Why do people misperceive long-term environmental change?

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Abstract

Environmental sciences seek to provide an unbiased quantitative and mechanistic basis for decision making, but conservation and management are often driven by personal perception of the environment. This, in turn, is made up of personal experiences, information exposure, personal values and beliefs. When documented changes in the natural world are in dissonance with people's perceptions, unintended environmental consequences (e.g. overlooked degradation, unacknowledged conservation successes) may occur. Here we compare long-term changes in the abundance of trees and birds and human perception thereof. We identify mismatches and personal characteristics driving these mismatches. We find that people were more often wrong than right (66% of the cases) in their assessment of species' changes that occurred in their lifetime, and change blindness prevailed as a perception phenomenon. Importantly, when species populations increased, respondents often exhibited change blindness, while population declines were more accurately perceived. This finding underlines the importance of relying on hard data rather than perception for decision making. Our study has implications for conservation science, restoration and land management practice, for which we recommend that (long-term) decision making should integrate hard monitoring data to mitigate the effects of change blindness and shifted baselines.

Keywords: human perception, long-term ecological change, historical datasets, shifting baseline syndrome, change blindness

Introduction

People's decision making, including conservationists and land managers, is often based on personal perceptions, i.e. individual observations and interpretations thereof (Bennett, 2016). Perceptions, in turn, are coloured by knowledge, experiences, information exposure, expert-based opinions, socio-demographic backgrounds, cultural values and ethics (Cosyns et al., 2020; Dietz, 2023; Haight et al., 2023; Wright and Bolger, 1992) as well as by the degree to which information aligns to personally held beliefs (confirmation bias, (Kappes et al., 2020)). When perceptions conflict with hard monitoring data, we speak of "misperception". In an attempt to support conservation, restoration and land management, environmental sciences seek to provide an unbiased data-founded and mechanistic basis for decision making and planning (Binkley, 2022; Sutherland et al., 2004; Thomas-Walters et al., 2021). But anecdotal evidence suggests that documented changes in the natural world are at times in dissonance with people's perceptions, possibly leading to unintended environmental consequences, a process broadly termed 'shifting baseline syndrome' (Papworth et al., 2009; Pauly, 1995; Soga and Gaston, 2018). To avoid the consequences of unintentionally overlooked processes, it is important to first understand if indeed documented environmental changes align with people's perception of those changes, and if they do not, identify the processes that lead to such dissonance.

The shifting baselines syndrome conceptual framework suggests that conservationists, decision makers and the general public may overlook environmental change due to a twofold psychological process in which the interplay of intergenerational and personal 'amnesia' leads to misperception of past environmental conditions (Jones et al., 2020; Papworth et al., 2009). As a consequence, personal and inter-generational amnesia undermines land management and conservation efforts because individuals plan interventions using already degraded or depleted ecosystems as baselines (Cammen et al., 2019; Clavero, 2014; Roman et al., 2015). Empirical evidence on these phenomena is still scarce and relies to a large extent on socially sourced information, often not considering the documented biological change in the ecosystem for comparison (Jones et al., 2020; Papworth et al., 2009). Such studies suggested, for example, that age, along with personal experience, are important drivers of the shifting baseline syndrome, highlighting that older and more experienced fishermen notice more species declines compared to novices (Lovell et al., 2018; Sáenz-Arroyo et al., 2005), or that senior members of communities are more aware of climate change (Soga and Gaston, 2018). But these examples contradict research from the fields of neuroscience, where increasing cognitive decline with age may also reduce the memory of past environmental conditions (Deary et al., 2009; Salthouse, 2012). How the interplay of age and experience affects the perception of long-term environmental change remains thus unclear.

Attributing people's perception to age and personal experience alone is a crude simplification of the very complex interactions of demographic and socio-cultural factors affecting perception of environmental change. Other demographic co-determinants of the shifted baselines have been suggested. Educational background, preferred information sources, cultural backgrounds or personal mobility may affect peoples' perception and predisposition towards experiencing shifting baseline syndrome (Jones et al., 2021; Soga and Gaston, 2018, 2016). However, little evidence is available that, indeed, these factors play a role in driving the perception of historical environments (Jones et al., 2021; Papworth et al., 2009). More so, the level of engagement and connectedness with the natural environment may also affect an individual's perception of historical conditions. There is little doubt remaining in the conservation world that feeling more connected to the natural environment leads to increased awareness of environmental issues, taxonomic knowledge and pro-environmental behaviours (Zhang *et al* 2014, Nisbet *et al* 2009, Berghöfer *et al* 2022, Mayer and Frantz 2004). But if indeed such increased connection to nature is also reflected in the perception of past conditions in the environment, or if those effects are trumped by stronger emotional or psychological phenomena remains unclear.

Emotions and preferences are likely to distort perceptions (Jayasinghe and Darner, 2020; Moesch et al., 2024; Phelps and Sharot, 2008; Zhang et al., 2014). When individuals feel emotionally attached to a species, they may exacerbate the threats to that species from a desire to protect it, a phenomenon that occurs often in the case of conservation flagship species (Douglas and Winkel, 2014). While promoting flagship species, individuals or events in conservation can increase awareness of species and the willingness to engage in conservation action (Jarić et al., 2024a, 2024b), it may also lead to an exacerbation of perceived trends in abundance of those species or a decreased awareness of counterpart species (Douglas and Winkel, 2014). Furthermore, humans are prone to confirmation bias, a process in which they align information or selectively accept information that aligns with their prior held beliefs (Kappes et al., 2020). In such cases, individuals may be reluctant to accept documented changes in an attempt to validate prior held beliefs or to reduce psychological discomfort - a phenomenon documented, for instance, in relation to recovering pinniped species in the US (Cammen et al., 2019). Altogether, how species changes over a long time interact with individuals' preferences and confirmation bias to produce perceptions remains largely unknown. It remains unclear in how far data provided by environmental research, e.g. long-term monitoring time series, align with human perception, and in cases when they do not, which are the demographic, socio-cultural or psychological drivers behind these mismatches.

To address this gap, our study aims to link documented changes in species abundances and human perception thereof at the scale of an individual's life experience, to identify mismatches and personal characteristics that drive these mismatches. In synthesizing the different combinations of environmental events and observer perceptions, Papworth et al (2009) have demonstrated that different conditions are required for perception phenomena to occur. We adapt the framework presented by Papworth et al (2009) for assessing the perception of trends in relation to documented trends to include four perception categories: accurate perception (*hard data and perception align*), change blindness *(change is reported in data, but not perceived by respondents*), shifted baselines (*change reported in data and perceived by respondents, but magnitude or direction are wrong*) and memory illusion *(no change reported in data but change is perceived by respondents*). We use the example of 18 tree and bird species changes in the Black Forest area of Germany to address the following two overarching goals:

a) Quantify the level of mismatch between documented change in species abundance (i.e. misperception) since the mid-20th century and human perception thereof.

b) Identify which individual characteristics may explain mismatches between documented and perceived change (i.e. misperception) and in which way. We hypothesize that age, mobility (how long individuals lived in the area, how many times they moved), personal connection to nature and preference for species will affect such mismatches.

Methods

Study region

We studied changes in tree and bird abundances in the Black Forest Region of Southern Germany (ca. 6000 km^2, *Supplementary Figure 1*), a conifer-dominated low mountain range characterized by a long tradition of multi-purpose land uses (Bauhus et al., 2009; von Carlowitz, 1713). Currently, the state forest management is aimed at increasing the biodiversity value of its production forests, but patterns differ amongst land owners (Asbeck et al., 2021; Storch et al., 2020). The long history of human use in the region led to periods of intensive forest uses, such as broad scale logging required to fund reparation costs after the Second World War, which affected the biodiversity and ecosystem functioning of the region (Stengele, 2007). The region's rich socio-ecological history, coupled with extensive historical data records, makes it a perfect case study for examining the congruence between species abundance data and public perception.

Ecological data

We reconstructed population change, defined as change in relative cover (trees) and abundance (birds), in eight tree species and ten bird species in the study area since the 1960s. Tree species abundance was reconstructed from historical and contemporary forestry statistics (German: *Forsteinrichtungsstatistik*) covering the Black Forest region at 10-year temporal intervals (ca. 6000 km^2). We reconstructed forest cover of eight of the most common and easily recognizable species that occur in the study region: spruce (*Picea abies*), fir (*Abies alba*), pine (*Pinus sylvestris*), Douglas fir (*Pseudotsuga menziesii)*, larch (*Larix decidua*), beech (*Fagus sylvatica*), oak (*Quercus* sp.) and maple *(Acer* sp.*)*. Oak and maple were not differentiated by species in the statistics, so genus level information was used. For each species, we compiled data on the total cover (ha) of the species in the study region for the 10 years interval using the reported values at the end of a decade (e.g. 2000). The reported value was assigned to the mean year of the interval, and all other values in between were linearly interpolated using the na.approx of the zoo package in R (Zeileis et al., 2004). For a full description of the data collection, data sources and results of the species area changes in the Black Forest ecoregion see *Supplementary Material S2*.

We reconstructed long term changes in bird species populations since the 1960s for 10 bird species including black woodpecker (*Dryocopus martius*), capercaillie (*Tetrao urogallus*), European robin (*Erithacus rubecula*), green woodpecker (*Picus viridis*), magpie (*Pica pica*), Eurasian jay (*Garrulus glandarius*), fieldfare (*Turdus pilaris*), European blackbird (*Turdus merula*), nuthatch (*Sitta europaea*) and red kite (*Milvus milvus*). Species data was compiled primarily based on red lists at the level of the state of Baden-Württemberg (Anonymous, 1974; Bauer et al., 2019; Hölzinger et al., 2008) and, where possible, complemented with references from specialized literature (Hölzinger, Jochen, 1999; Walz, 2000; Westermann, 2006). Species were chosen based on their described population trend in the red lists (to cover both increases and decreases), and based on species identification ease (ornithologist expert advice) to avoid species confusion. We note that population estimates in the Red Lists are based on a combination of expert opinion and territory mapping. Where available, data was complemented with published estimates of population size. For example, for the capercaillie, monitoring data specific to the Black Forest area was used (number of displaying males) (Coppes et al., 2016). For each species, we used the number of breeding pairs or number of territories, and in the case of capercaillie, the number of males as indications for population size at the times when counts were available and linearly interpolated all other values using the na.approx of the zoo package in R (Zeileis et al., 2004). Linear interpolation was used as a generalizable approach applicable both to tree and bird changes because the exact nature of the changes between known data points was uncertain and time intervals relatively small. For a full description of the data collection, data sources and results of the species area changes in the Black Forest ecoregion see *Supplementary Material S2.*

Perception data

We conducted a large-scale questionnaire on human perception of bird and tree changes in the Black Forest using the Qualtrics Platform ("Qualtrics XM," 2023). The questionnaire was piloted with 30 participants in December 2022 and responses were collected between March 2023 and January 2024. Participants were recruited through non-random sampling techniques targeting academics, conservation and forestry practitioners, as well as the general public who live or work in the Black Forest region or have done so in the past. Questionnaires were distributed online and made available in both English and German language. We advertised the questionnaires analogously (posters, flyers, mini-exhibitions at science events) and digitally (e-mail lists, websites, social media). The expected completion time for the questionnaire was 15 minutes. Respondents were pre-selected based on two criteria: they must have lived or worked in the Black Forest region and be over 18 years old (the selected baseline for analysing perception within their lifetime) (see *Supplementary Material S3* for full questionnaire).

For assessing the respondents' perception of the selected species and their change over time, we first asked people to identify the selected bird and tree species, including two control bird species (American robin and cardinal) and two control tree species (baobab and eucalypt) and subsequently carried out the analyses with only those species that were recognized and named correctly by respondents. Species identification was based on modified textbook images: for birds, we used species drawings provided by the Royal Society for the Protection of Birds (RSPB, 2023) and for trees, tree silhouette, leaf and fruiting body modified after (Hempel and Wilhelm, 1889). For naming the species, a dropdown menu of all species included in the questionnaire was provided. We asked each respondent how each species changed in its abundance on a 5-step Likert scale (strong decline, decline, no change, increase, strong increase) in relation to the selected personal baseline at age 18, which serves as a 'memory anchor', enabling easier recall of experience-based episodic memory and comparison across individuals (Havari and Mazzonna, 2015). In addition to species recognition and change information, we also collected socio-demographic data, including age (year of birth), gender, time lived in the Black Forest region, level of education, and living and working conditions. Further, we asked for the amount of time spent outdoors, preferred information sources and nature relatedness based on the NR6 index developed by (Nisbet et al., 2009; Nisbet and Zelenski, 2013) (full list of variables and summary statistics in *Supplementary Material S4*).

Data matching, analyses and modelling

For each respondent and species, we calculated the documented and perceived change during their adult life, and assigned their combination to one of the possible four outcomes: accurate perception (*hard data and perception alingn*), change blindness *(change is reported in data, but not perceived by respondents*) , shifted baselines (*change reported in data and perceived by respondents, but magnitude or direction are wrong*) and memory illusion *(no change reported in data but change is perceived by respondents*) (*Fig. 2*a). To do so, we first calculated the percentage rate of change for each tree and bird species for every year between 1960 and 2023, aligning the changes to the Likert scale from the questionnaire based on the year of birth of each respondent. For trees, we defined changes as follows: increases over 5% in the species area (ha) indicated a species increase, changes within -5% to 5% indicated stability, and decreases over 5% in the area covered by the species (ha) indicated a decline in the species areas. For birds, population changes greater than 50% were considered large increases or decreases, changes between 20% and 50% were marked as increases or decreases, and fluctuations within -20% to 20% were classified as stable, following the Red List population change criteria (Bauer et al., 2019). We calculated for each species two values for each participant: the perceived change since age 18 (represented on the x-axis in *Fig. 2*a) and the documented change since turning 18 (y-axis in *Fig. 2*a).

To compare the prevalence of the different perception phenomena, we assessed the abundance of each category across all selected species as well as across species trends. To evaluate the relative importance of individual characteristics in perceiving change, as well as to assess how selected personal characteristics may drive perception, we modelled the occurrence of the different perception categories (accurate perception, shifting baselines, change blindness). For each response type we used a boosted regression tree with binomial distribution (Elith et al., 2008; Hijmans et al., 2020) to model the occurrence of the perception phenomena. We did not model outcomes for memory illusion because the phenomena was a) relatively rare (small sample size), and b) largely reliant on distinct psychological phenomena. We parameterized the model with a maximum of 20,000 trees using the gbm.step function in R's dismo (Elith et al., 2008; Hijmans et al., 2020). Data points were weighted to sum to the same value for each species to create balanced responses. We allowed for three-way interactions, used a bag fraction of 0.5 (50% of the data used at each model fit) and 5-fold cross validation. Our model included variables related to the species (species identity, species change trend since a person's age 18), demographic variables (age, no. of times a person moved in their lifetime, no. of years they lived in the Black Forest, rurality of living environment) as well as variables that captured individual's connectedness to nature (NR6, time spent in natural spaces/week, working time spent outdoor). For variable description and summary statistics, see *Supplementary Material S4.* We computed the relative influence of each variable in the model and assessed model performance based on the sensitivity-specificity relationship and reported the areas under the received operator curve (Friedman, 2001; Ridgeway and Developers, 2003). We relied on a stratified bootstrapping approach where we randomly sampled respondents including all their observations to generate partial dependence plots that indicate the strength and the direction of the effect when all other variables are kept at their median or mode. Statistical analyses and data processing were performed using the R software (R Core Team, 2023), utilizing the R packages: 'dplyr' and 'tidyr' for data manipulation (Wickham et al., 2023), 'ggplot2' for data visualization (Wickham, 2016) and 'gbm', 'dismo' and 'pdp' for modelling and results interpretation (Greenwell, 2016; Hijmans et al., 2020; Ridgeway and Developers, 2003). To ensure robustness of our modelling approach, we compared our results with those obtained through a traditional mixed-effect-model approach, using the respondent id and species as nested random effects (*Supplementary Material S5*) but decided for the machine learning approach because of its flexibility and fewer assumptions.

Results

Change in species abundance since mid-20th century

Since the 1960s, the total area of occupancy of the selected tree species has changed from 229,400 ha to 221,500 ha. Using the absolute area change (ha) between the 1960s and 2023, we identified a change in the area covered by most species: spruce (-7%), fir (-34%) and pine (-52%), Douglas fir (+420%), larch (+10%), beech (+37%), oak (+5%) and maple (+860%) (Fig 2). The results of our bird population interpolation since the 1960s followed the general species trends of the Red List of BW: the blackbird (+230%), red kite (+1800%), jay (+37%), nuthatch (+120%), magpie (+45%), capercaillie (-73%), fieldfare (-93%). For robin (<+1%), black woodpecker (+7%) and green woodpecker (+12%), no substantial long-term population changes were reported (Fig 2). All values for population estimates are based on breeding pairs or territories. Overall, the documented changes provide a large variability in trends that can be exploited for our analyses. A detailed description of each species changes and data values is presented in *Supplementary Material S3.*

Perception of ecological change since the mid-20th century

We collected 311 usable questionnaire responses, which resulted in a total of 4095 observations of all tree (n=1950) and bird (n=2145) species across all respondents. On average, respondents were able to correctly name 94% of the species that they visually recognized. Spruce, beech and oak were the most recognized species among respondents. Average respondent age was 48 years (range: 20-80), and median time lived in the Black Forest region 28 years (range: 0-80). More than 80% of the respondents had moved at least once in their lifetime. 43% of the respondents were female, and the nature relatedness (NR) score was 3.05 (on a 1-5 scale), with a median amount of time spent outdoors being 14 h/week *(Supplementary Material S4).*

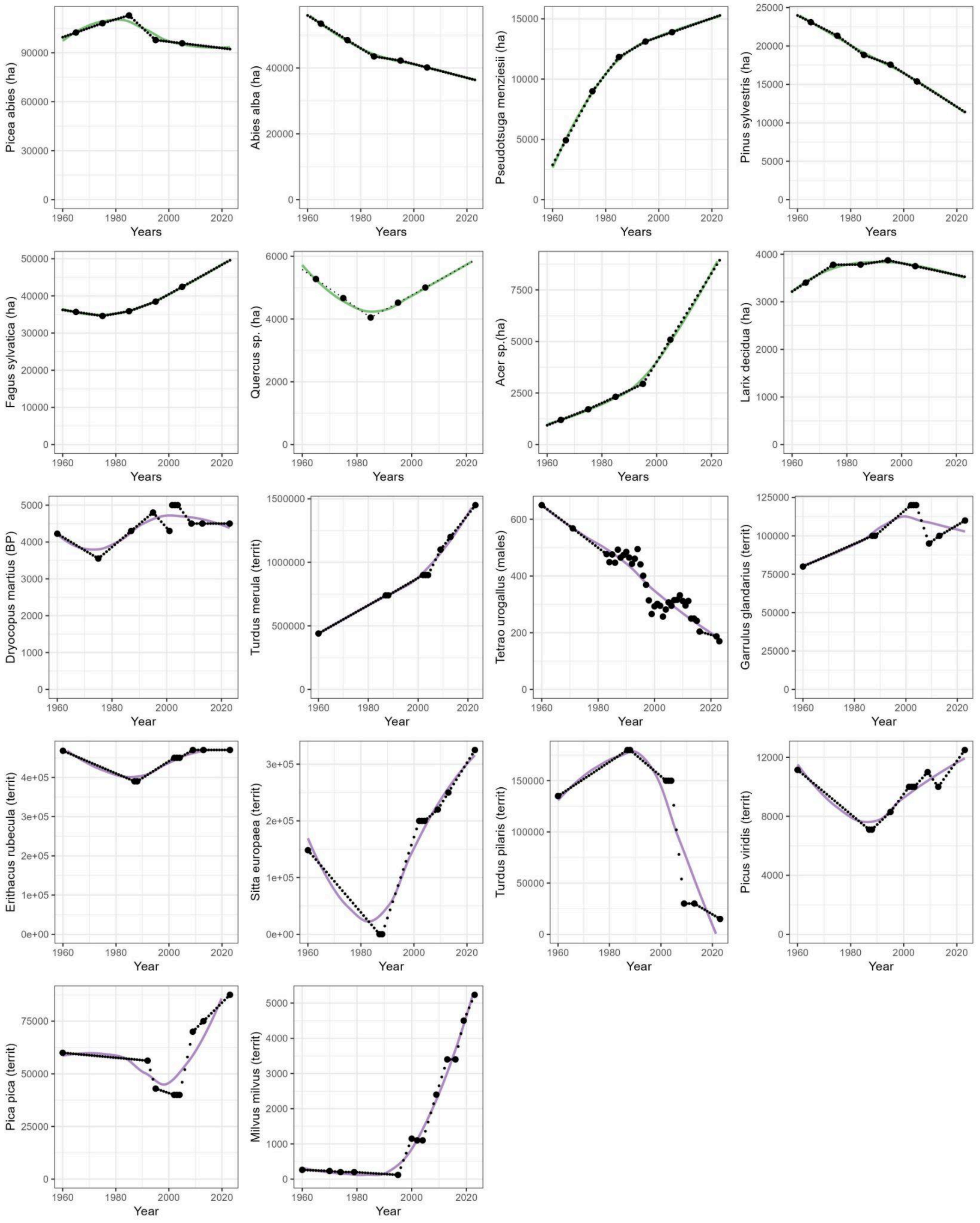

Fig. 1 Change in eight tree (green) and ten bird species (purple) since the 1960s. Tree data represents overall species area trends (ha) for the Black Forest ecoregion; bird data represents overall population size changes (breeding pairs or territories or displaying males) for the state of Baden-Württemberg, Germany. Lines represent data smoothed using the Locally Weighted Scatterplot Smoothing (LOWESS) method. Larger black dots represent data extracted from literature, small black dots interpolated data.

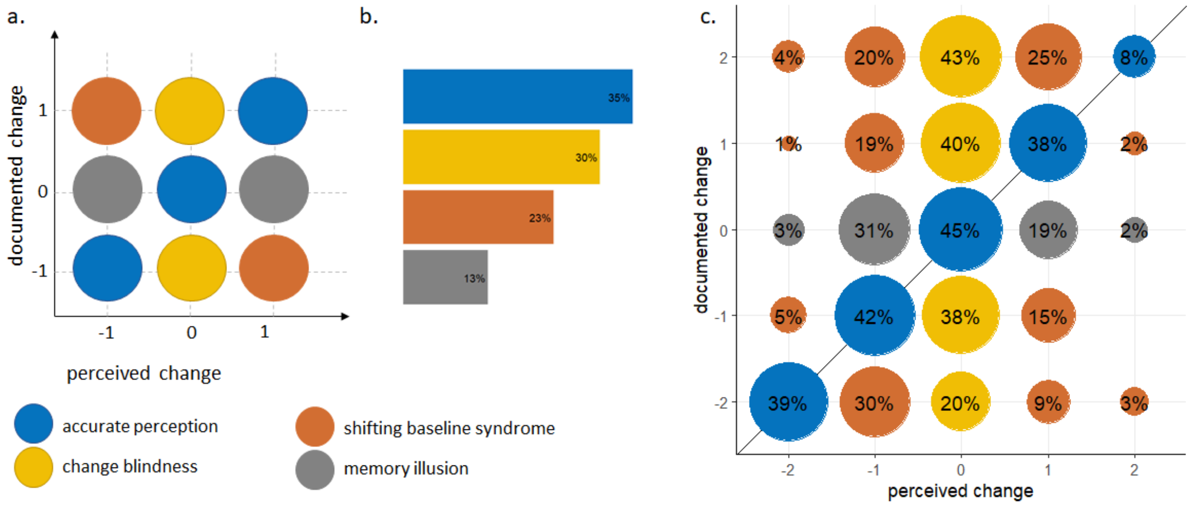

Fig. 2 a. Typology of different perception phenomena at individual level (adapted from Papworth et al 2009). The graphic denotes how documented change (y-axis, -1= decrease of a species population, 0= stable population, 1=increasing population) and perceived change (x-axis, , -1= perceived decrease of a species population, 0= perceived stable population, 1=perceived increasing population) combine to create different phenomena like accurate perception or change blindness. b. Proportion of each perception event occurring across the entire sample (N=4095) and c. proportion of each perception event occurring within each of the 5 possible data trends (strong decrease -2 to strong increase 2).

Across all 18 study species and all respondents, only 34% of the responses were accurate in terms of aligning trends in documented and perceived change (including 10% accurate static perception and 24% accurate change perception *(Fig. 1b*). More individuals experienced change blindness (29% n=1219) than shifting baseline syndrome (22%, n=1110). When compared within a selected trend species (i.e. horizontal entries in the perception matrix) for each change trend, inaccurate perception was occurring more often than not (*Fig. 2c)*. Importantly, when species data indicated increases in population size, respondents tended towards change blindness (overall, but especially for species like blackbird, magpie, nuthatch), and when species declined, a higher proportion of responses were accurate (e.g. capercaillie, *Fig. 1c, Supplementary Figure S5)* When looking at trees alone, 38% respondents were accurate in their perception (n=797), but change blindness was also prevalent across all species (n=688). For birds, we encountered more instances of shifted baselines (n=761) than accurate (29%, n=624) or change blindness (n=531), but patterns differed greatly amongst individual species (*Fig. 1, Supplementary Figure S5).*

Model performance and variable contribution

Models explaining perception performed overall well (cross-validation AUC > 0.75:accurate perception: 0.78, change blindness: 0.88, shifting baseline syndrome: 0.82, *Supplementary Figure S6*). Pseudo-R^2 values ranged between 0.22 and 0.43 (accurate perception: 0.22, change blindness: 0.43, shifting baseline syndrome: 0.*33; Supplementary Figure S7).* Across the three models, the largest proportion of variance explained was captured by variable 'species' (accurate perception: 56%, change blindness: 59%, shifting baseline syndrome: 56%), followed consistently by the data trend of the species (8-14%) and age (5-7%). NR6, mobility and species preference explained only a small proportion of the variance (3-5%, *Supplementary Figure S7*). The variables capturing formal education, media consumption or reliance on personal experience each explained less than 2% of the full model variance.

Drivers of perception: age, mobility, NR

We did not find support for either of the shifting baseline syndrome or cognitive decline expectations related to age. Our models indicate that all individuals are (equally) inaccurate in judging population change that they experienced within their lifetime. The variable ‘age’ contributed approx. 7% of the variance, and we found a slight tendency that middle aged individuals (age 30-50) are more accurate in their perception and that older individuals (age >60) are more blind to change – however, when averaging predictions across model subsets, this effect remains very small *(Fig. 3*). We also did not find any support for the mobility hypothesis – individuals were neither more accurate, nor more likely to experience change blindness or shifting baseline syndrome across different mobility patterns *(Fig. 3*). Furthermore, the two mobility variables (number of years lived in the Black Forest Region and number of times moved) had less than 2% contribution to model explanatory power. We found that individuals who scored higher on the NR6 scale tended to be more accurate about past change (variable importance 3%) and less change blind (variable importance 5%), but we note that the probability of accuracy still lies below 50% in all cases *(Fig. 3d*).

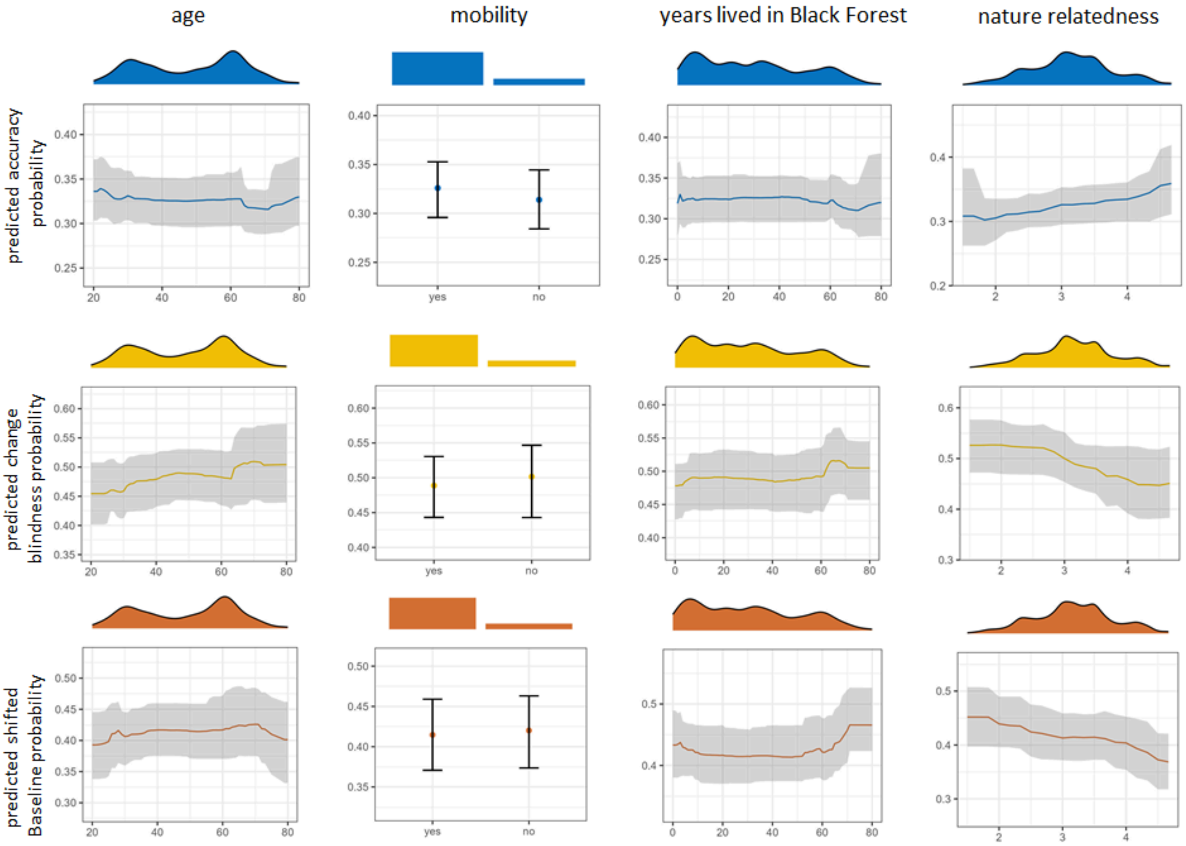

Fig. 3 Partial dependence plots showing the effect of age, mobility expressed as whether a person moved house in their lifetime or not and number of years that they lived in the Black Forest region and effect of nature-relatedness index on accurate perception, change blindness and shifting baseline syndrome. Y-axis represents probability of perception phenomena occurring (blue= accurate, yellow =change blindness, orange = shifted baseline). Top of the graphs are response distributions across the variable ranges. Error envelopes were computed using bootstrapping.

Drivers of perception: species preference and trends

The variable “species” had the largest contribution to the models’ variance explained and we found significant differences across the 18 species studied: people tended to be most accurate about the trends in Douglas fir (*Pseudotsuga menziesii*), jay (*Garrulus glandarius),* European robin (*Erithacus rubecula*) and capercaillie (*Tetrao urogallus*). Conversely, the probability of respondents experiencing change blindness was highest for Scots pine (*Pinus sylvestris*) and larch (*Larix decidua*) as well as for fieldfare (*Turdus pilaris*) and nuthatch (*Sitta europaea*) (*Fig.*

4a). We hypothesized that these differences would be explained by an individual's preference for specific species, but this was not confirmed by our analysis – most people reported to like all species, with no substantial differences across levels of accuracy along the species preference Likert scale (*Fig. 4c)*. However, we found a significant difference in probability of occurrence of accurate perception, change blindness and shifted baseline depending on species trend: the probability of accuracy was significantly lower for ‘increasing’ species *(Fig. 4b)* than for ‘declining’ or ‘stable’ species. Similarly, change blindness and shifted baselines were more likely to occur for ‘increasing’ species than for ‘declining’ ones *(Fig. 4b)*. Overall, respondents were more accurate about species declines and experienced lower rates of change blindness or shifting baseline syndrome when delines happened, but they tended to be affected by negativity bias when it comes to historical environmental change (i.e. perceived declines where there are none).

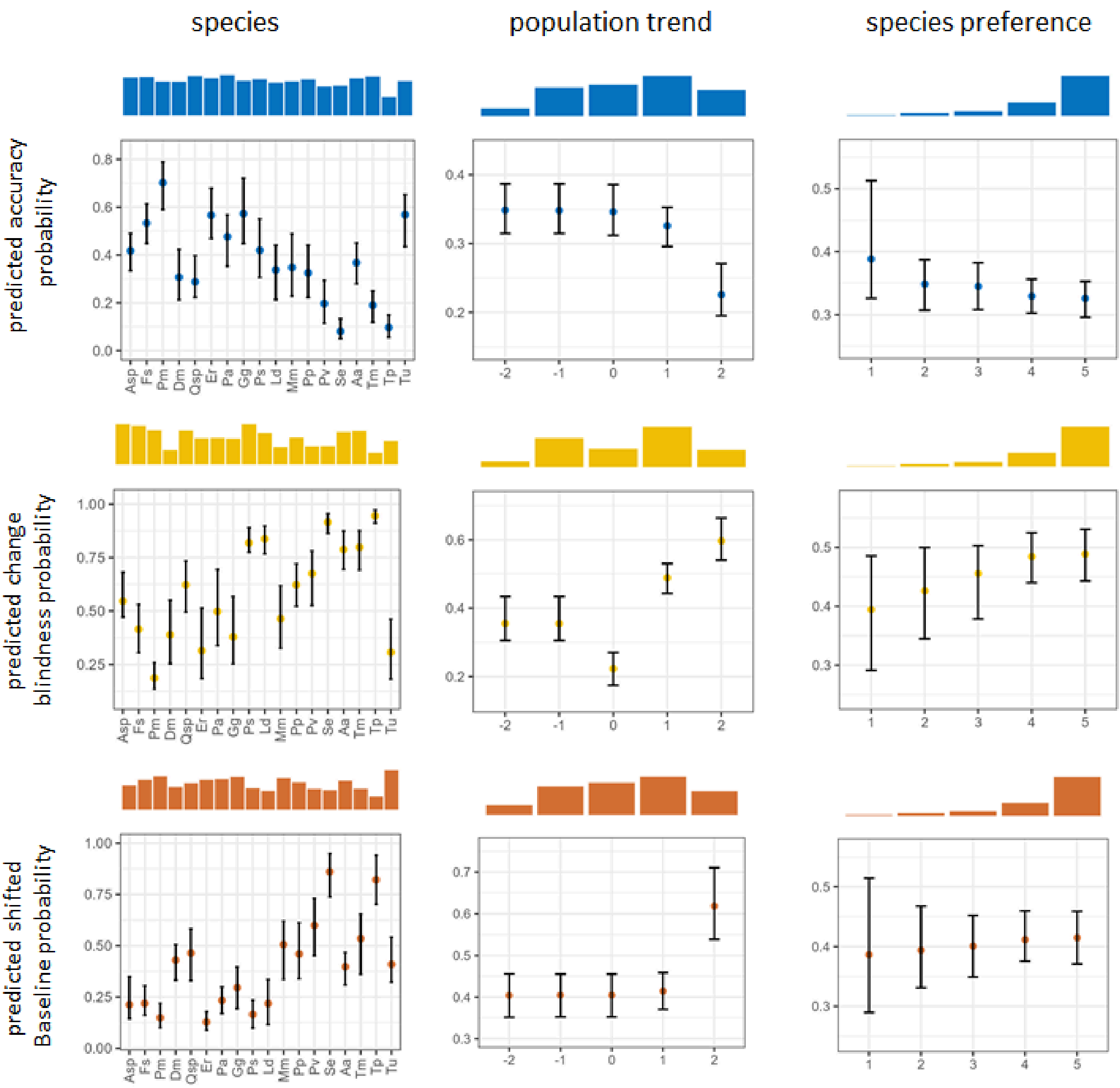

Fig. 4 The effect of species, species population trend (strong decrease, -2 to strong increase 2) and c) species preference (1 strong dislike to 5 strong like) on accurate perception (blue), change blindness (yellow) and shifted baseline (orange). Color bars indicate data distributions. Species abbreviations: Aa: Abies alba; Dm: Dryocopus martius; Er: Erithacus rubecula; Fs: Fagus sylvatica); Gg: Garrulus glandarius; Ld: Larix decidua; Mm: Milvus milvus; Pa: Picea abies; Pm: Pseudotsuga menziesii; Pp: Pica pica; Ps: Pinus sylvestris; Pv: Picus viridis; Qsp: Quercus sp.; Asp: Acer sp.; Se: Sitta europaea; Tm: Turdus merula; Tp: Turdus pilaris; Tu: Tetrao urogallus

Discussion

Our results on mapping documented and perceived environmental change of 18 bird and tree species in the Black Forest region of Southern Germany revealed that people often misperceive population changes that occurred in their lifetime (66% of the cases). Moreover, we highlight that change blindness prevails as a perception phenomenon, where people largely do not acknowledge changes that have occurred in their adult life. The accuracy of perception varies greatly amongst species. Most interestingly, even after accounting for species, socio-demographic factors (age, education, personal mobility, nature relatedness and media reliance) as well as for species preferences, our respondents' perceptions are substantially different across species trends. Specifically, we found that change blindness and shifted baselines are more likely to occur when species are increasing compared to when they are declining and that overall accuracy is slightly higher for declining compared to stable or increasing species.

Contrary to our expectation that people will correctly recognize the trends for the most common bird and tree species in the area they live and for the period of time they experienced, our findings reveal a substantial discrepancy between documented and perceived environmental change (only 34% of accurate responses). While conservation science long acknowledged the personal and inter-generational mechanisms behind the shifting baseline syndrome (Jones et al., 2020; Papworth et al., 2009; Soga and Gaston, 2018), the observed low rates of accuracy in perception strengthen existing conservation concerns that such mechanisms may impact conservation action when individuals are involved in management or conservation decision making (Jones et al., 2021; Pauly, 1995) or may affect the general public willingness to engage in (pro-)environmental and conservation behaviour (Mónus, 2021; Soga and Gaston, 2018, 2016).

Despite the majority of perceived trends not aligning with documented ecological change, this is not entirely surprising from a psychological perspective. Memory scientists estimate that when asked about real-world experiences from the past, people will be wrong in approx. 60% of the cases (for comparison, 66% in our study), and that this percentage will be affected by the age and the time since the experience occurred (Diamond et al., 2020). Importantly, details freely recalled from such one-time experiences can retain high correspondence to the ground truth despite significant forgetting (Diamond et al., 2020) - likely because the respondents' attention was focused exactly on those experiences. But when attention is focussed on a specific event, people can fail to notice other changes that occur in their environment, in a psychological phenomenon termed change blindness or attention bias (Simons and Levin, 1998). Indeed, some 30% of the responses in our sample indicated that, for certain species, people are 'blind' towards their population change, leaving the question open towards what drives this blindness.

We found that irrespective of respondents' preference for a species, accurate perception was significantly more likely to occur for declining species compared to increasing ones, and change blindness was more likely for increasing species. These results are in line with research on negativity bias, suggesting that losses loom larger than gains not just in an economic or financial setting (Kahneman, 1979, Baumeister 2001, Buijs and Jacobs 2021), but also in an environmental change context. In environmental contexts, a similar phenomenon has been documented when attention was focused on flagship species (Douglas and Winkel, 2014). We note that (with the exception of the capercaillie), the tree and bird species in our survey are common in the study area and are not of high conservation concern – or have not experienced exceptional conservation attention (Bauer et al., 2019). Despite this, trends in declining species are still more often accurately perceived than increasing trends. Species with notable increases in our sample throughout the study period that may be affected by negativity bias included Douglas fir, maple, blackbird, nuthatch and the red kite. Although increases in these species are not necessarily indicative of conservation successes in the Black Forest because no direct conservation measures were implemented to support species increase, we point out that the phenomena of people not acknowledging species increases is common in other parts of the world where endangered or threatened species are recovering (Roman et al., 2015).

Much of the negativity bias detected in our analyses may be attributed to the fact that conservation operates largely on ‘negative messages’(Swaisgood and Sheppard, 2010) but see (Johns and Jacquet, 2018) and to the fact that media coverage for declining species may be incomplete, biased towards NGOs over scientists, and exceeding the coverage of recovering species (Shiffman et al., 2021). Such negative messaging in the media could, in turn, increase the accuracy of perception for declining but not for increasing species (e.g. capercaillie, spruce). Although we did not find a significant effect of reliance on media-sourced information in our models, we caution that this effect is merely a self-reported value across species. The effect of media coverage of different species could in our analyses rather be captured by the ‘species’ variable. We speculate that media coverage of certain species may influence perception through priming effects, confirmation bias and anchoring memories of respondents (Hirst et al., 2015). Similar effects and the way memories change over time in emotionally loaded situations have already been demonstrated in the context of recollections of shocking news (e.g. Challenger space shuttle, September 11) (Bohannon, 1988; Hirst et al., 2015; Neisser and Harsch, 1992). Although this was beyond the goals of our study, we compared the number of media records since 1990 for the species of concern and indeed found that media coverage in the study region varies greatly across species *(Supplementary Material S9*). Amongst our study species, oaks, beech, spruce and capercaillie had the largest media coverage, while green and black woodpecker, fieldfare and blackbird had nearly no media coverage since 2000 (*Supplementary Material S9*). These results suggest that a moderate to high amount of media coverage, such as those of Douglas fir (*Pseudotsuga menziesii*), jay (*Garrulus glandarius*) and European robin (*Erithacus rubecula*), may increase awareness and improve perception accuracy. This is in line with recent theories suggesting that a moderate (versus very low or very high) amount of politicization and media coverage is most efficient in achieving policy changes (Feindt et al., 2021). Perception, and therefore also conservation or management action implementation may therefore benefit from a moderate media coverage.

We did not find support for either the shifted baseline or cognitive decline expectations related to age or mobility. Anecdotal evidence on the occurrence of the shifting baselines syndrome suggests that older individuals may be more accurate in their perception of historical environmental conditions. However, with few exceptions (e.g., Jones *et al* 2020), most studies did not consider the paired effects of perceived and documented data within an individual’s experience. As a result, these studies often provide only a snapshot of an individual's professional or environmental experiences (Sáenz-Arroyo et al., 2005; Soga and Gaston, 2018). On the other hand, although cognitive decline with age may be expected (Berman et al., 2008; Deary et al., 2009; Salthouse, 2012), we did not find evidence for declining memory of environmental change with age. Rather, our findings related to age are in line with those found in psychological studies that investigated memory of real-world experiences and found that general trends across age groups are similar although a large proportion of the information is forgotten when the experiences in question reach a few years back (Diamond et al., 2020). Furthermore, research showed that both young and older individuals remember their childhood circumstances well (health status and living conditions) (Havari and Mazzonna, 2015), contributing to a growing body of work suggesting that it is not age but rather more subtle psychological phenomena affecting their perception of historical environmental change. Notably, attention heuristics likely contribute to the attention of respondents being focused on rather few species, for which they remember long term trends well, making the trends in other species to be largely ‘forgotten’ (Kahneman, 2011; Simons and Levin, 1998). Last but not least, we found a small but positive effect of NR6 on perception of historical trends, in line with the hypothesis that higher interaction with nature improves cognitive function (Berman et al., 2008) confirming that the NR6 index can capture aspects of human-environment interactions (Nisbet and Zelenski, 2013).

The results of our analysis are unambiguous and consistent across different analyses approaches (*Supplementary Material S5*). The low overall variance explained by our models

(Supplementary Figure S7) indicates that there are other processes at play that affect perception. Specifically, it is well recognized that, amongst others, cultural and personal values and beliefs (Chwialkowska et al., 2020), social norms (Helferich et al., 2023), political orientation (Birch, 2020; Cheung et al., 2019) the experience of traumatic life-events (de Vito et al., 2009) can affect both perception of the environment as well as the willingness to engage in environmental type actions. Further, contextual information about the time when people recall the past, such as emotional disposition at the time of response, attention or tiredness (Buijs and Jacobs, 2021; Jayasinghe and Darner, 2020; Martell and Rodewald, 2024) can influence the accuracy of participants' responses. We further acknowledge several limitations in our datasets that may affect the strength of the effects we observe. A spatial mismatch exists between the extent of the 'documented datasets' (for birds, this was the area of the state of Baden-Württemberg; for trees, the Black Forest ecoregion), but to our knowledge, these data represent to date the best broad-scale datasets for the length of the selected time period. Furthermore, Red List assessments, as those used in the bird analyses, are compiled from both territory mapping data and expert knowledge suggesting that our data may capture an implicit bias that we cannot account for in this analysis. Further, although we specifically asked respondents to report their perception of trends throughout the Black Forest ecoregion, some may ground this perception in their locally observed changes (e.g. personal garden) - a phenomenon that we could not directly control for in our models. However, because most species in our sample are common (with the exception of the capercaillie), we expect that trends will be largely generalizable across scales. Last but not least, at the time of the analyses, no recent data (since approx. 2015) was available for either trees or birds at broad spatial scales, and our data for the last 10 years are based on a business-as-usual extrapolation. Last but not least, our sample of respondents was non-random and may be biased towards people who have close work or personal relationships with the natural environment. We would expect that such elements may induce further uncertainty and bias in our dataset towards even higher rates of change blindness or shifted baselines in the general public. Overall, our estimates here remain conservative.

In this study, we exclusively assessed personal amnesia, or individual remembrance of events that occurred within respondents' lifetime (Jones et al., 2020; Papworth et al., 2009), but another important component of the shifting baseline theory refers to the loss of environmental information across generations, leading to a gradual and unintended acceptance of progressive environmental degradation (Ainsworth et al., 2008; McClenachan, 2009; Pauly, 1995). To consistently assess *inter-generational* information transfer, accurate measurements of a) what individuals know, b) the sources of knowledge and c) how much of that knowledge gets transferred to subsequent generations is necessary. Our work contributes to the first two points. We acknowledge that the inter-generational information transfer (or lack thereof) may also affect individual perception, but this element is still very hard to quantify and remains beyond the scope of this study.

Our study has implications for conservation science and for restoration and land management practice. Importantly, we provide evidence for the existence of strong mismatches between documented and perceived historical environmental change. Our data suggests that conservation and restoration action should not rely solely on data or information from human observers, nor on data from expert knowledge alone (such is the case for some Red Lists assessments) because these are prone to misperception. This may affect the allocation of conservation and restoration priorities. Importantly, our work highlights that the integration of both social and ecological datasets may shed light on processes, interdependencies and mechanisms that may otherwise remain overlooked. Our study also provides evidence that species increases are significantly less accurately perceived than species declines - suggesting that more focus should be given to 'positively framed' environmental messages in both research and public awareness – which in turn could improve perception of environmental conditions and processes.

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Author contributions

CM conceptualized the study, CM, RSS, TKL, SM designed the survey, CM, SR collected and pre-processed the data, CM, CFD, JK analyzed and interpreted the data, CM wrote the initial manuscript, IS, CS, GS acquired funding, all authors revised and agreed with the manuscript.

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Supplementary Material

for

Why do people misperceive long-term environmental change?

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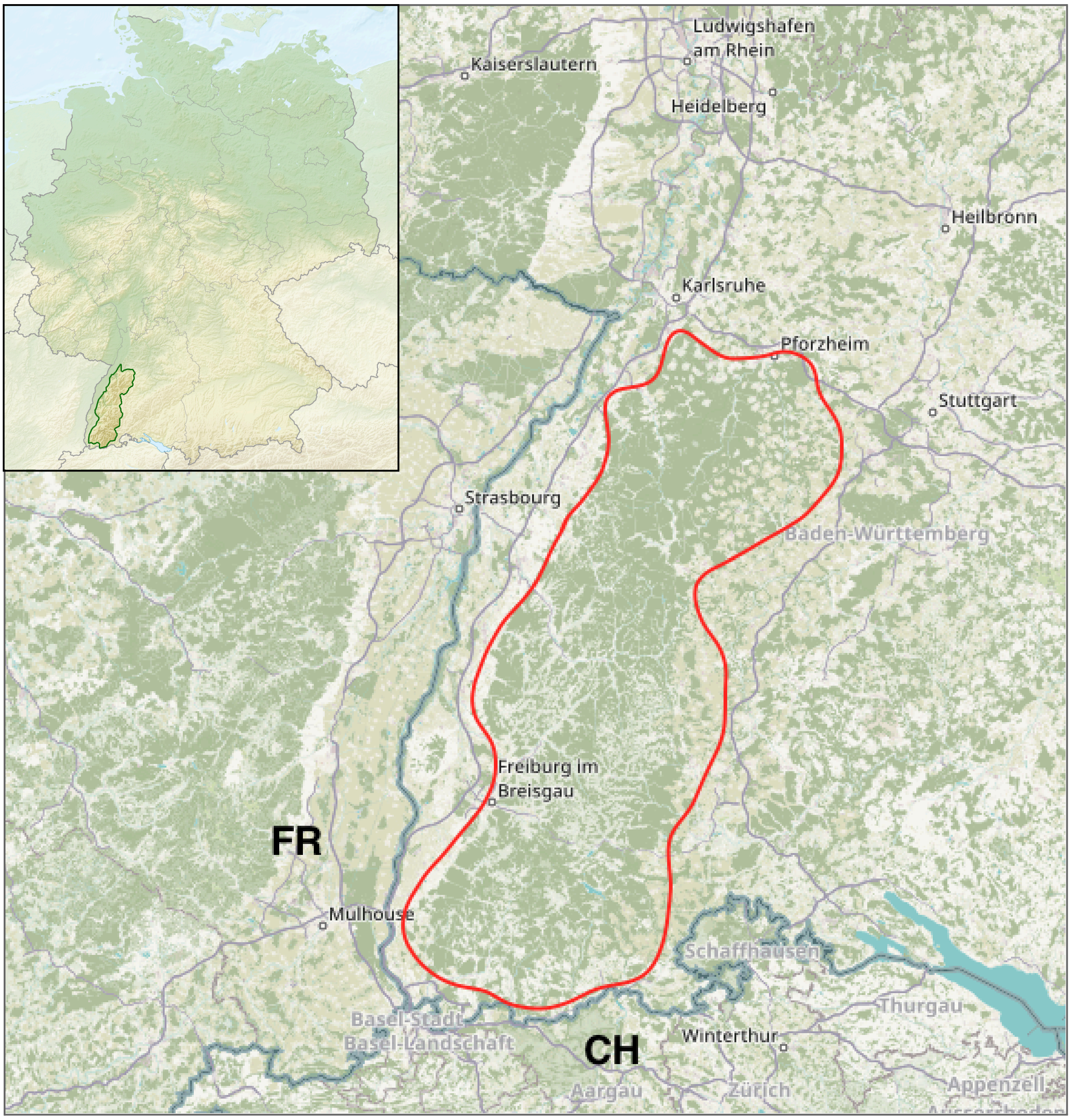
1. Supplementary Figure S1

The location of the study area, Black Forest in Southwest Germany



2. Supplementary Material S2

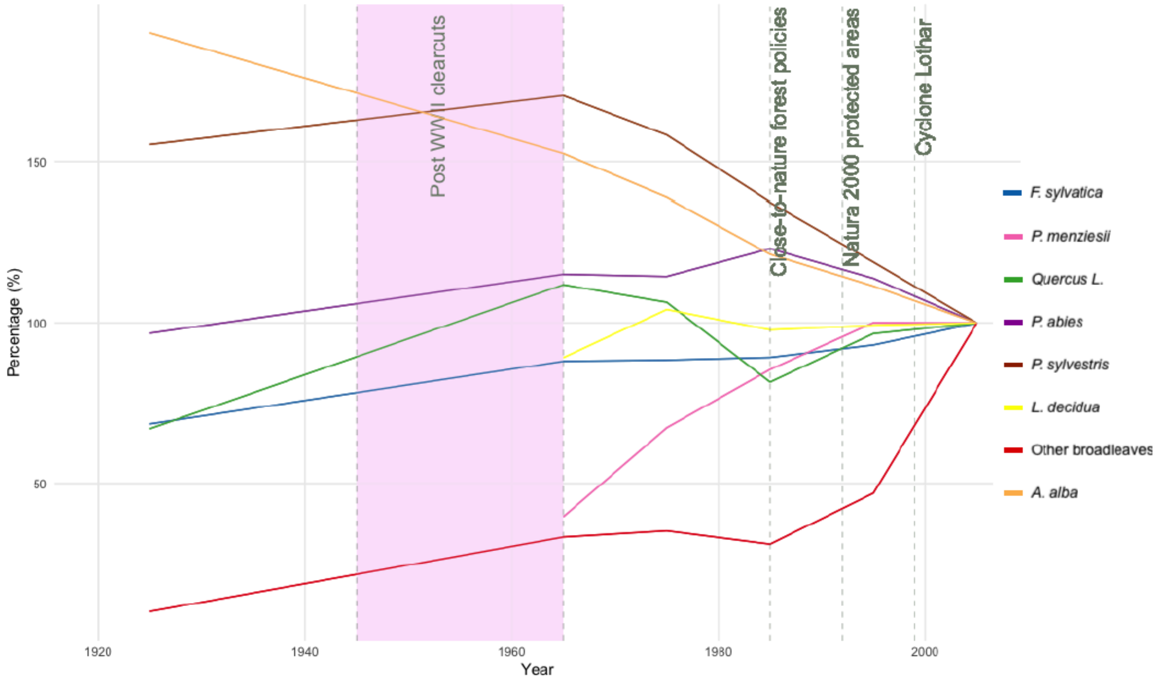
Description of historical data trends and their reconstruction for 18 tree and bird species in the Black Forest Region.

a) Tree species changes

To reconstruct the evolution of the Black Forest's forest landscape over the last century, the primary archival sources employed in this research are sourced from the Land Baden-Württemberg "Forsteinrichtungsstatistik" (Forsteinrichtungsstatistik 1922-31; 1961-70; 1971-80; 1981-90; 1991-2000; 2001-2010), which include periodic forest inventory reports conducted at ten-year intervals. These extensive reports cover the entirety ofBaden-Württemberg and are categorized into specific subsections delineating smaller geographic regions, e.g. the north Black Forest (bounded by a line from Karlsruhe to Pforzheim in the north and the Kinzig river in the south) and the south Black Forest (extending from the Kinzig river to the districts of Lörrach and Waldshut). All data collected prior to the 1950s are further divided into North and South Baden, and North and South Württemberg since the administrative areas of Baden and Württemberg were only merged on 25 April 1952. The collected material includes graphical representations and quantitative documentation, presenting detailed tables illustrating the growing stock per species and stand, age, classifications, descriptions of vegetation stages, outlines of forest management strategies, and planned interventions. Each inventory is organized based on distinct land ownership categories, namely Staatswald (state-owned forests), Gemeindewald (community-owned forests), and öffentlicher Wald (the combined total of the preceding two categories).

The analysis of changes in species composition at the landscape level reveals that each tree species, among the state-owned forest in the Black Forest, has experienced a shift in prevalence of at least 20% over the past century. Notably, there has been a significant decline in conifer populations alongside a marked increase in broadleaf species. Norway spruce populations in the Black Forest showed a modest increase until the 1970s, followed by a significant surge that continued until the mid-1980s, when it became the most prevalent species in the region, covering nearly 52,000 hectares. However, from that peak, there has been a steady decline, culminating in only 41,500 hectares by the 2010s: a decrease of almost 25% - marking its lowest extent since the mid 20th century. In contrast, silver fir has shown a persistent declining trend, experiencing the largest percentage loss in area among the species. From covering over 27,000 hectares in the 1920s (+90% compared to the current status), its presence decreased to approximately 14,000 hectares by the 2010s. Pine species in the Black Forest experienced an increase in their presence until the 1960s, followed by a rapid decline: their coverage halved over the next four decades, stabilizing at approximately 5,300 hectares by the 2010s. In contrast, larch populations have remained relatively stable over the years. Douglas fir, a notable exception among the conifers, has seen a significant increase since its first recorded presence in the Black Forest for commercial use in the 1960s, more than doubling its area within just four decades.

Broadleaved trees in the Black Forest have followed a trajectory opposite to that of their coniferous counterparts. European beech has shown a significant upward trend throughout the 20th century, with a marked increase particularly from the 1980s onwards. This rise coincides with the adoption of close-to-nature forest management practices initiated in the mid-1980s. Oak species displayed a more varied pattern, initially increasing until the 1960s, then declining, followed by a pronounced rise starting in the mid-1980s, culminating in an overall increase of about 20% over the century. Other broadleaved species collectively experienced a gradual rise until the mid-1980s, after which there was a sharp rise, boosting their presence by over 60% in the final two decades of the study, to nearly 5,000 hectares today.



Change in tree species changes in the Black Forest since the 1920s in relation to the contemporary conditions. The year 2010 represents the 100% benchmark.

b) Bird species changes

To reconstruct bird species trends between 1960s and today we relied primarily on red lists at the level of the state of Baden-Württemberg (Bauer et al 2019, Hölzinger et al 2008, *** 1974) and where possible complemented with references from specialized literature (Hölzinger, Jochen 1999, Westermann 2006, Walz 2000). From these sources we consistently reconstructed approximate population sizes for the years around 1987-1989, 1995 (except blackbird, red kite, magpie), 2002-2004, 2009, and 2013. For some species (capercaillie, red kite, black woodpecker) additional information for more years was available from additional sources. We further relied on the information on the long term (since 1960) and short term (1992 to present) reported in RL 2013 to estimate approximate population size in the 1960s. For all the years for which no data was available we used linear interpolation between the two nearest data points. Our general results are presented in Fig 1 and described briefly here:

Tetrao urogallus: in the State of BW capercaillie only occur in the Black Forest; the population declined throughout most of the research period, RL status in BW in decline since the 1960s. Population data (number of displaying malesat leks) was available from Coppes (2016) in addition to the information provided by the BW Red Lists (2004: max. 300 displaying males; 1995: 550 males, 1973: approx. 500 males). Since 1987 the population of capercaillie has declined by some 50% (Hölzinger, 2014). Data preceding Red Lists has only been reported as part of hunting statistics e.g. 1 male/1000 ha in 1904 and 1.5 males/1000 ha in 1936 (Hölzinger and Boschert, 2001).

Turdus merula: the population of blackbirds has increased steadily in Baden-Würrtemberg, a long term trend since the 1960s. Population estimates are scarce, RL report estimates of number of territories or breeding pairs. In European blackbirds, territorial males are usually associated with a single breeding female – here we assume that the number of territories is equal with the number of breeding pairs and use the maximum value of the estimates for each of the RL years.

The smallest recorded population in BW was reported in 1987-1988 at 740.000 territories (Hölzinger, 1999), and the maximum at some 1.200.000 territories in 2019.

Milvus milvus: since the 1960s, the population of red kite has shown a slow initial increase, followed by a significant rise from around 1995 onwards. In particular, between 1995 and 2019, the number of territories climbed from just over 500 in 1995 to nearly 5000 by 2020 (RL 2019). In contrast, populations in East Germany experienced a decline, especially between 1994 and 1997, while in Baden-Württemberg (BW), the population mostly increased. Earlier estimates by Hölzinger in the 1970s indicated around 230 pairs. The introduction of the hunting ban on raptors in 1977 likely played a crucial role in the species' recovery, as reflected in the steadily increasing trend from that period onwards.

Dryocopus martius: the population of Black woodpecker has shown a slight increase in breeding pairs (BP) over the past decades, with long-term trends indicating a growth of approximately 7% since the 1960s. From the 1960s to the early 1990s, the number of breeding pairs fluctuated between 4,000 and 4,500, peaking in the mid-1990s when around 4,800 pairs were recorded. After this peak, the population gradually declined but remained relatively stable in recent years, with estimates around 4,300 breeding pairs by the early 2000s. This stability is consistent with estimates from the Red List (RL) 6th and 7th editions (2013, 2019), which report between 3,500 and 4,500 breeding pairs. The slight decrease from earlier counts, such as the 2001 estimate by Vögel Baden-Württemberg of 4,300 pairs and 18,000 individuals during the winter periods of 1988–1992, reflects a modest but sustained population size. Although a few local studies on the Black Woodpecker exist (e.g., Westermann 2006, Masurat 1981), their integration into this assessment is limited due to spatial inconsistencies and differing methodologies. Nevertheless, the overall trend reflected in the graph aligns with documented population data from the region.

Erithacus rubecula: the population of the Eurasian Robin, measured by the number of territories, has remained relatively stable over the long term, with only slight fluctuations since the 1960s. In the early 1960s, the number of territories was close to 400,000, followed by a minor dip in the 1980s. However, by the mid-1990s, the population began to recover, and the number of territories has since stabilized at around 400,000 to 450,000. According to the Red List (RL) 6th and 7th editions (2013, 2019), population estimates for the Eurasian Robin were recorded at 410,000–470,000 territories, which aligns well with earlier data, including the 350,000–450,000 territories reported in the RL 5th edition (2004). A line transect survey from 1987/1988 (Hölzinger, 1999) extrapolated an estimate of 390,000 territories, further supporting the conclusion that the population has remained stable over time. Both long-term and short-term trends for this species are listed as stable, reflecting the consistent population levels observed across decades. This stability suggests that the Eurasian Robin has been able to maintain its territory numbers despite minor fluctuations over the years.

Garrulus glandarius: the population of the Eurasian Jay, measured by the number of territories, has shown significant growth since the 1960s. The number of territories increased from approximately 80,000 in 1960 to a peak of around 110,000 by the early 2000s, reflecting an overall rise of about 38% during this period. This growth was relatively steady until the early 2000s, after which a slight decline occurred, followed by stabilization in more recent years. According to Red List (RL) data from 2013, the population is now considered stable. Earlier studies, including a 1987–1988 line transect survey (Hölzinger and Hölzinger, 1997), estimated around 100,000 territories for the Eurasian Jay during that period, aligning with the trends seen in Fig. 1. Although there was a slight decline in territory numbers after the early 2000s peak, the population has since stabilized at around 100,000 territories. This recent stabilization reflects the current population trend, as supported by RL2013.

Pica pica: the population of the Eurasian Magpie, measured by the number of territories, has experienced significant fluctuations over the decades. Starting with around 60,000 territories in 1960, the population remained relatively stable until the mid-1990s, when a notable decline occurred, dropping to its lowest point of approximately 30,000 territories.Territory numbers increased substantially from 2000 onward. By 2020, the number of territories had reached approximately 75,000, marking a substantial recovery from the earlier decline. Estimates from the Red List (RL) 6th and 7th editions (2013, 2019) place the Eurasian Magpie population between 50,000 and 75,000 territories. Currently the population is stable at aprox. 75,000 territories.

Picus viridis: the population of the European Green Woodpecker experienced a significant decline starting in the 1950s, as reported by Hölzinger and Bauer (2001), with this downward trend continuing into the 1980s. A steep drop in the number of territories, from approximately 10,000 in the 1960s to around 7,100 by the late 1980s, is evident in Fig. 1, aligning with Hölzinger's (2014) estimates for Baden-Württemberg during 1987/1988. However, after this low point, the population began to recover, and since the 1990s, the number of territories has steadily increased. By the 2000s, the population had returned to levels similar to those observed in the 1960s, with the upward trend continuing into recent years. By 2020, the number of territories reached about 12,000, reflecting a strong recovery. Red List (RL) data also support this stabilization and recovery. In the RL 2019, the population was estimated at 8,000–11,000 territories, consistent with the RL 2013 estimate of 8,000–10,000 and the RL 2004 estimate of 8,300 territories.

Sitta europaea: the population of the Eurasian Nuthatch has shown strong growth since the mid-1980s. As depicted in Fig. 1, a substatial increase in the number of territories began around 1984, with rapid growth continuing into the 2000s. Prior to this recovery, the population had experienced a notable decline, bottoming out in the late 1970s and early 1980s when territory numbers dropped to below 100,000. This trend aligns with the findings of Hölzinger (1997), who reported a population low of approximately 80,000 territories around 1988. Following this low point, the population rebound sharply, with the number of territories surpassing 200,000 by the early 2000s. By 2020, the population had reached around 300,000 territories. The Red List (RL) 7th and 6th editions (2019, 2013) recorded the Eurasian Nuthatch population at 150,000–250,000 and 160,000–220,000 territories, respectively. In the RL 5th edition (2004), the number of breeding pairs was estimated at 160,000–200,000, further confirming this upward trend. Localized data from the Black Forest and Baar-Wutach regions, including nesting box experiments (Gatter, 1998), confirm these regional trends and align with the broader population growth reflected in the territory estimates.

Turdus pilaris: the Fieldfare population has experienced a significant decline over the study period. In the 1960s, the population was estimated at over 130,000 territories, but since then, there has been a sharp and steady decrease. Starting in the late 1980s, the population began to decline, dropping to less than 50,000 territories by the early 2000s, and continuing to decrease rapidly thereafter. Currently, the number of territories is less than a third of the estimates from the 1960s. According to the Red List (RL), the Fieldfare population was monitored at 20,000–30,000 territories in both the 6th and 7th editions (2013, 2019). This marks a substantial decline from earlier estimates in 2013 (RL 5th edition), which placed the breeding stock at 100,000–150,000 territories. A line-transect survey in the late 1990s estimated the Fieldfare population at around 180,000 territories (Hölzinger, 1999) prior to the sharp decline observed since the early 2000s.

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3. **Supplementary Material S3**

Survey Questions

Black Forest – trends in forest and bird species change

Thank you for taking part in this survey on forest and bird population changes in the region of the Black Forest. Anyone living, working in or visiting regularly the region can take this survey. By Black Forest region we mean the area South of Karlsruhe and North of Basel, including the Black Forest mountains and the adjacent rural and urban regions.

This study is being carried out at the University of Freiburg, as part of the Research Training Group ConFoBi: Conservation of Forest Biodiversity in Multiple-Use Landscapes of Central Europe. For questions about the project, please visit www.confobi.uni-freiburg.de. For questions about this survey, please contact Catalina Munteanu at catalina.munteanu@wildlife.uni-freiburg.de.

Your participation in this study is entirely voluntary and you can withdraw at any time. All answers will remain anonymous and confidential. The survey will take you approximately 10-15 minutes. Please answer all questions instinctively, and without looking up any answers. By continuing you agree to participate in this survey.

What is your year of birth?

Do you live, work or visit regularly the Black Forest region now, or have you done so in the past?

o No

o Yes

Between which years have you lived, worked or regularly visited the Black Forest region?

o from ____

o to ____

Click on the images of the following tree species that you think you recognize. Please answer instinctively, selecting any image you feel you remember or recall from previous experience.

[10 tree silhouettes, leaf, flower, seed shown here]

Match the following tree pictures with their names.

[only recognized species shown, dropdown of all 10 possible names]

Rank the following the following trees in order of how much you like them.

Dislike a great deal/Dislike somewhat/Neither like nor dislike/Like somewhat/Like a great deal

How would you describe the trends in the following tree species in the Black forest today compared towhen you were 18 years old?

Decline Stable Increase Don't know

How much do you think these tree species changed in the Black Forest area? The slider indicates the approximate percent change compared to approximately the year ${e://Field/when18} when you were 18 years old.

Click on the images of the following bird species that you think you recognize. Please answer instinctively, selecting any image you feel you remember or recall from previous experience.

[12 bird species shown here]

Match the following birds with their name.

[only recognized species shown, dropdown of all 12 possible names]

Rank the following the following trees in order of how much you like them.

Dislike a great deal/Dislike somewhat/Neither like nor dislike/Like somewhat/Like a great deal

How would you describe the trends in the following bird species in the Black forest today compared to aprox. to ${e://Field/when18},when you were 18 years old?

Large decline/Moderate decline/Stable/Moderate increase/Large increase/Don't know

What is your gender?

o Woman

o Man

o Non-binary

o Prefer not to disclose

Would you describe you living and work areas as urban or rural?

Slider Urban to Rural

0 10 20 30 40 50 60 70 80 90 100

Living area

Work area

What is the highest level of education you have completed?

o No school-leaving certificate

o Lower secondary educuation

o Secondary education

o Higher secondary education

o Completed apprenticeship

o University of applied science

o University (Diplom)

o University (Bachelor)

o University (Master)

o University (PhD)

o Prefer not to disclose

What percentage of your work time do you spend outdoors (vs. in an office)?

[Slider from Office (0) to Field/ Outdoor (100)]

How much do you learn about forests in the Black Forest from following sources?

	None at all	A little	A moderate amount	A lot	A great deal
Personal experience	o	o	o	o	o
Media (TV, internet, newspapers, magazines)	o	o	o	o	o

On average, how many hours per week do you spend in natural spaces (garden, park, forest)?

To what extent do you agree with the following statements?

Response scale: Strongly disagree/Somewhat disagree/Neither agree nor disagree/ Somewhat agree/Strongly agree

My ideal vacation spot would be a remote, wilderness area.

My relationship to nature is an important part of who I am.

I feel very connected to all living things and the earth.

I take notice of wildlife wherever I am.

I always think about how my actions affect the environment.

My connection to nature and the environment is a part of my spirituality.

If you would like to receive information about the results of this study, please leave your e-mail address.

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4. Supplementary Material S4

List of predictors used in the perception phenomena models for 311 respondents and 4095 observations. In the modelling approach, only the selected species were used for accurate perception: n=3963, change blindness n=2546 , shifting baselines syndrome n=2509.

Variable	**Description**	**Unit**	**Mean**	**SD**
Age	Age of respondent	years	47	15
Education	Educational level of respondent	Ordinal factor (1: no education, 8:higher education)	2:1 3:16 4:10 5:28 6:60 7:120 8:35	-
perc_living_rural	Self-assessment of how rural the living area of the respondent is	percent	0.56	0.34
perc_work_rural	Self-assessment of how rural the working area of the respondent is	percent	0.47	0.35
time_field work	Percent of work time spent outdoors	percent	0.32	0.34
NR6	Nature Relatedness Index 6	Index calculated based on (Nisbet 2013)	3.04	0.64
Years_in_BF	Number of years lived in the Black Forest region	years	28.19	21.5
Time_nat_space	Estimated number of hours per week spent in natural spaces (self-reported)	Hours/ week	15	0.32
sp_named	Percent of species named correctly	0.85	0.20	
gender	Self-identified respondent gender	Factor	Man: 147 Woman: 140 Non-binary: 2	-
media	Self-reported importance of media in acquiring information about environmental change	Ordinal factor (not important =1, very important =5)	1:11 2:114 3:87 4:49 5:10	-
pers_exp	Self-reported importance of media in acquiring information about environmental change	Ordinal factor (not important =1, very important =5)	2:17 3:66 4:116 5:72	-
moved	Has the respondent moved residence to/from the Black Forest during their lifetime	Factor	Yes:229 No:44	-
sp_group	Species group the respondent identified	Factor	Birds: 2145 Trees: 1950	-
sp_trend	Documented species change trend	Ordered factor, likert scale (-2 to 2)	-2:231 -1:872 0:959 1:1223	-

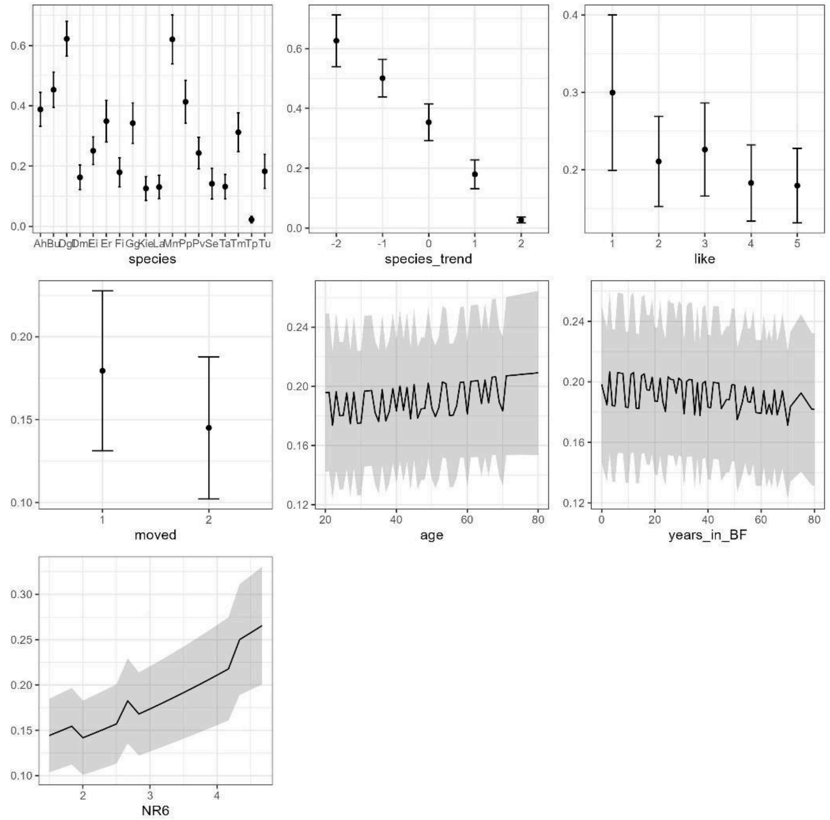
			2:800	
like	Likert scale of preference for the selected species	Ordered factor, likert scale (1: dislike a lot, 5: like a lot)	1:38 2:162 3:292 4:891 5:2671	

5. Supplementary Material S5

Model parametrization and results using a linear mixed effect model

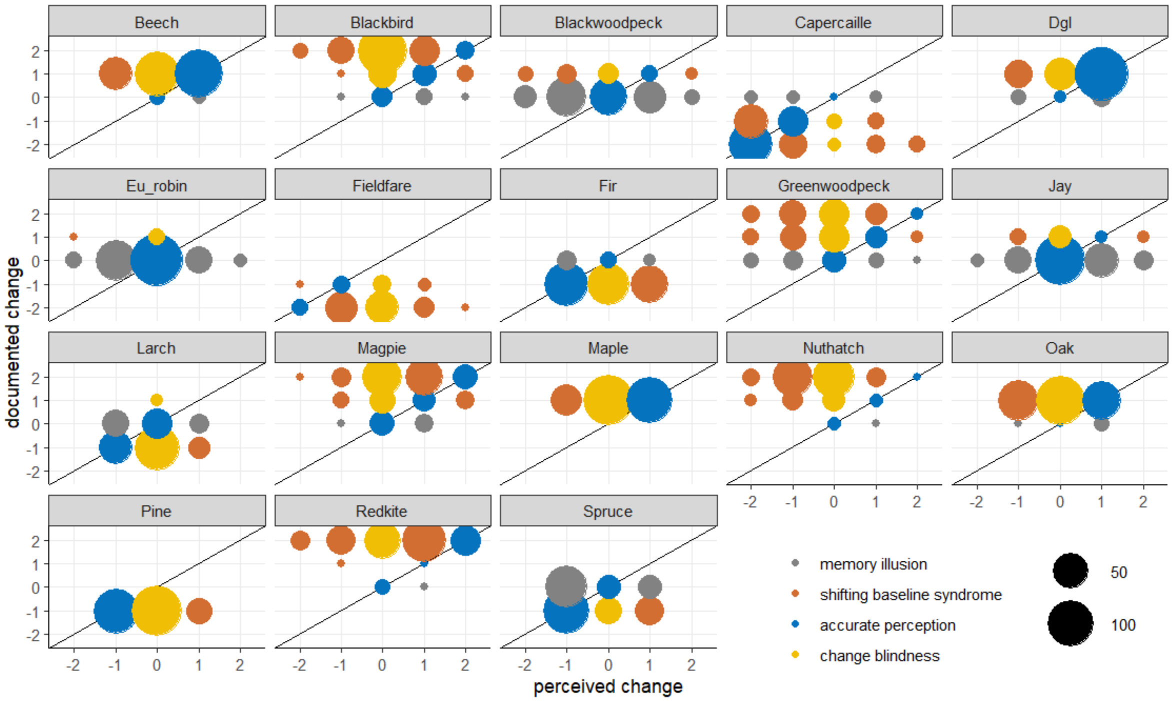
We also analysed our dataset on accurate perception using a generalized mixed effect modelling approach using the glmmTMB package in R studio. The mixed effect model allowed us to fit nested random effects and to control for the fact that we did not have the same number of observations for all people and species. However, the disadvantage of the mixed model is that it does not capture as well non-linearities in the data, and it does not handle missing data well, which is why we decided for the machine learning approach for the final analyses.

To fit the mixed effect model, we first used data imputation by predictive mean matching using Multivariate Imputation by Chained Equations method implemented in the mice R package. We considered the full model including all variables, exponentiated factors for age and nested random effects for species and respondents. We performed automated model selection considering ‘all possible’ combinations and using AIC as a model selection criteria and the dredge function in R. The best selected model had an AIC value of 4647 (compared to 4660 for the full model). We further checked variance inflation factors, but all values were below 2.5, so retained all variables in the model. We performed model diagnostics using the DHARMa package in R and used the area under the receiver-operator-curve as an indication of model performance. Conditional R-squared value for the model was 0.51, and marginal R-squared 0.26 for accurate perception, which was similar to the machine learning model. AUC value was 0.75. Our results from the mixed effect models on accurate perception were in line with those obtained with the machine learning approach, but models had lower performance, so we decided to retain the latter in our final data reporting. The graphs below show the partial dependence plots for accurate perception for the variables hypothesized to have an effect in our work. Trends are consistent with those shown in the machine learning approach.



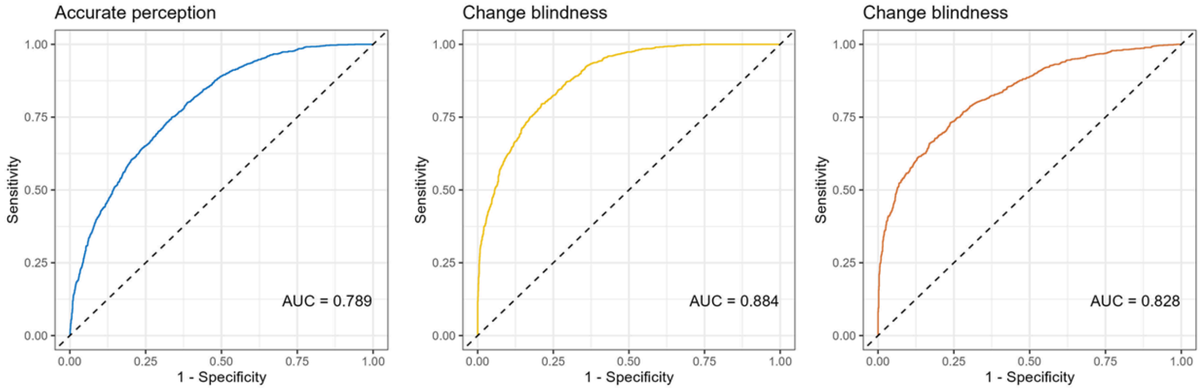
6. Supplementary Figure S6

Number of responses per perception phenomena since age 18 of survey respondents for 10 bird and 8 tree species. The x-axis depicts the perceived trend of each individual of each species and the y-axis the documented species change, calculated since that individuals' personal baseline (age 18). The color of the bubble represents the typology of perception phenomena and the size the number of responses.



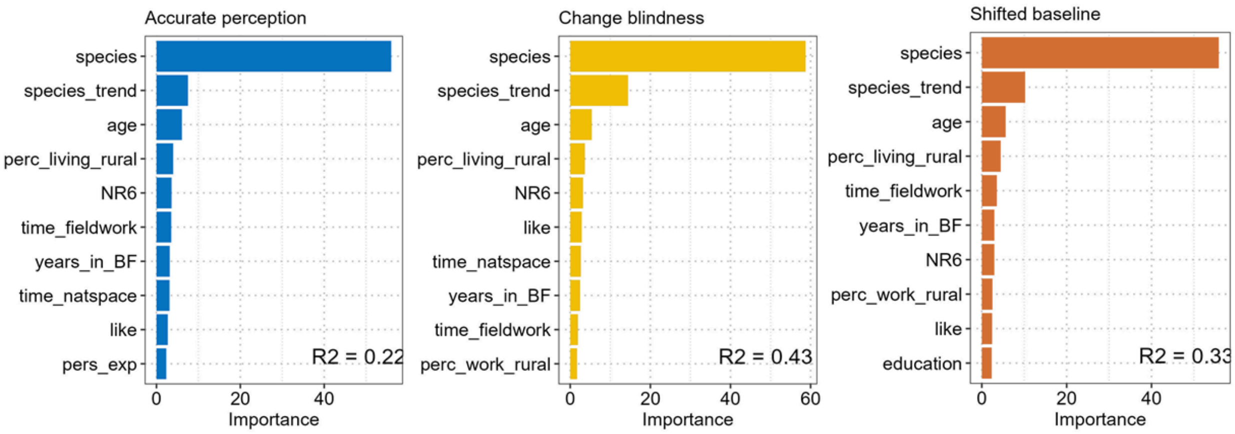
7. Supplementary Figure S7

Model performance: Area under Receiver Operator Curve (AUC)



8. Supplementary Figure S8

Variable importance for selected models and pseudo R^2 values



9. Supplementary Material S9

Media coverage of individual species

We performed a media-search to identify the number of species-specific articles published in the German language media between 2000-2024. We performed a species specific search using following search string template '(Latin name OR common name) AND (Baden Württemberg OR Schwarzwald)' in the Lexis Nexis University Archive (https://www.lexisnexis.com/en-us/professional/academic/nexis-uni.page) as well as the specific archives of two major newspapers not covered there (Frankfurter Allgemeine and Süddeutsche Zeitung). We removed all duplicate articles as well as non-relevant articles.

Species	**Lexisnexis Database**	**Frankfurter Allgemeine Archive**	**Süddeutsche Zeitung Archive**	**Total relevant hits 2000-2024**
Picea abies	116	0	19	135
Abies alba	74	2	14	90
Pinus sylvestris	46	1	7	54
Pseudotsuga menziesii	64	0	6	70
Larix decidua	14	0	3	17
Fagus sylvatica	141	1	15	157
Quercus	226	14	16	256
Acer	2	2	0	4
Garrulus glandarius	3	0	2	5
Erithacus rubecula	15	0	1	16
Turdus pilaris	0	0	1	1
Sitta europea	0	0	4	4
Tetrao urogallus	104	3	0	107
Dryocopus martius	5	0	0	5
Picus viridis	0	0	0	0
Pica pica	0	0	0	0
Turdus merula	4	0	0	4
Milvus milvus	26	0	2	28

We found that oak, spruce and beech are the species that dominate the media discourse, with common bird species such as the blackbird or the woodpeckers missing entirely from the media discourse. Overall, increasing species tend to be less covered by media than declining ones (e.g. red kite vs. capercaillie).