status (EEA, 2020, 2025). The biogeographical regions with the highest number of sites in inadequate or bad (hereafter: unfavourable) conservation status are the Atlantic and Continental regions, which together cover almost half of the EU territory (Sundseth, 2009; EEA, 2020).

Among the factors discussed to be responsible for the low number of Natura 2000 sites in a favourable state are management regimes, land-use changes and landscape context (Kubacka & Smaga, 2019; EEA, 2020; Ricci et al., 2024). Land-use change is one of the major drivers for biodiversity change on a global scale (Jaureguiberry et al., 2022), and therefore, also affects the conservation status of Natura 2000 sites, both when occurring inside and outside of the sites' boundaries (Leroux & Kerr, 2013). In contrast, sustainable land use can be an integral part of biodiversity conservation (e.g., integrated forest management; Aggestam et al., 2020), especially in densely populated regions such as Europe, where human activities have been shaping landscapes for centuries and thereby created ecosystems with high conservation value (Poschlod & Braun-Reichert, 2017). For this reason, the Habitats Directive demands the development of management plans to obtain positive trends for focal habitats and species in Natura 2000 areas. Yet, even if suitable management plans exist, positive trends likely only become visible years after area designation; first, because plans are often developed or implemented with delay (BirdLife et al., 2018; EC, 2021a), and second, because of ecological time lags in population or habitat developments after conservation actions (Watts et al., 2020). Consequently, older Natura 2000 sites would be expected to have a more favourable conservation status than newly designated sites. Finally, area size can affect the conservation status of habitats and species, with too small or isolated sites less likely withstanding surrounding pressures (Geldmann et al., 2015; Rodrigues & Cazalis, 2020).

To investigate which factors might be responsible for unfavourable conservation states of Natura 2000 sites, we focus on Germany, one of the largest EU member states in terms of area, covering parts of the Continental, Atlantic and Alpine regions. In Europe, Germany currently has the highest number of sites protected under the Habitats Directive with 4544 sites, covering 33,600 km^2 (9.4 %) of land and 20,900 km^2 (37.0 %) of marine surface. According to a national study based on 560 assessments from example sites including all 93 habitat types occurring in Germany and 195 different annex-listed species, 30 % of assessed habitats and 25 % of species were in favourable conservation state (BMU & BfN, 2020). To obtain a more representative picture of the overall state of biodiversity in German Natura 2000 sites and to identify its key drivers, we used information from standard data forms available on the websites of federal authorities on 23 % of German Natura 2000 sites, choosing sites in each biogeographical region in representative shares for the whole of Germany. Differentiating between agricultural/open land, forests, inland water and coasts/oceans, as well as urbanised areas (major habitats according to the taxonomy of the German National Assessment of Biodiversity, Wirth et al., 2024), we analysed the effects of protected area size, time since designation and the drivers most frequently reported across all standard data forms on the conservation states of habitats and species. When mentioning Natura 2000 sites in the following, we solely refer to areas protected by the Habitats Directive.

We expected (I) that less than the 30 % of habitats and 25 % of species assessments reported by BMU and BfN (2020) were rated favourable. Instead, by selecting Natura 2000 sites from biogeographical regions and major habitat types in proportions comparable to the distribution of all sites in Germany, a larger majority of assessments was assumed to reflect an unfavourable conservation state. Finally, we hypothesised (II) that drivers reported on the standard data forms as negative influences, as well as a small area and a short time since designation of the Natura 2000 sites were related to a more unfavourable conservation state of habitats and species. With this study, we want to sharpen the understanding which factors are promoting or impeding effective area protection in regions of dense human population and land use, such as Central Europe.

Methods

Choice of sites: Evaluation data from German Natura 2000 sites are currently not available in a format ready for analysis but need to be manually extracted from standard data forms provided on the websites of the respective responsible federal authority of which there are sixteen. We therefore decided to base our analysis on a subsample of 1049 (23 %) out of the current 4544 Natura 2000 sites to get a realistic approximation of the proportion of habitat and species assessments in Germany indicating a favourable status. Sites were chosen randomly but in numbers representative for the area share of the three biogeographic regions in Germany, i.e. Atlantic region (22 %, 225 sites), Continental region (77 %, 810 sites) and Alpine region (1 %, 14 sites) Table 1.

Data extraction: First, we extracted overall conservation ratings for habitat types and species from the most current standard data forms available for selected sites. We translated the categorical values "favourable" (A), "inadequate" (B) and "bad" (C) to numerical values ($A = 1$, $B = 2$, $C = 3$) to enable averaging by groups of habitat types and by taxon groups of species (Appendix A: Table A1, Table A2). Second, we assigned each habitat type to one of the major habitat types: agricultural/open land, forests, inland waters, and coasts/ocean. To approximate a representative coverage of major habitat types compared to their proportion in all Natura 2000 sites in Germany, we extracted the area of each habitat per site and calculated the total area per major habitat type. As coasts/oceans were overrepresented in our random selection, we dropped the three largest areas of ocean/coast habitat from our data set and thus reached better area representativity (Appendix A: Table A3). The last major habitat type, urban areas, could not be inferred directly from standard data forms. Instead, we intersected our selection of sites with a map based on the European classification of the degree of urbanisation of 2011 (DEGURBA; EC, 2021b), categorising each site as either densely populated, intermediately or thinly populated, depending on the urbanisation category that covered most of its area. Finally, we extracted information on the total site area and years passed since designation as Natura 2000 site. Further, we noted for each site which drivers from the reference list of threats, pressures and activities (EEA,

Table 1
Effects of site characteristics (time since designation and area size) and reported drivers (positive, negative, inside and outside of site combined) on the conservation state of habitats and species, resulting from regression analyses with GLMs. Bold text indicates significant effects ($p < 0.05$).

	Habitats			Species		
Predictor	Estimates ± SE	df	p-value	Estimates ± SE	df	p-value
Time since designation	−0.010 ± 0.002	1	**<0.001**	0.005 ± 0.003	1	0.080
Area size*		4	**<0.001**		4	**<0.001**
< 113 ha	−0.007 ± 0.018		0.717	0.075 ± 0.024		0.002
< 279 ha	0.026 ± 0.018		0.145	0.065 ± 0.024		0.006
< 870 ha	−0.016 ± 0.019		0.388	0.073 ± 0.024		0.003
< 532 100	−0.100 ± 0.020		**<0.001**	0.021 ± 0.025		0.393
Agriculture	0.048 ± 0.012	1	**<0.001**	0.045 ± 0.015	1	**0.003**
Forestry	0.024 ± 0.011	1	**0.034**	0.037 ± 0.014	1	**0.007**
Natural system modification	−0.012 ± 0.011	1	0.288	0.030 ± 0.014	1	**0.030**
Human intrusions/ disturbances	−0.033 ± 0.011	1	**0.003**	0.006 ± 0.013	1	0.643

* reference level: smallest areas <29 ha.

2019) were reported, including their classification (positive or negative influence) and their source location (inside the protected area, outside or both). To match these data on site level, we additionally calculated one averaged value for the conservation status of all habitats and species per site.

Exploration of conservation status: Conservation status is usually depicted in either green (= *A* or 1, "favourable state"), yellow (= *B* or 2, "inadequate state") or red (= *C* or 3, "bad state"). Because we averaged conservation states, e.g. across multiple habitats of the same type in one site, decimal values were created that do not fit in this three-category traffic light system. We therefore introduced cut values in our continuous scale of conservation state to form five categories which reflect the former three levels and two transition levels: favourable = 1.0 – 1.4 (dark green), favourable tending inadequate >/= 1.4 – 1.8 (light green), inadequate >/= 1.8 – 2.2 (yellow), inadequate tending bad >/= 2.2 – 2.6 (orange) and bad >/= 2.6 – 3.0 (red).

Statistical analyses: All statistical analyses were performed with R (version 4.3.3, www.r-project.org). To check whether the mean conservation status was significantly different among major habitat types, species groups or biogeographical regions, we calculated ANOVAs and subsequent Tukey post-hoc tests for multiple comparisons of each pair. To investigate which variables influence the conservation status of biodiversity in Natura 2000 sites, we built Generalised Linear Models (GLM) with a lognormal error distribution and a log link function using averaged conservation status of either habitats or species per site as response variable (values between 1 and 3). As predictors, we included area size (between < 0.01 and 532,100 ha), time since designation (between 12 and 25 years) and the presence/absence of the four most frequently listed drivers of all standard data forms (see results). The area variable was skewed by a few very large areas and was therefore transformed to categorical variables with five levels of similar sampling sizes (< 29 ha, 29 to < 113 ha, 113 to < 279, 279 to < 870, 870 to 532,100 ha). All models were calculated with the package glmmTMB (version 1.1.8, Brooks et al., 2017). Model diagnostics were assessed with the DHARMa package (version 0.4.6, Hartig, 2022). P-values and estimates were calculated with the car package (version 3.1.2, Fox & Weisberg, 2019).

Results

Conservation status of habitats and species: For habitats, we analysed 3168 assessments, of which most were from deciduous forests, grassland, freshwater, raised bogs and rock (each > 200 assessments). In total, 5.9 % of habitat assessments were rated favourable (dark and light green), 29.7 % inadequate (yellow) and 64.4 % bad (orange and red; Fig. 1). The highest share of habitat assessments reporting favourable conservation states were found in the Alpine region (30.4 % from 79 assessments), followed by the Atlantic (5.7 % from 599) and Continental region (5.1 % from 2490; Fig. 1). In agricultural/open land ($N = 1324$), forests ($N = 852$) and inland water habitats ($N = 943$), the proportion of favourable assessments was each around 6 % and higher for coasts/ oceans ($N = 49$) with 18.4 % (Fig. 1). The mean rating of habitat conservation state was 2.39 with variance among subcategories of habitats (means: 1.99 – 2.62; Appendix B: Fig. B1).

For species, we analysed 1953 assessments divided by groups: mammals ($N = 482$, referring to a mean number of 2.12 different species per site), invertebrates (674, 2.08), fish (308, 2.21), amphibians (290, 1.28), plants (157, 1.49), and birds (43, 7.23). Overall, the conservation status of species was assessed as favourable in 3.6 % ($N = 61$) of assessments. The highest share of species' assessments in favourable conservation states were found in the Alpine region (16.0 % of 26 assessments), followed by the Continental (3.5 % of 1451) and the Atlantic region (2.9 % of 242; Fig. 2). The highest proportion of favourable conservation states was found for plants (10.2 %), the lowest for amphibians (1.7 %; Fig. 2). Invertebrate ratings were further made up from beetles ($N = 138$), dragonflies ($N = 135$), butterflies ($N = 224$), molluscs ($N = 149$) and others ($N = 28$). Overall, 7.0 % of invertebrate assessments were rated favourable ($N = 47$), with molluscs (14.8 %) having the most favourable ratings and dragonflies having the least (2.2 %; Appendix B: Fig. B2& Table B1). No habitat rating and only two species ratings were favourable in sites within areas of high urbanisation, but ratings did not significantly differ among the urbanisation classes (Appendix B: Fig. B3& Table B2, Table B3).

Drivers: Out of the 1049 analysed standard data forms, 868 gave information on drivers present in or around the corresponding Natura 2000 site. The most frequently reported negative drivers were in descending order: agricultural activities, natural system modification, forestry activities, human disturbances (> 600 reports each, Fig. 3 top). Positive drivers were reported less frequently and were mostly agricultural and forestry activities (>150 reports each). Most negative (76 %) and almost all positive drivers (97 %) originated exclusively from within Natura 2000 sites (Appendix C: Fig. C1). Only influences of the drivers pollution, residential/commercial development, mining/energy production, and climate change were identified in >30 % of cases to originate from either outside or both inside and outside of the site (Fig. 3 bottom). Specification of drivers by giving subcategories in standard data forms were only made rarely (Fig. 3 top, Appendix C: Table C1). Most of Natura 2000 sites were located in thinly populated areas (61.7 %), followed by intermediately (31.5 %) and densely populated areas (6.8 %).

Effects of site characteristics and drivers on conservation status: The rating of habitat conservation state was better in Natura 2000 sites that were earlier established than later and best in very large sites, while there was no difference in rating among sites between < 29 ha and < 870 ha. Agricultural and forestry activities had a slight negative influence on habitat conservation status (Fig. 4), while human disturbance was positively associated with conservation status (Table 1). Ratings of species conservation state were better in small (< 29 ha) and very large sites (> 870 ha), compared to area sizes in between and, by trend, better in younger sites than in older sites. Similar to habitat conservation status, agricultural and forestry activity had a slight negative influence on the conservation status of species, as did natural system modification (Fig. 4, Table 1).

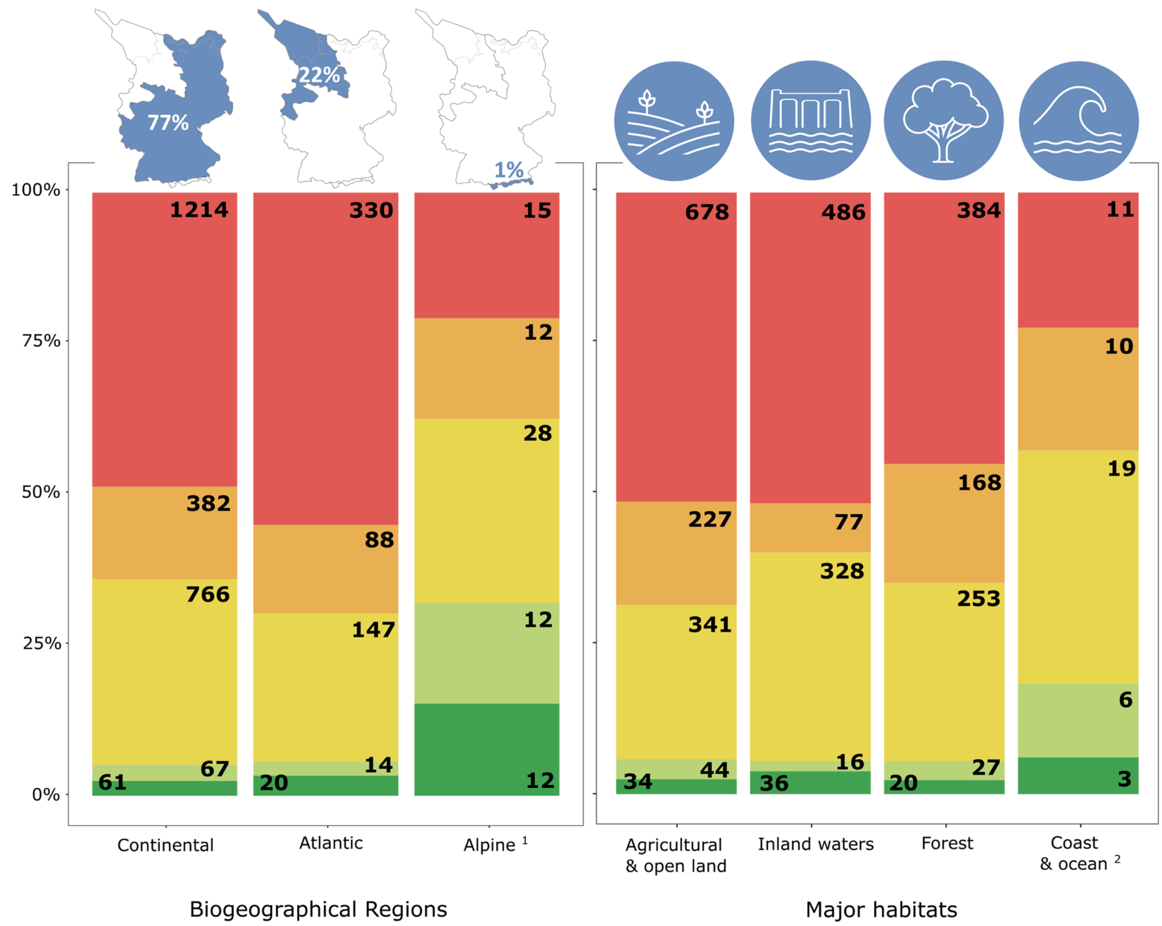

Fig. 1. Proportion of habitat assessments in each evaluation category of conservation status based on standard data forms of 1049 Natura 2000 sites. Total number of habitats in each group are indicated by bold numbers. The number of habitat assessments reporting favourable states differed among biogeographical regions (left) and major habitat types (right), but differences were only significant between following groups (Appendix B: Table B1): [1] Habitats were significantly better rated in Alpine regions than in Continental and Atlantic regions. [2] Coast/ocean habitats were significantly better rated than all other habitats.

Discussion

Most assessments from Germany's Natura 2000 sites protected by the EU Habitats Directive do not reflect the favourable conservation status of habitats and species targeted by the directive (random sample of 23 % of all sites). Only around 6 % of habitat assessments showed a favourable conservation status, most of which were in the Alpine region or within coastal and marine habitats. Similarly, only around 4 % of species assessments were rated favourable. Many assessments reported negative influences by agricultural activities, modifications of natural systems, forestry activities, and human disturbances on sites, which we found significant for agriculture and forestry. However, depending on the type of agricultural and forestry practices, these drivers were also sometimes reported as positive for habitats and/or species. Both very small and very large sites were associated with more favourable conservation states.

German Natura 2000 sites are considerably below the European average of 15 % of habitats' and 27 % of species' assessments reporting a favourable state (EEA, 2020). This is in line with our expectation because 99 % of Natura 2000 sites in Germany are located within the Atlantic and Continental region which have the worst conservation states across Europe (Sundseth, 2009; EEA, 2020). Most sites in Atlantic and Continental regions are found within managed cultural landscapes. As the Natura 2000 network follows a land sharing (vs. land sparing) approach, i.e., incorporating local land use into management of Natura 2000 sites (Grass et al., 2019), management plans need to be tailored to the target species, habitats and the local site conditions to benefit biodiversity. This requires local knowledge of stakeholders. However, land-use intensification due to increasing demands on profitability as well as ceasing traditional practices have contributed to reducing semi-natural habitats of high conservation value and associated local knowledge (IPBES, 2018). This may explain the poor conservation status found in our study (IPBES, 2018).

Our results show a small but significant negative effect of both forestry and agricultural activities on Natura 2000 sites' conservation status. Many assessed standard data forms suggested pollution caused by mineral fertilisers commonly used in conventional agriculture. This is in line with evidence from literature, indicating negative effects of long-term fertilisation in high-intensity agriculture on above- and below-ground biodiversity (Haddad et al., 2000; Tsiafouli et al., 2015; Melts et al., 2018; Fan et al., 2019). However, there are many examples of non-intensive agricultural practices, e.g., small-scale organic farming without pesticides, having positive effects on the biodiversity of plants and certain animal taxa (Bengtsson et al., 2005; Fuller et al., 2005; Gabriel et al., 2013). This divergence is mirrored on standard data forms where agriculture is frequently listed as both negative and positive influence for Natura 2000 sites. Similarly, forest management for timber production can affect biodiversity. For example, large clear-cuts reduce species richness, while selective cutting and retention forestry largely minimise negative effects for non-specialized groups (Fedrowitz et al., 2014). Specifically, tree replanting was frequently listed on standard data forms as both a positive and a negative driver. Although standard data forms do not attribute drivers to species listed for the respective Natura 2000 site, it can be assumed that replanting was classified as

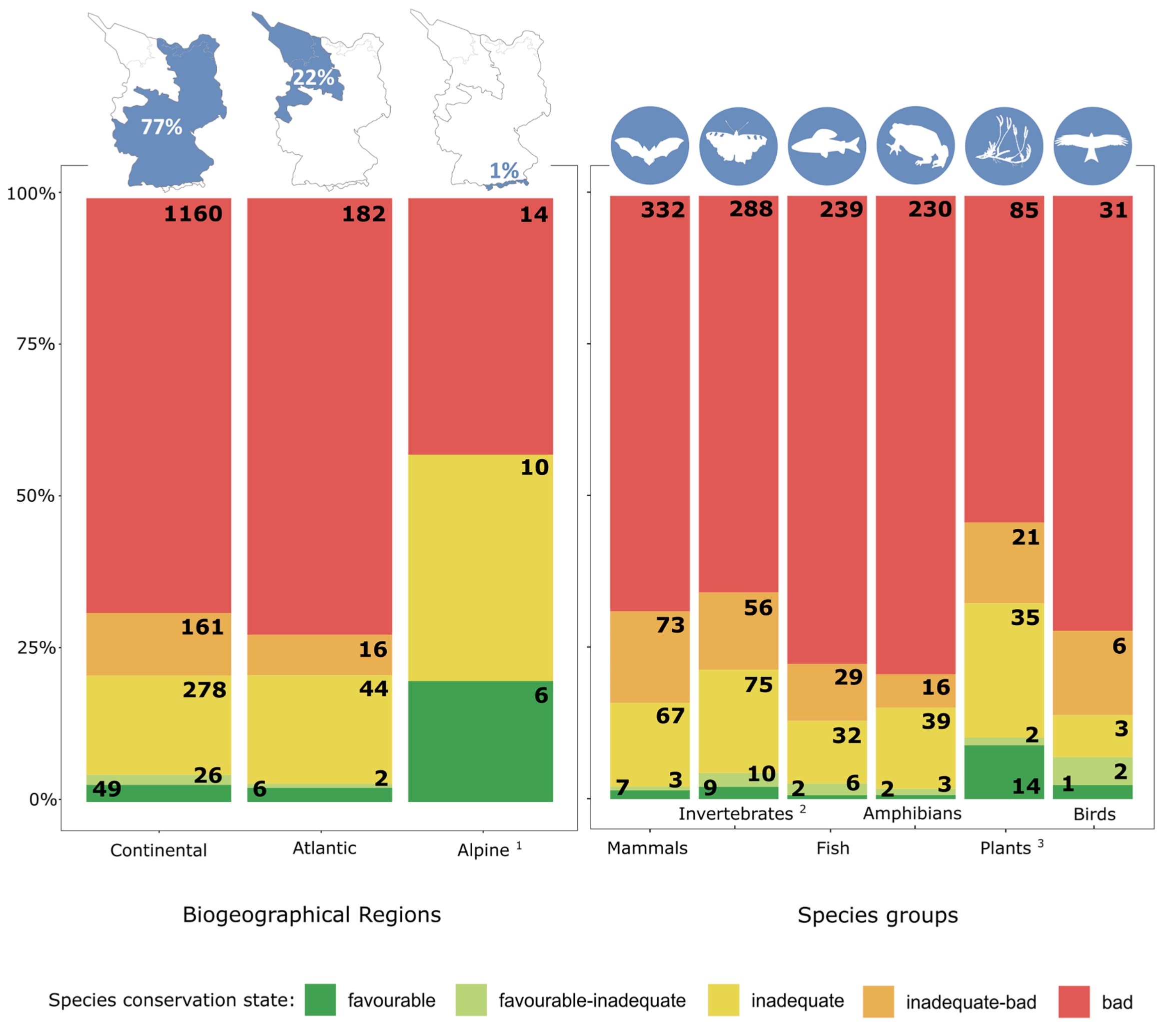

Fig. 2. Proportion of species assessment in each evaluation category of conservation status based on standard data forms of 1049 Natura 2000 sites. Total number of species assessments in each group are indicated by bold numbers. The proportion of species' assessments indicating a favourable conservation status differed among biogeographical regions (left) and species groups (right), but differences were only significant between the following groups (Appendix B: Table B3): [1] Species were significantly better rated in Alpine regions than in Continental and Atlantic regions. [2] Invertebrate species were significantly better rated than amphibian and fish species. [3] Plant species were significantly better rated than invertebrate, amphibian, fish and mammal species.

negative for species characteristic of open habitats, and as positive at sites targeting the conservation of forest-specialised species (Fedrowitz et al., 2014). This illustrates that there is no one-fits-all solution to biodiversity conservation in managed landscapes and that habitat context is crucial to consider when designing conservation measures.

The question of whether single large areas or several small areas are preferable when designing protected areas is a controversial discussion in nature conservation (so-called SLOSS debate, e.g. Ovaskainen, 2002; Rösch et al., 2015; Fahrig, 2020). This ambivalence is also visible in our study's finding that the conservation status of species in the smallest Natura 2000 sites (< 29 ha) is rated similarly to conservation status in the largest areas (≥ 930 ha) and a little better compared to mid-sized sites. The better conservation status of smaller Natura 2000 sites may partly be brought about because at smaller sites an overview can be more easily maintained, and management can be more efficiently performed than at larger sites. This underlines the value of small protected areas (Fahrig, 2020). This is particularly relevant for urban areas, where space is usually scarce and pressures on biodiversity are high, though increasing the size of protected areas by creating urban conservation corridors shows potentials for further improving conservation states and reducing the impact of surrounding land use (Beninde et al., 2014; Kail et al., 2023). Accordingly, our data implies that urban protected areas are not less effective in sustaining species and habitats than more remote sites, since Natura 2000 sites in more urbanised areas were not rated significantly worse than in less urbanised areas.

We found that habitats in the oldest Natura 2000 sites which were designated in the early 2000's are now in a better habitat conservation status compared to sites designated in later years. This could indicate that habitat conservation status improved with time, which could however not be tested in this study due to lacking time series data. We found an opposite pattern in species conservation status which, by trend, was better in more recently established Natura 2000 sites than in those established longer ago. This does not necessarily mean that establishing Natura 2000 sites has no effect on species. For example, a study on butterflies showed declining trends in German Natura 2000 sites but at a slower rate than outside of sites (Rada et al., 2019). Our results do, however, suggest that habitats might profit more from protected areas than species populations. Importantly, the designation of a Natura 2000 site is usually not immediately followed by conservation measures. In the case of Germany, in 2023 concrete conservation measures were still missing for 16 % of Natura 2000 sites protected by the Habitats Directive (LBV, 2023). Finally, and against our expectations, we found no negative effect of the presence of human disturbances (e.g., outdoor sports) or natural system modification (e.g., changes in hydraulic conditions) on

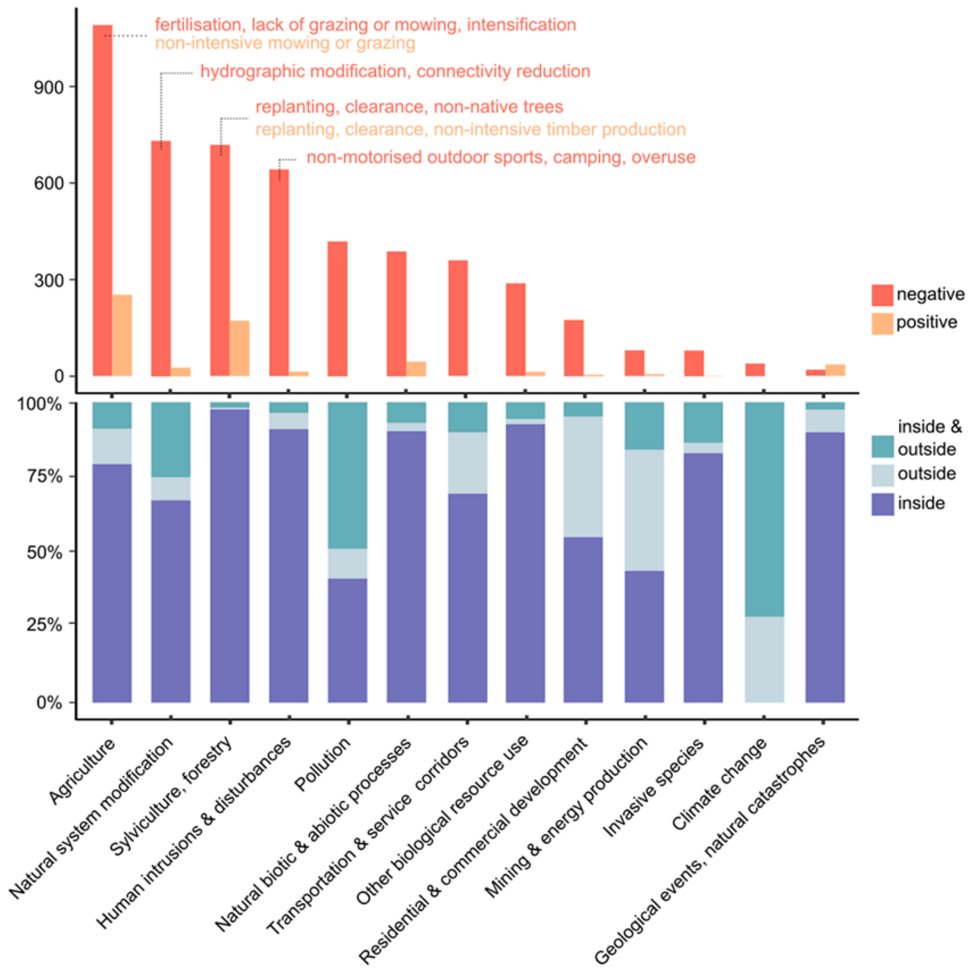

Fig. 3. Most frequently reported categories of drivers of conservation status in Natura 2000 sites. Top: number of reported negative and positive drivers in each category. Text in red and orange indicates the overall most frequently reported negative and positive subcategories of drivers. Bottom: Proportion of drivers for each category which originated from either inside or outside the Natura 2000 site's boundary, or both.

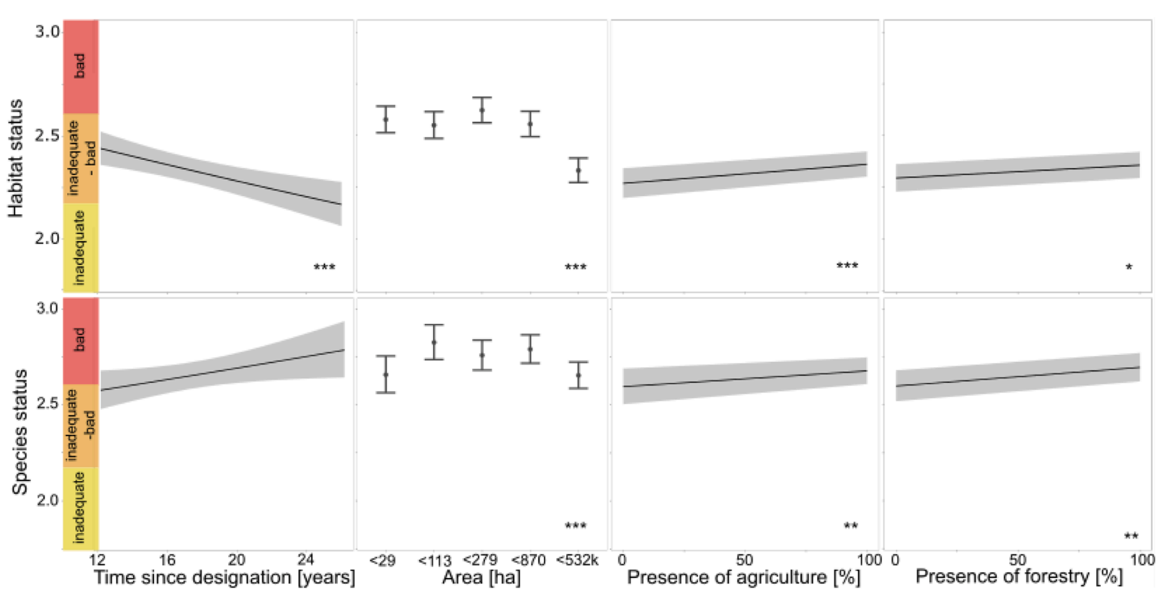

Fig. 4. Effects of site characteristics (time since designation and area size) and reported drivers (positive, negative, inside and outside of sites combined) on the conservation state of habitats (top row) and species (bottom row), based on the results of the GLM (Table 1). Presence of agriculture/ forestry refers to the effect of the presence or absence of the respective land use across sites. Ascending lines mean a worsening in conservation status. Grey shades show the 95 % confidence interval. Asterisks indicate significance levels (*** < 0.001 < ** <0.01 < * <0.05 < non-significant). For plots of all results including data points see Appendix D: Fig. D1, Appendix D: Fig. D2.

the rating of habitats and species Natura 2000 sites. On the contrary, the report of human disturbances was correlated with a better rating of conservation status in habitats although both factors are considered major drivers of biodiversity decline (Jaureguiberry et al., 2022). Possibly, this is due to methodological weaknesses of the "best expert judgement" approach, as both drivers may be more challenging to evaluate at a site than, e.g., type and methods of land use.

In our study, the proportion of conservation assessments rated "favourable" were considerably lower than in a preceding study on Natura 2000 sites in Germany conducted by the federal environment agencies, where 30 % of habitats and 25 % of species assessments were assessed "favourable" (BMU & BfN, 2020). However, that study was based to one-third on sites from the Alpine region where habitats and species are in better conservation states than in sites from the Atlantic and Continental region, but which only make up a small fraction of habitats in Germany. Similarly, better conservation states were found in coastal sites than in sites in forests, agricultural/open land or inland waters in our study. It is important to notice that our sampling size for the Alpine regions (79 assessments for habitats, 25 for species) as well as for ocean/coast habitats (49 assessments for habitats) was relatively small compared to other regions and major habitats, because both hold only few Natura 2000 sites and, thus, were not the major focus of our study.

Generally, the designation of a protected area itself does not necessarily lead to benefits for biodiversity (Geldmann et al., 2015; Hallmann et al., 2017; Engelhardt et al., 2023; Langhammer et al., 2024). An EU wide evaluation of the effectiveness of Habitats and Birds Directive suggested in 2017 that both directives are important policy tools for European nature conservation but additionally implemented measures are not yet sufficient to achieve their conservation goals (EC, 2016). Problems mainly result from insufficient land-use management and lack of funding (EC, 2016). In line with this, our data suggest that the effectiveness of the Natura 2000 network in achieving a favourable conservation status is still questionable also in Germany. Many of Germany's Natura 2000 sites are on private land and, unlike nature conservation sites based on national legislation ("Naturschutzgebiete", BNatSchG § 23), the Habitats Directive does not provide for strict land-use restrictions, creating the challenge to integrate conservation measures and land-use interests to support both ecosystem functions and services. The example of Natura 2000 sites in Germany illustrates the nowadays widespread challenges to integrate protected areas into a landscape matrix of dense human population and land use. The newly implemented EU Nature Restoration Law includes the target to prioritize the significant improvement of the conditions of Natura 2000 sites in line with the EU Biodiversity Strategy 2030 (Luick et al., 2025). Thus, meeting these challenges adequately and thereby improving the conditions of Natura 2000 sites to protect and enhance biodiversity should be an important policy objective for the coming years.

Conclusion

The assessments of Natura 2000 sites predominantly reflect unfavourable conservation states in all major habitat types, species groups, biogeographical regions and across different urbanisation degrees. This calls for an improvement of Natura 2000 site management not only in Germany but throughout densely populated Europe. Although our study showed a negative relationship between the presence of agriculture or forestry and the conservation status of habitats and species, the list of reported positive and negative drivers suggests that the type of land-use practices is decisive. Most likely, with adapted land-use practices and site-specific conservation measures even small Natura 2000 sites and other types of protected areas could have an impact in sustaining biodiversity.

Thus, a thorough understanding of the local ecological and land-use context is necessary for effective conservation areas such as Natura 2000 sites, and integration of nature conservation must be feasible for landowners. Finally, the evaluation of Natura 2000 sites in Germany as well as in all EU member states should be improved by integrating more quantitative metrics in the monitoring scheme, and by implementing systematic assessments of management measures for focal species and habitats before and after any intervention to enable evidence-based adjustments and increase the overall effectiveness of sites.

CRediT authorship contribution statement

Julia S. Ellerbrok: Visualization, Data curation, Writing – original draft, Formal analysis, Methodology, Conceptualization. **Theresa Spatz:** Methodology, Conceptualization. **Veronika Braunisch:** Writing – review & editing. **Michael Strohbach:** Writing – review & editing, Formal analysis. **Dagmar Haase:** Writing – review & editing. **Kathrin Januschke:** Writing – review & editing. **Josef Kaiser:** Writing – review & editing. **Marion Mehring:** Writing – review & editing. **Thilo Wellmann:** Writing – review & editing. **Helge Bruelheide:** Conceptualization, Funding acquisition, Writing – review & editing. **Jori Maylin Marx:** Conceptualization, Writing – review & editing. **Josef Settele:** Funding acquisition, Writing – review & editing, Conceptualization. **Christian Wirth:** Funding acquisition, Writing – review & editing, Conceptualization. **Nina Farwig:** Funding acquisition, Supervision, Writing – review & editing, Conceptualization.

Declaration of competing interest

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

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Appendix A: Methods

Table A1
Assignment of the habitat codes used in the evaluation of Natura 2000 sites with standard data forms to the four major habitat types and number of ratings assessed in our study for each group.

Major habitats	Habitat types	Codes	Number
agricultural & open land	grasslands	6xxx	669
	raised bogs	71xx	225
	rocks	8xxx	212
	heaths	40xx	163
	other open land	23xx	55
forests	deciduous forests	91xx (except 91T0, 91U0)	749
	hardwood forests	51xx	70
	coniferous forests	94xx, 91T0, 91U0	24
	other forests	2180	9
inland waters	lakes	31xx	404
	rivers	32xx	353
	fens	72xx	173
	other inland waters	1340*	13
coast & oceans	coasts	12xx, 13xx, 21xx (except 1340*, 2180)	27
	oceans	11xx	22

Table A2
Codes for species groups used in the evaluation of Natura 2000 sites with standard data forms and number of ratings assessed in our study for each group. For our analysis, the invertebrate group was split down into five subcategories.

Species group	Code	Number
Mammals	M	482
Invertebrates	I	438
- butterflies	I	224
- molluscs	I	149
- beetles	I	138
- dragonflies	I	135
- other	I	28
Fish	F	308
Amphibians	A	290
Plants	P	157
Birds	B	43
Reptiles	R	3*

* Reptiles were not considered in our analysis due to the small sampling size.

Table A3
Area share of major habitat types in selected sites and in all German Natura 2000 sites protected by the Habitats Directive. To obtain a representative assessment of the overall conservation states in Germany, we seek to match the actual area share of major habitat types.

Major habitats	Area share in selected Natura 2000 sites [%]	Area share in all German Natura 2000 sites [%]
Agricultural/open land	16.2	20.5
Inland waters	5.6	4.5
Coast/ocean	44.5	39.1
Forest	33.67	35.9

Appendix B: Results/ Conservation status of habitats and species

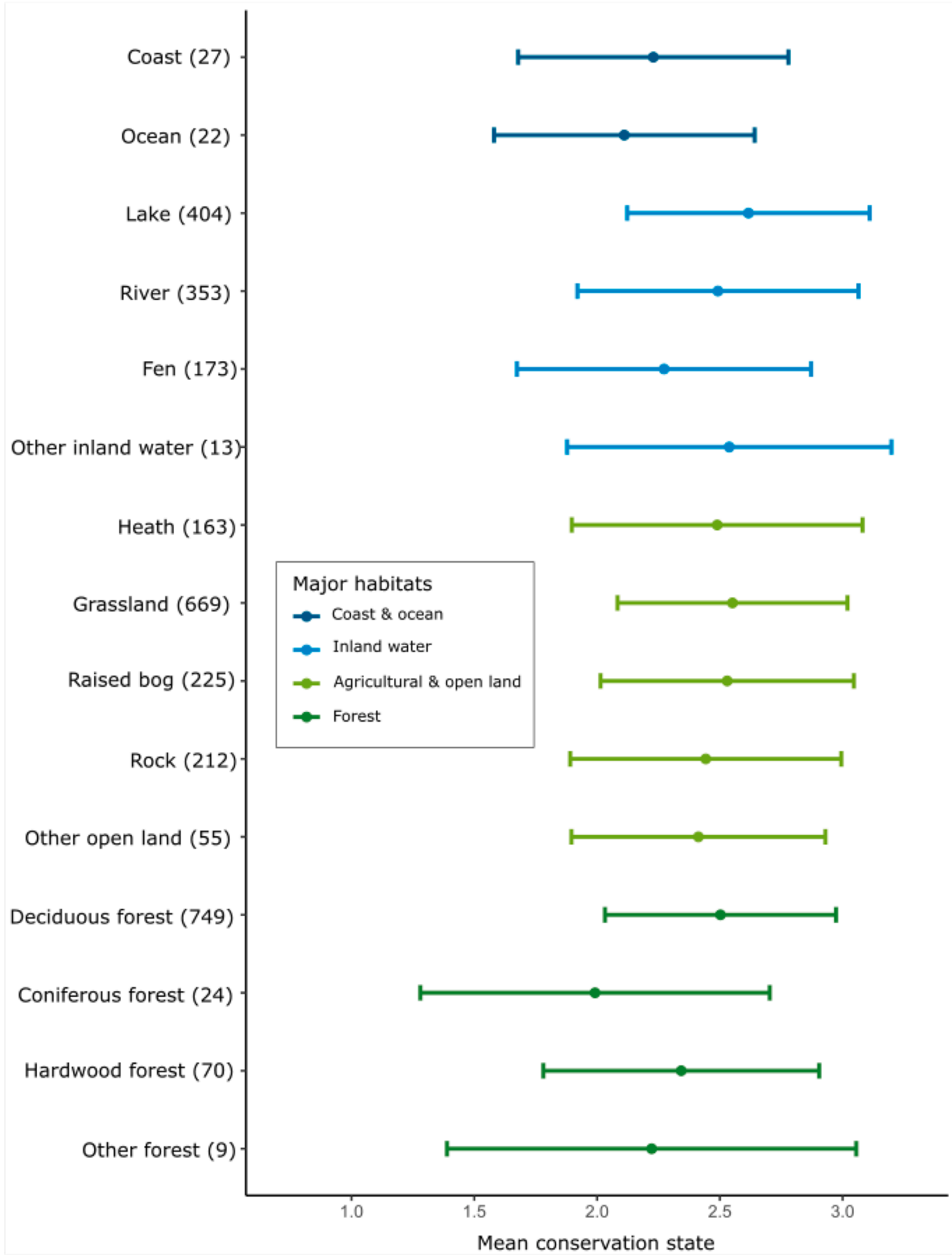

Fig. B1. Average conservation states of habitat types grouped by major habitat types based on raw data. Dots indicate mean values, lines indicate standard deviations. Numbers in brackets show how many habitats of each type were included in the analysis.

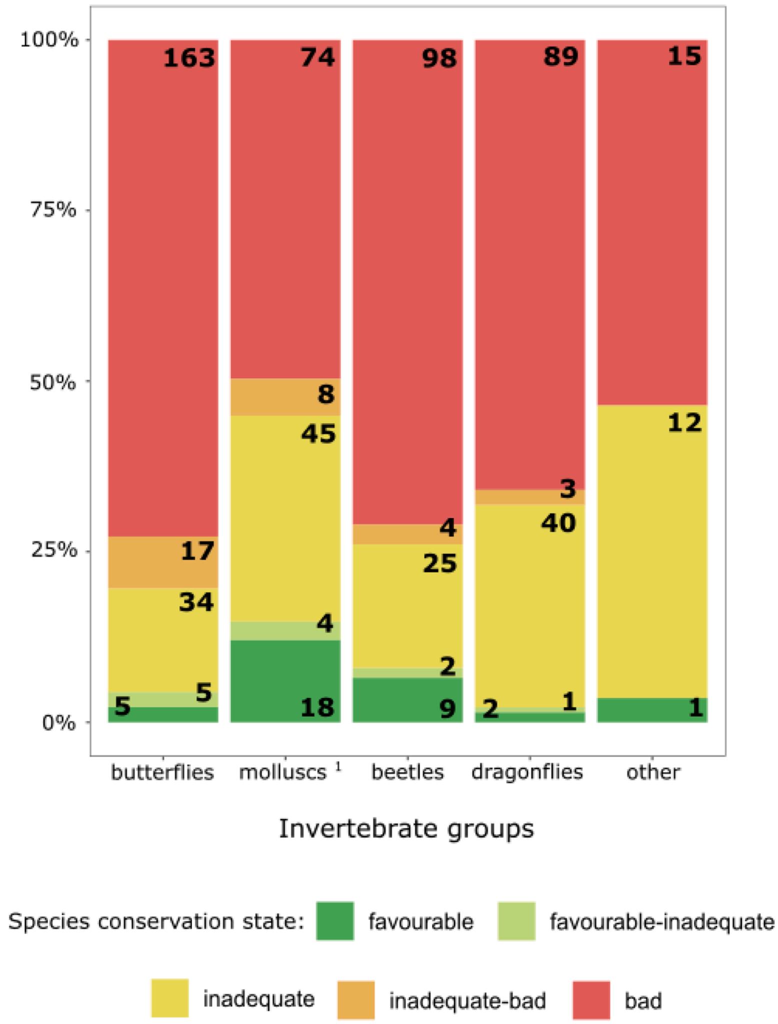

Fig. B2. Proportion of invertebrate species assessment in each evaluation category of conservation status based on standard data forms of 1049 Natura 2000 sites. Total number of species assessments in each group are indicated by bold numbers. The amount of species' assessments indicating a favourable conservation status differed between species groups. Differences were only significant between the following groups (Table B2): [1] Molluscs were significantly better rated than beetles, butterflies and dragonflies.

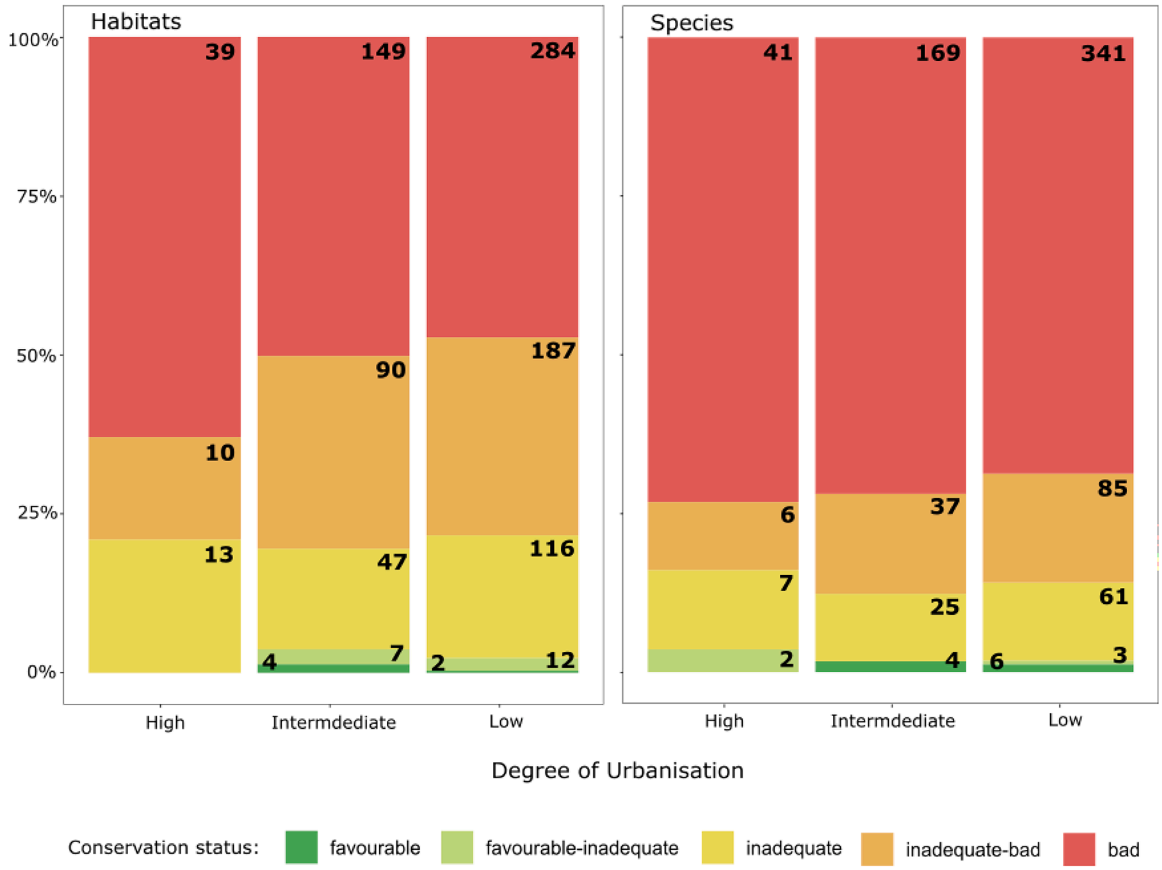

Fig. B3. Proportion of habitat and species assessment in each evaluation category of conservation status in areas of different urbanisation degree based on standard data forms of 1049 Natura 2000 sites. Total number of species assessments in each group are indicated by bold numbers. Natura 2000 sites are located in areas with different degrees of urbanisation. Differences in ratings were not significant between degrees of urbanisation (Table B3).

Table B1
Mean differences in ratings of habitat types in Natura 2000 sites among biogeographical regions, species groups and degrees of urbanisation. Results were obtained with Tukey post-hoc tests based on an ANOVA. Bold text indicates significant differences.

Pairwise comparison for habitats	Difference in rating	p-value
Biogeographical regions		
Atlantic - Alpine	0.51	**< 0.001**
Continental - Alpine	0.46	**< 0.001**
Continental - Atlantic	- 0.05	0.07
Major habitats		
Inland waters - agricultural/open land	- 0.01	0.959
Coasts/oceans - agricultural/ open land	- 0.34	**< 0.001**
Forest - agricultural/open land	- 0.05	0.206
Coasts/oceans - inland waters	- 0.33	**< 0.001**
Forest - inland waters	- 0.03	0.522
Forest - coasts/oceans	0.30	**< 0.001**
Degree of urbanisation		
Intermediate - high	- 0.05	0.604
Low - intermediate	- 0.02	0.675
Low - high	- 0.07	0.315

Table B2
Mean differences in ratings of invertebrate species in Natura 2000. Results were obtained with a Tukey post-hoc test. Bold text indicates significant differences.

Pairwise comparison for invertebrates	Difference in rating	p-value
Butterflies - beetles	0.08	0.775
Dragonflies - beetles	0.00	1.000
Molluscs - beetles	- 2.27	**0.001**
Other invertebrates - beetles	- 0.15	0.811
Dragonflies - butterflies	- 0.08	0.809
Molluscs - butterflies	- 0.35	**< 0.001**
Other invertebrates - butterflies	- 0.23	0.340
Molluscs - dragonflies	- 0.27	**0.001**
Other invertebrates - dragonflies	- 0.15	0.798
Other invertebrates - molluscs	- 0.05	0.922

Table B3
Mean differences in ratings of species in Natura 2000 sites among biogeographical regions and species groups. Results were obtained with a Tukey post-hoc test. Bold text indicates significant differences.

Pairwise comparison for species	Difference in rating	p-value
Biogeographical regions		
Atlantic - Alpine	0.46	**< 0.001**
Continental - Alpine	0.42	**< 0.001**
Continental - Atlantic	- 0.04	0.52
Species groups		
Amphibians - invertebrates	0.15	**< 0.001**
Birds - invertebrates	0.01	1.000
Fish - invertebrates	0.13	**0.003**
Mammals - invertebrates	0.06	0.388
Plants - invertebrates	- 0.17	**0.001**
Birds - amphibians	- 0.14	0.405
Fish - amphibians	- 0.02	0.988
Mammals - amphibians	- 0.09	0.068
Plants - amphibians	- 0.32	**< 0.001**
Fish - birds	0.12	0.613
Mammals - birds	0.05	0.99
Plants - birds	- 0.18	0.214
Mammals - fish	- 0.07	0.305
Plants - fish	- 0.29	**< 0.001**
Plants - mammals	- 0.23	**< 0.001**
Degree of urbanisation		
Intermediate - high	0.00	0.999
Low - intermediate	- 0.03	0.593
Low - high	- 0.03	0.874

Appendix C: Results/ Drivers

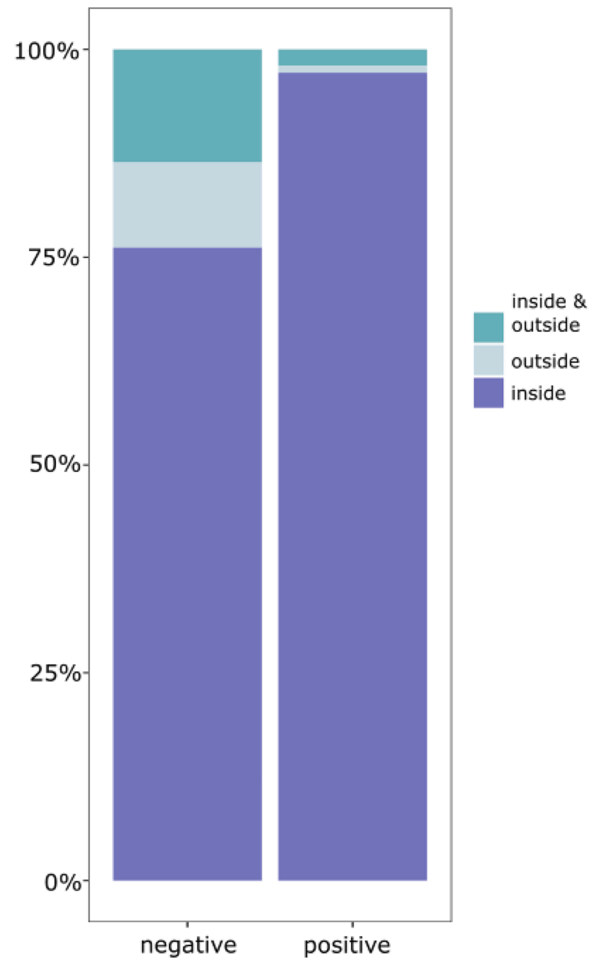

Fig. C1. Reported source location (inside of Natura 2000 sites, outside or both) of drivers of conservation status depending on their evaluation as positive or negative drivers on standard data forms.

Table C1
Frequent positive and negative drivers on Natura 2000 sites. On standard data forms, drivers can be listed in up to four levels with increasing details (shades of grey). Displayed are the four most mentioned main categories (> 150 times) and within them the most mentioned subcategories (> 40 times) and sub subcategories (> 10 times).

Frequent negative drivers	Count	Frequent positive drivers	Count
Agriculture	1090	Agriculture	252
1. Fertilisation	290	1. Mowing/ cutting of grassland	111
2. Grazing	211	- Non-intensive mowing	12
- Lack of grazing	100		
3. Modification of cultivation practices	177	2. Grazing	91
- Agricultural intensification	45	- Non-intensive grazing	26
4. Mowing/ cutting of grassland	107	3. Cultivation	42
- Lack of mowing	54		
Forestry	718	Forestry	172
1. Forest & Plantation management use	339	1. Forest & Plantation management use	155
- Forest replanting	113		
- Forestry clearance	53	- Forest replanting	74
2. Forest planting on open ground	206	- Non-intensive timber production	64
- Artificial planting on open ground (non-native trees)	173	- Forestry clearance	17
Natural system modifications	732		
1. Human induced changes in hydraulic conditions	635		
- Modification of hydrographic functioning	274		
2. Other ecosystem modifications	97		
- anthropogenic reduction of habitat connectivity	86		
Human intrusions & disturbances	642		
1. Outdoor sports & leisure activities	361		
- Walking, horse-riding & non-motorised vehicles	106		

(*continued on next page*)

Table C1 (*continued*)

Frequent negative drivers	Count	Frequent positive drivers	Count
2. Other human intrusions & disturbances	188		
- Trampling, overuse	52		
3. Sport and leisure structures	69		
- camping & caravans	24		

Appendix D: Results/ GLMs

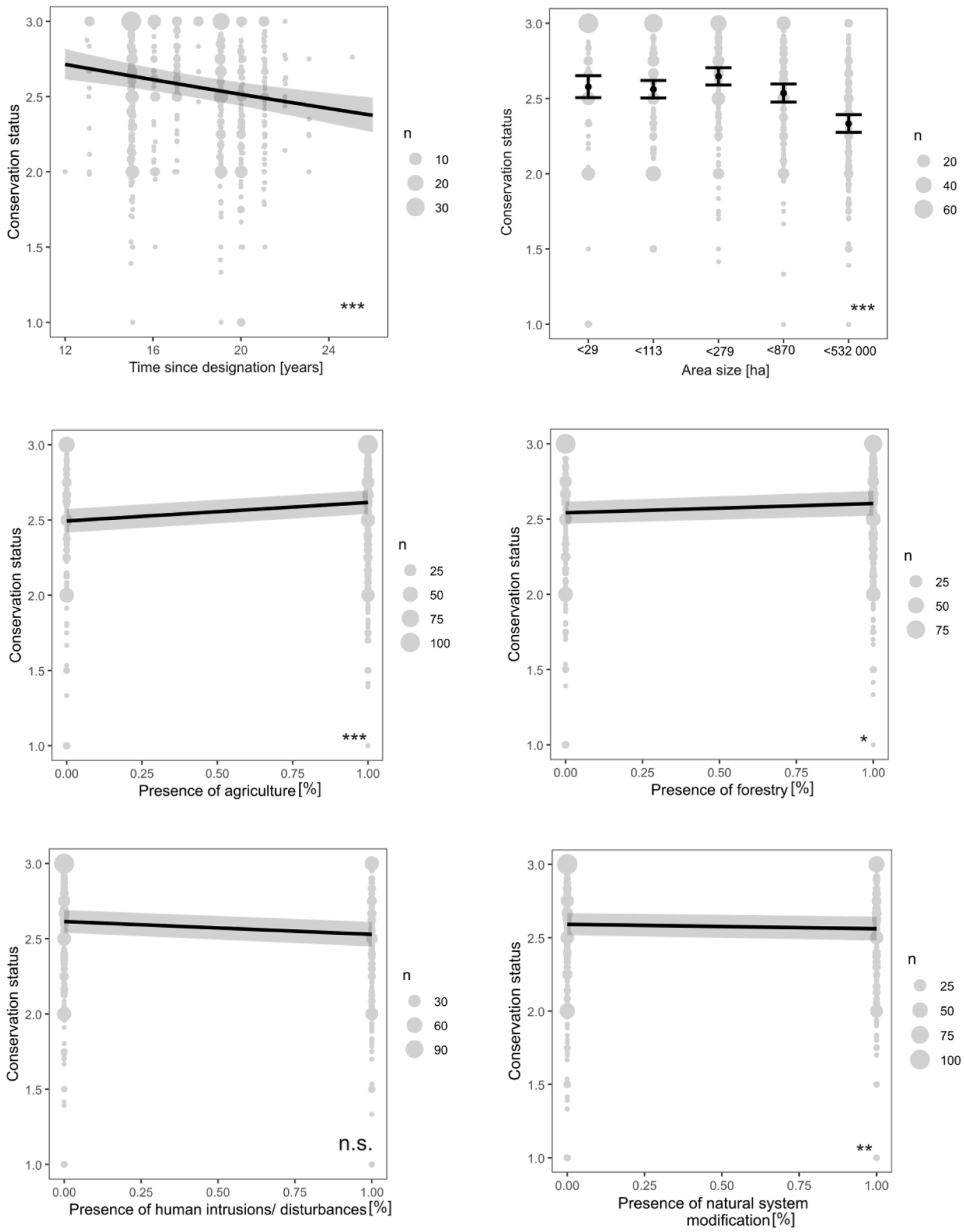

Fig. D1. Effects of all predictors included in the GLM on the conservation state of **habitats**. Ascending lines mean a worsening in conservation status. Grey shades show the 95 % confidence interval, grey circles represent raw data points. Asterisks indicate significance levels (*** < 0.001 < ** <0.01 < * <0.05 < non-significant). For full statistical results see Table 1 in the main publication.

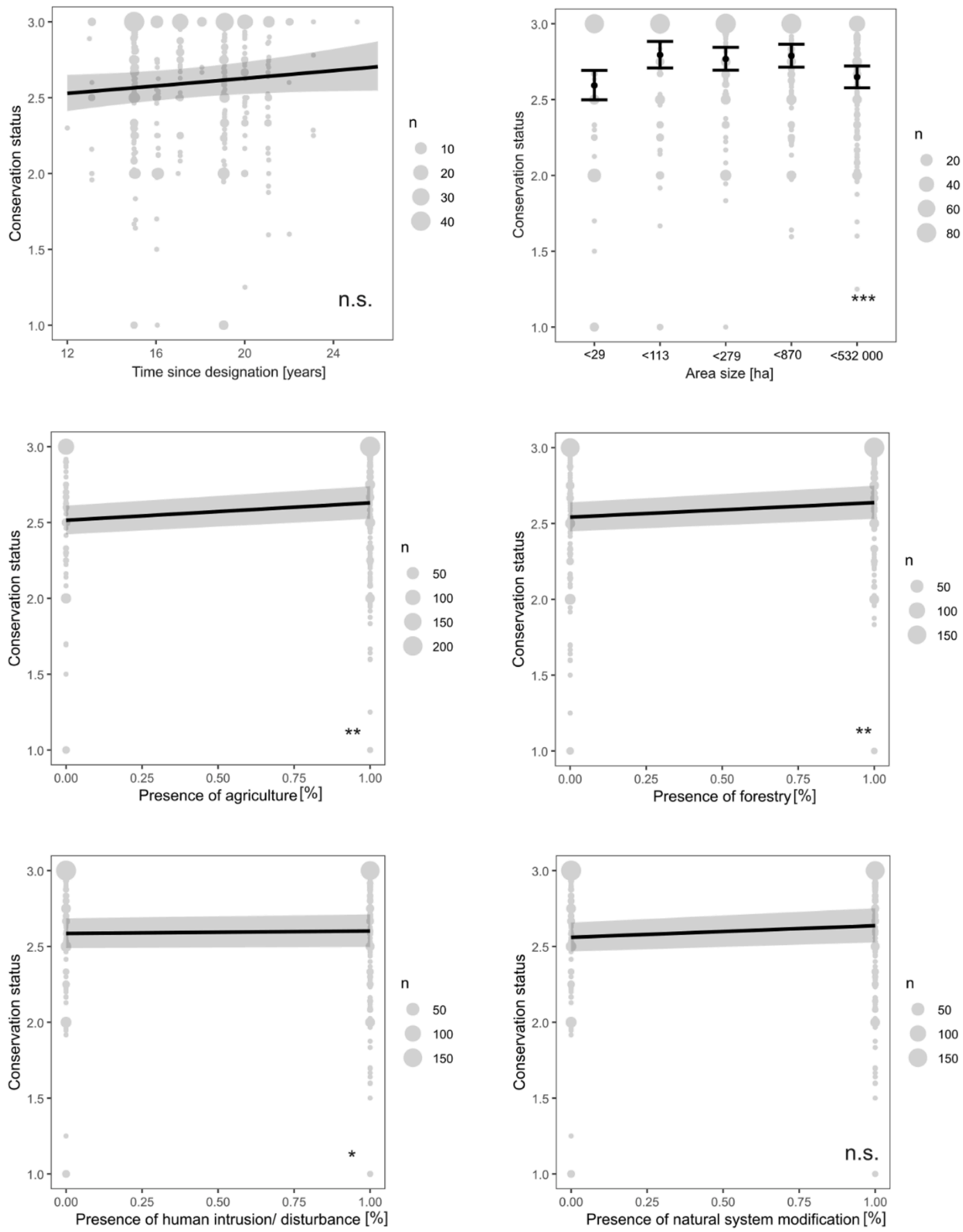

Fig. D2. Effects of all predictors included in the GLM on the conservation state of species. Ascending lines mean a worsening in conservation status. Grey shades show the 95 % confidence interval, grey circles represent raw data points. Asterisks indicate significance levels (*** < 0.001 < ** <0.01 < * <0.05 < non-significant). For full statistical results see Table 1 in the main publication.

References

Aggestam, F., Konczal, A., Sotirov, M., Wallin, I., Paillet, Y., Spinelli, R., Lindner, M., Derks, J., Hanewinkel, M., & Winkel, G. (2020). Can nature conservation and wood production be reconciled in managed forests? A review of driving factors for integrated forest management in Europe. *Journal of Environmental Management, 268*, Article 110670. https://doi.org/10.1016/j.jenvman.2020.110670

Baylis, K., Honey-Rosés, J., Börner, J., Corbera, E., Ezzine-de-Blas, D., Ferraro, P. J., Lapeyre, R., Persson, U. M., Pfaff, A., & Wunder, S. (2016). Mainstreaming impact evaluation in nature conservation. *Conservation Letters, 9*(1), 58–64. https://doi.org/10.1111/conl.12180

Bengtsson, J., Ahnström, J., & Weibull, A.-C (2005). The effects of organic agriculture on biodiversity and abundance: A meta-analysis. *Journal of Applied Ecology, 42*(2), 261–269. https://doi.org/10.1111/j.1365-2664.2005.01005.x

Beninde, J., Veith, M., & Hochkirch, A. (2014). Biodiversity in cities needs space: A meta-analysis of factors determining intra-urban biodiversity variation. *Ecology Letters, 18*, 581–592. https://doi.org/10.1111/ele.12427

BirdLife, W.W.F., EEB, & FoEE. (2018). *The State of implementation of the birds and habitats directives in the EU*. https://wwfeu.awsassets.panda.org/downloads/Nature_Scorecards_Report_March2018.pdf.

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU), & Bundesamt für Naturschutz (BfN) (2020). *Die Lage der Natur in Deutschland. Ergebnisse von EU-Vogelschutz- und FFH-Bericht.* https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Naturschutz/bericht_lage_natur_2020_bf.pdf.

Brooks, M. E., Kristensen, K., Benthem, K. J., van-Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Mächler, M., & Bolker, B. M (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized Linear Mixed modeling. *The R Journal, 9*(2), 378. https://doi.org/10.32614/RJ-2017-066

Conference of the Parties (COP) (2022). Decision adopted by the conference of the parties to the convention on biological diversity. 15/4. Kunming-Montreal Global Biodiversity Framework, (2022). https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf.

Engelhardt, E. K., Bowler, D. E., & Hof, C. (2023). European Habitats Directive has fostered monitoring but not prevented species declines. *Conservation Letters, 16*(3). https://doi.org/10.1111/conl.12948

European Commision (EC). (2013). *Interpretation manual of European Union habitats*. https://cdr.eionet.europa.eu/help/natura2000/Documents/Int_Manual_EU28.pdf.

European Commision (EC). (2016). *Fitness check of the EU Nature legislation (Birds and Habitats Directives)*. https://commission.europa.eu/document/download/c23e061a-a04e-4e71-881a-9e7feb520321_en?filename=swd-2016-472-final_en.pdf.

European Commision (EC). (2021a). *Nature protection: Commission decides to refer GERMANY to the European Court of Justice over failure to properly implement the Habitats Directive*. https://ec.europa.eu/commission/presscorner/detail/en/ip_21_412.

European Commission (EC). (2021b). *Applying the degree of urbanisation: A methodological manual to define cities, towns and rural areas for international comparisons: 2021 edition.* https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-02-20-499.

European Environment Agency (EEA). (2019). *Reference list threats, pressures and activities. Last updated 04.04.2019*. Available at: Reference Portal for Natura 2000 (12). https://cdr.eionet.europa.eu/help/natura2000.

European Environment Agency (EEA). (2020). *State of nature in the EU - results from reporting under the nature directives 2013-2018*. https://doi.org/10.2800/705440.

European Environment Agency (EEA). (2025). *Natura 2000 barometer*. https://www.eea.europa.eu/data-and-maps/dashboards/natura-2000-barometer.

European Union (EU) (2011). Commission implementing decision of 11 July 2011 concerning a site information format for Natura 2000 sites. In *Official journal of the european union* (Vol. 30). https://eur-lex.europa.eu/eli/dec_impl/2011/484/oj/eng.

Fahrig, L. (2020). Why do several small patches hold more species than few large patches? *Global Ecology and Biogeography, 29*(4), 615–628. https://doi.org/10.1111/geb.13059

Fan, K., Delgado-Baquerizo, M., Guo, X., Wang, D., Wu, Y., Zhu, M., & Chu, H. (2019). Suppressed N fixation and diazotrophs after four decades of fertilization. *Microbiome, 7*(1), 143. https://doi.org/10.1186/s40168-019-0757-8

Fedrowitz, K., Koricheva, J., Baker, S. C., Lindenmayer, D. B., Palik, B., Rosenvald, R., & Gustafsson, L. (2014). Can retention forestry help conserve biodiversity? A meta-analysis. *Journal of Applied Ecology, 51*(6), 1669–1679. https://doi.org/10.1111/1365-2664.12289

Fox, J., & Weisberg, S. (2019). *An r companion to applied regression* (3rd edition). Sage publications (3.1.2).

Fuller, R. J., Norton, L. R., Feber, R. E., Johnson, P. J., Chamberlain, D. E., Joys, A. C., & Firbank, L. G. (2005). Benefits of organic farming to biodiversity vary among taxa. *Biology Letters, 1*(4), 431–434. https://doi.org/10.1098/rsbl.2005.0357

Gabriel, D., Sait, S. M., Kunin, W. E., & Benton, T. G. (2013). Food production vs. biodiversity: Comparing organic and conventional agriculture. *Journal of Applied Ecology, 50*(2), 355–364. https://doi.org/10.1111/1365-2664.12035

Geldmann, J., Coad, L., Barnes, M., Craigie, I. D., Hockings, M., Knights, K., Leverington, F., Cuadros, I. C., Zamora, C., Woodley, S., & Burgess, N. D. (2015). Changes in protected area management effectiveness over time: A global analysis. *Biological Conservation, 191*, 692–699. https://doi.org/10.1016/j.biocon.2015.08.029

Grass, I., Loos, J., Baensch, S., Batáry, P., Librán-Embid, F., Ficiciyan, A., & Tscharntke, T. (2019). Land-sharing/-sparing connectivity landscapes for ecosystem services and biodiversity conservation. *People and Nature, 1*(2), 262–272. https://doi.org/10.1002/pan3.21

Gray, C. L., Hill, S. L. L., Newbold, T., Hudson, L. N., Börger, L., Contu, S., Hoskins, A. J., Ferrier, S., Purvis, A., & Scharlemann, J. P. W. (2016). Local biodiversity is higher inside than outside terrestrial protected areas worldwide. *Nature Communications, 7* (1), Article 12306. https://doi.org/10.1038/ncomms12306

Haddad, N. M., Haarstad, J., & Tilman, D. (2000). The effects of long-term nitrogen loading on grassland insect communities. *Oecologia, 124*(1), 73–84. https://doi.org/10.1007/s004420050026

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., & Kroon, H. de (2017). >75 percent decline over 27 years in total flying insect biomass in protected areas. *PloS One, 12*(10), Article e0185809. https://doi.org/10.1371/journal.pone.0185809

Hartig, F. (2022). *DHARMa: Residual diagnostics for hierarchical (Multi-Level /Mixed) regression models* (0.4.6). R package.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). (2018). *The regional assessment report on biodiversity and ecosystem services for Europe and Central Asia. Summary for policymakers*. https://www.ipbes.net/assessment-reports/eca.

Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D. E., Coscieme, L., Golden, A. S., Guerra, C. A., Jacob, U., Takahashi, Y., Settele, J., Díaz, S., Molnár, Z., & Purvis, A. (2022). The direct drivers of recent global anthropogenic biodiversity loss. *Science Advances, 8*(45). https://doi.org/10.1126/sciadv.abm9982

Kail, J., Januschke, K., & Hering, D. (2023). Freshwater-related species richness in Natura 2000 sites strongly depends on the surrounding land use besides local habitat conditions. *Journal of Environmental Management, 340*, Article 118025. https://doi.org/10.1016/j.jenvman.2023.118025 (December 2022).

Kubacka, M., & Smaga, Ł. (2019). Effectiveness of Natura 2000 areas for environmental protection in 21 European countries. *Regional Environmental Change, 19*(7), 2079–2088. https://doi.org/10.1007/s10113-019-01543-2

Landesbund für Vogel- und Naturschutz in Bayern (LBV). (2023). *Deutschland muss in FFH-Schutzgebieten deutlich nachlegen*. https://www.nul-N.de/aktuelles/news/article-7715598-201976/deutschland-muss-in-ffh-schutzgebieten-deutlich-nachlegen-.html.

Langhammer, P. F., Bull, J. W., Bicknell, J. E., Oakley, J. L., Brown, M. H., Bruford, M. W., & Brooks, T. M. (2024). The positive impact of conservation action. *Science (New York, N.Y.), 384*(6694), 453–458. https://doi.org/10.1126/science.adj6598

Leroux, S. J., & Kerr, J. T. (2013). Land development in and around protected areas at the wilderness frontier. *Conservation Biology, 27*(1), 166–176. https://doi.org/10.1111/j.1523-1739.2012.01953.x

Luick, Rainer, Jedicke, Eckhard, Fartmann, Thomas, Großmann, Manfred, Ibisch, Pierre L., Potthast, Thomas, & Settele, Josef (2025). The implementation of the EU Nature Restoration Law. *Naturschutz und Landschaftsplanung (NuL), 57*(4), 16. https://doi.org/10.1399/NuL.119483

Melts, I., Lanno, K., Sammul, M., Uchida, K., Heinsoo, K., Kull, T., & Laanisto, L. (2018). Fertilising semi-natural grasslands may cause long-term negative effects on both biodiversity and ecosystem stability. *Journal of Applied Ecology, 55*(4), 1951–1955. https://doi.org/10.1111/1365-2664.13129

Ovaskainen, O. (2002). Long-term persistence of species and the SLOSS problem. *Journal of Theoretical Biology, 218*(4), 419–433. https://doi.org/10.1006/jtbi.2002.3089

Ricci, L., di Musciano, M., Sabatini, F. M., Chiarucci, A., Zannini, P., Gatti, R. C., Beierkuhnlein, C., Walentowitz, A., Lawrence, A., Frattaroli, A. R., & Hoffmann, S. (2024). A multitaxonomic assessment of Natura 2000 effectiveness across European biogeographic regions. *Conservation Biology, 38*(3). https://doi.org/10.1111/cobi.14212

Poschlod, P., & Braun-Reichert, R. (2017). Small natural features with large ecological roles in ancient agricultural landscapes of Central Europe - history, value, status, and conservation. *Biological Conservation, 211*, 60–68. https://doi.org/10.1016/j.biocon.2016.12.016

Rada, S., Schweiger, O., Harpke, A., Kühn, E., Kuras, T., Settele, J., & Musche, M. (2019). Protected areas do not mitigate biodiversity declines: A case study on butterflies. *Diversity and Distributions, 25*(2), 217–224. https://doi.org/10.1111/ddi.12854

Rodrigues, A. S. L., & Cazalis, V. (2020). The multifaceted challenge of evaluating protected area effectiveness. *Nature Communications, 11*(1), 5147. https://doi.org/10.1038/s41467-020-18989-2

Rösch, V., Tscharntke, T., Scherber, C., & Batáry, P. (2015). Biodiversity conservation across taxa and landscapes requires many small as well as single large habitat fragments. *Oecologia, 179*(1), 209–222. https://doi.org/10.1007/s00442-015-3315-5

Sundseth, K. (2009). *Natura 2000 in the Continental Region 2 Natura 2000 in the Continental Region European Commission Environment Directorate General*. https://doi.org/10.2779/83178.

Sutherland, W. J., Taylor, N. G., MacFarlane, D., Amano, T., Christie, A. P., Dicks, L.v., Lemasson, A. J., Littlewood, N. A., Martin, P. A., Ockendon, N., Petrovan, S. O., Robertson, R. J., Rocha, R., Shackelford, G. E., Smith, R. K., Tyler, E. H. M., & Wordley, C. F. R (2019). Building a tool to overcome barriers in research-implementation spaces: The Conservation Evidence database. *Biological Conservation, 238*, Article 108199. https://doi.org/10.1016/j.biocon.2019.108199

Tsiafouli, M. A., Thébault, E., Sgardelis, S. P., Ruiter, P. C.de, van der Putten, W. H., Birkhofer, K., & Hedlund, K. (2015). Intensive agriculture reduces soil biodiversity across Europe. *Global Change Biology, 21*(2), 973–985. https://doi.org/10.1111/gcb.12752

UNEP-WCMC, & IUCN. (2025). *Protected Planet Report 2024*. https://livereport.protectedplanet.net/.

Watts, K., Whytock, R. C., Park, K. J., Fuentes-Montemayor, E., Macgregor, N. A., Duffield, S., & McGowan, P. J. K. (2020). Ecological time lags and the journey towards conservation success. *Nature Ecology and Evolution, 4*(3), 304–311. https://doi.org/10.1038/s41559-019-1087-8. Nature Research.

Wirth, C., Bruelheide, H., Farwig, N., Marx, J.M., & Settele, J. (2024). *Faktencheck Artenvielfalt. Bestandsaufnahme und perspektiven für den erhalt der biologischen Vielfalt in Deutschland.* oekom science. https://www.oekom.de/9783987260957.