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Monitoring Data and Public Perception Diverge – Especially When Species Abundance Increases

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Abstract

Environmental sciences aim to provide unbiased data for decision making, yet conservation management, and personal decisions often rely on perception shaped by experiences, information exchange, media exposure, and values. When monitoring data differs from people's perceptions, unintended consequences (e.g. overlooked degradation, unacknowledged conservation successes) may occur. We compare long-term monitoring data of tree and bird abundance with self-reported perceptions, revealing mismatches in 74% of the cases as well as their drivers. Phenomena like shifted baselines and change blindness were prevalent. Importantly, when environmental data

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reported population increases, these were often overlooked or minimized, but when species declined, the two datasets were more consistently aligned. This highlights the need to base decision-making on long-term datasets that account for the mismatches in perception and monitoring data. Our study has implications for conservation science, restoration, and land management, recommending integration of long-term monitoring data to mitigate change blindness and shifted baselines.

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

Introduction

People's decision making, including conservationists and land managers, is often based on personal perceptions. An individuals' perception is made up of individual observations and interpretations thereof (Bennett, 2016) corroborated with knowledge retrieved from different sources. As such, perception is colored by education experiences, information exposure, expert-based opinions, socio-demographic backgrounds, cultural values and ethics (Cosyns et al., 2020; Dietz, 2023; Haight et al., 2023; Wright & Bolger, 1992) as well as by the degree to which information aligns to personally held beliefs, a psychological phenomenon termed confirmation bias (Kappes et al., 2020). When perceptions misalign with environmental monitoring data, this discrepancy can lead to outcomes such as overlooked degradation or unrecognized conservation successes. In an attempt to support conservation, restoration and land management, environmental sciences seek to provide an unbiased data-founded 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 (Papworth et al., 2009; Pauly, 1995; Soga & 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 conceptual framework of the shifting baselines syndrome 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 (Pauly, 1995) 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., 2020; Sáenz-Arroyo et al., 2005), or that senior members of communities are more aware of climate change (Soga & 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, hereafter 'cognitive aging' (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 toward experiencing shifting baseline syndrome (Jones et al., 2021; Soga & Gaston, 2016, 2018). 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 behaviors often described as pro-environmental (Berghöfer et al., 2022; Mayer & Frantz, 2004; Nisbet et al., 2009; Zhang et al., 2014). 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 & Darner, 2020; Moesch et al., 2024; Phelps & 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 & 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, Crowley, et al., 2024; Jarić, Normande, et al., 2024), it may also lead to an exacerbation of perceived trends in abundance of those species or a decreased awareness of counterpart species (Douglas & 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 consider data from environmental monitoring in an attempt to validate prior held beliefs or to reduce psychological discomfort. For instance, recovering pinniped species in the USA are perceived as a conflict source likely due to diverging biases in fishers and hunters (Arias del Razo et al., 2020; Cammen et al., 2019; but see Huntington et al., 2017). Altogether, how species changes over a long time interacts with individuals' preferences and backgrounds to produce perceptions remains largely unknown. It remains unclear if and to what extent data provided by environmental research, for example, long-term monitoring time series, align with human perception, and in cases when they do not, which are the demographic, socio-cultural or psychological factors driving these misalignments.

To address this gap, our study aims to link changes in species abundances from environmental monitoring and human perception at the scale of an individual's life experience, to identify misalignments, their typology as well as the personal characteristics that drive these misalignments. Here, we define perception as an individual phenomenon that is based on personal experiences corroborated with information retrieved through education, media, social networks, etc. 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 monitoring data to include four perception categories: accurate perception (*environmental monitoring data and perception align*), change blindness (*change is reported in data, but not reported by respondents*), shifted baselines (*change reported in data and reported by respondents, but magnitude or direction are mismatching*) and memory illusion (*no change reported in data but change is reported 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 objectives:

a. Quantify the typologies of misalignment between ecological monitoring data and human perception of species change since the mid-20th century.
b. Identify which individual characteristics may explain mismatches between documented and perceived change and in which way. We hypothesize that age, mobility (how long individuals lived in the area, whether 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 Germany (ca. 6,000 km^2, Figure S1), 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 among 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 led to an increase of spruce plantations, affecting 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 an ideal 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. 6,000 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, as reported and published at the end of 10-year management intervals (e.g. data on cover of spruce was collected between 2000 and 2010 and reported and published in 2010). 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 Supplemental 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 (Berthold et al., 1974; Bauer et al., 2019; Hölzinger et al., 2008) and, where possible, complemented with references from specialized literature (Hölzinger, 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 as a proxy of territories; 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 were 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 Supplemental 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 the general public, academics, conservation and forestry practitioners who live or work in the Black Forest region or have done so in the past. The age distribution of our respondents (bimodal) is representative of the age distribution in the region of Baden-Württemberg (statististik-bw.de) but our sample may be biased toward environmentally minded respondents. Questionnaires were distributed online and made available in both English and German. 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 min. 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 analyzing perception within their lifetime; see Supplemental 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 they perceived each species to have 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 & 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 & Zelenski, 2013; Table 1).

Data Matching, Analyses and Modeling

For each respondent and species, we calculated the documented and perceived change during the respondent's adult life, and assigned their combination to one of the possible four outcomes: accurate perception (*documented*

Table 1. List of Predictors Used in the Perception Phenomena Models Based on Subsets of 311 Respondents (Summing Up to 4,095 Observations of Correctly Identified Species).

Variable	Description	Expected effect. Perception accuracy. . .	Unit	Mean (*SD*)
age	Age of respondent	increases with age (Soga & Gaston, 2018)	years	47 (15)
education	Educational level of respondent	increases with education due to more acquired natural history knowledge (Soga & Gaston, 2018)	ordinal factor (1: no education, 8:higher education)	1:0, 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	increases with rurality due to increased exposure to natural environment (Soga & Gaston, 2016)	percent	0.56 (0.34)
perc_ work_ rural	Self-assessment of how rural the working area of the respondent is	increases with rurality due to increased exposure to natural environment (Soga & Gaston, 2016)	percent	0.47 (0.35)
time_ fieldwork	Percent of work time spent outdoors	increases with amount of time spent outdoor due to exposure to natural environments (Soga & Gaston, 2018)	percent	0.32 (0.34)
NR6	Nature Relatedness Index 6	Increases with increasing NR6 due to personal feelings of connectedness to nature (Nisbet, 2013)	index	3.04 (0.64)
Years_in_ BF	Number of years lived in the Black Forest region	increases with number of years spent in Black Forest due to increase exposure to selected species (Soga & Gaston, 2018)	years	28.19 (21.5)
Time_nat_ space	Estimated number of hours per week spent in natural spaces (self-reported)	increases with time spent in natural spaces due to increase exposure to selected species (Soga & Gaston, 2018)	hours/week	15 (0.32)
sp_named	Percent of species named correctly	increases with more species a person recognizes	percent	0.85 (0.20)
gender	Self-identified respondent gender	NA	factor	Man: 147, Woman: 140 Non-binary: 2

(continued)

Table 1. (continued)

Variable	Description	Expected effect. Perception accuracy. . .	Unit	Mean (*SD*)
media	Self-reported importance of media in acquiring information about environmental change	increases with media consumption to a point but then drops due to overpoliticization (Feindt et al., 2021).	oordinal factor (not important = 1, very important = 5)	1:11, 2:114, 3:87, 4:49, 5:10
pers_exp	Self-reported importance of personal experiences in natural environments	increases with increased personal experiences, in line with SBS theory (Soga & Gaston, 2018)	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	increased mobility could lead to shifted baselines	factor	Yes:229 No:44
sp_group	Species group the respondent identified	NA	factor	Birds: 2,145 Trees: 1,950
pchange	Documented species change trend	NA	percentual change in species population	3.77 (64.1)
like	Likert scale of preference for the selected species	increases with individual's preference for a selected species	oordered factor, Likert scale (1: dislike a lot, 5: like a lot)	1:38, 2:162, 3:292, 4:891, 5:2,671

Note. Only responses with correctly named species were included in the modeling. Sample sizes per model were as follows: accurate perception: $N = 3{,}984$ (all correctly named species with matching or non-matching trend combinations); change blindness: $N = 2{,}151$ (subset comparing matching responses with those where ecological data showed change but self-reported perception not); shifting baselines syndrome: $N = 2{,}521$ (subset comparing matching responses with cases with various degrees of mismatch). NA = not any.

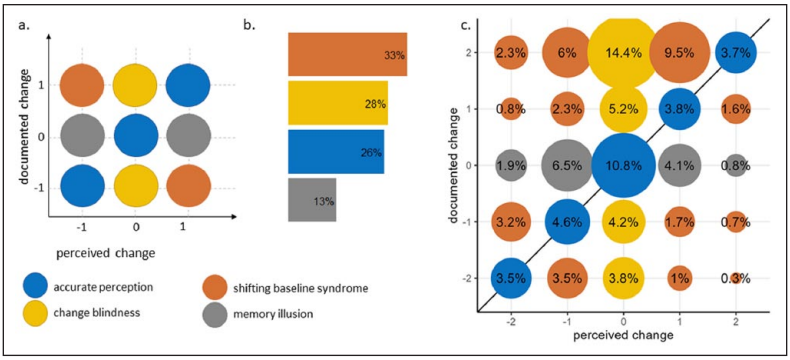


Figure 1. (a). Typology of perception phenomena at the individual level. The figure illustrates how ecologically documented change (*y*-axis, −1 = decreasing population, 0 = stable, 1 = increasing) and perceived change (*x*-axis, −1 = perceived decreasing population, 0 = perceived stable, 1 = perceived increasing) combine to form categories such as accurate perception or change blindness. (b). Proportion of each perception category occurring across the entire sample ($N = 4{,}095$) and (c). Proportion of each perception category within the different combinations of ecological monitoring and perception data change combinations (from strong decrease −2 to strong increase 2).
Source. Figure 1a adapted from Papworth et al. (2009).

environmental monitoring data and self-reported perception align), change blindness (*change is reported in data, but not reported by respondents*), shifted baselines (*change reported in data and reported by respondents, but magnitude or direction are different*) and memory illusion (*no change reported in monitoring data but change is reported by respondents*; Figure 1a). 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 baseline year of age 18 for each respondent. For trees, we defined changes as follows: changes greater than 20% were considered large increases or decreases, 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). Because population fluctuations can happen slower when lifespans are longer, we accounted for the vastly different turnover rates and lifespans for birds (small and medium-sized birds average

lifespan of 5–10 years) and trees (rotation times 70–100 years) by adjusting our definition of population change. We calculated for each species two values for each participant: the perceived change since turning 18 (represented on an ordinal scale from 1–5 on the *x*-axis in Figure 1c) and the documented change since turning 18 (*y*-axis in Figure 1c). For modeling effects of change on perception, the percent change in the species population was retained as a continuous variable.

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 modeled 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 phenomenon 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). To ensure balanced representation across species, data points were weighted so that the total weight for each species was equal. 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, percentual change in species population since a person's age 18), demographic variables (age, whether they 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 Table 1. 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 & Developers, 2003). We relied on a 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 modeling and results interpretation (Greenwell, 2016; Hijmans

et al., 2020; Ridgeway & Developers, 2003). Because boosted regression trees are not designed to handle random effects, this variable was not included in the model. To ensure robustness of our modeling approach, we compared our results with those obtained through a traditional parametric mixed-effect-model approach, using the respondent ID and species as random effects (Supplemental Material S4) and because results were consistent, we 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%; Figure 2). The results of our bird population interpolation since the 1960s followed the general species trends of the Red List of Baden Württemberg: the blackbird (+230%), red kite (+1,800%), 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 (Figure 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 Supplemental Material S2.

Perception of Ecological Change Since the Mid-20th Century

We collected 311 usable questionnaire responses, which resulted in a total of 4,095 observations of all tree (n=1,950) and bird (n=2,145) 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). The average age for the state of Baden Württemberg in year 2023 was 44 years, and the age distribution bimodal, mirroring our data (statistic-bw.de). More than 80% of the respondents had moved at least once in their lifetime. 43% of the respondents were female, and the nature

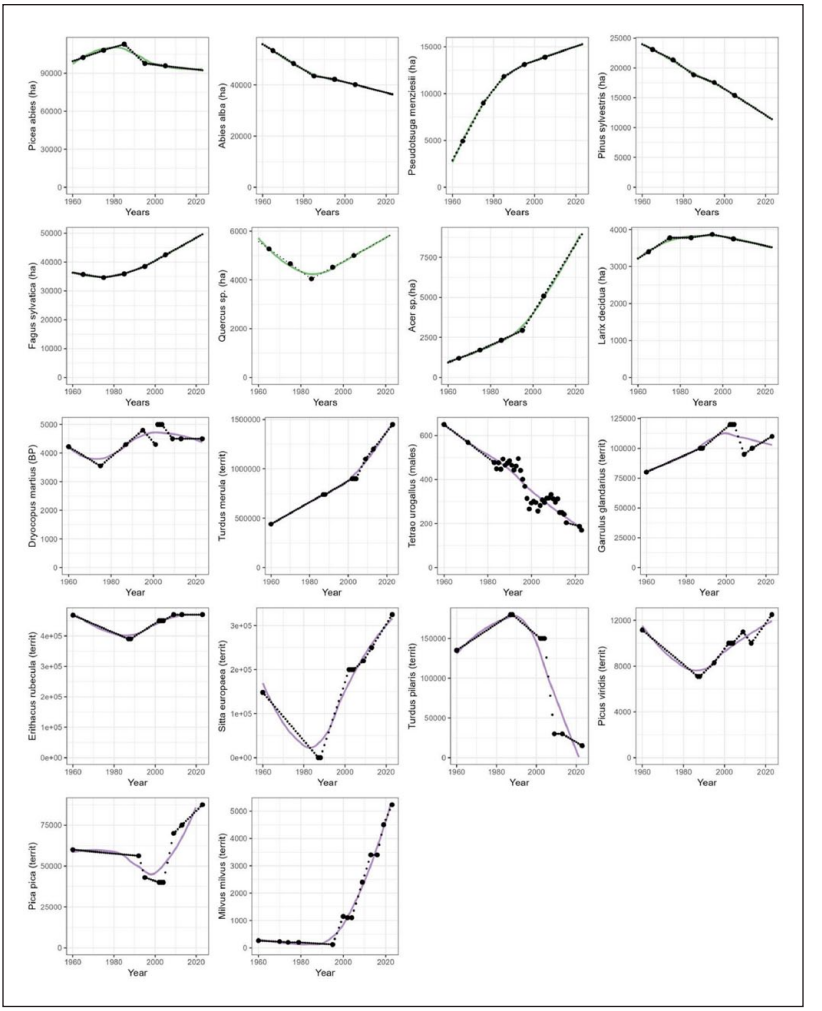


Figure 2. Change in eight tree (green) and ten bird species (purple) since the 1960s.

Note. 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.

relatedness (NR) score was 3.04 (on a 1–5 scale), with a median amount of time spent outdoors being 14 hr/week (Table 1).

Across all 18 study species and all respondents, 26% had an accurate perception of the population change trends (including 10% accurate static perception and 16% accurate change perception (Figure 1b). More individuals experienced shifting baseline syndrome (33% $n = 1{,}496$) than change blindness (22%, $n = 1{,}099$). For any of the possible species trends reported in ecological data (increase, decrease, etc), self-reported perception most often did not align with the ecological monitoring data (Figure 1c and Figure S5). Importantly, when environmental monitoring data indicated increases in population size, respondents tended toward change blindness (overall, but especially for species like red kite, nuthatch, maple or oak), and when species declined, a higher proportion of responses were accurate (e.g. capercaillie, Figure 1c and Figure S7) When looking at trees alone, 23% responses were accurate ($n = 428$), but change blindness was also prevalent across all species ($n = 531$). 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 among individual species (Figure 1 and Figure S7).

Model Performance and Variable Contribution

Models explaining perception performed overall well (cross-validation AUC > 0.8: accurate perception: 0.81, change blindness: 0.91, shifting baseline syndrome: 0.82, Figure S8). Pseudo-R^2 values ranged between .23 and .53 (accurate perception: .23, change blindness: .53, shifting baseline syndrome: .33; Figure S9). Across the three models, the largest proportion of variance explained was captured by variable 'species' (accurate perception: 51%, change blindness: 58%, shifting baseline syndrome: 50%), followed consistently by the percentual change in the species (14%–15%) and age (5%–7%). NR6, mobility and species preference explained only a small proportion of the variance (3%–5%, 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 the shifting baseline syndrome or cognitive aging expectations related to age. Our models indicate that in all cases, individuals can misalign their perception to environmental monitoring from the periods they experienced within their lifetime. The variable 'age' contributed approx. 5% of the variance, and we found a very slight tendency that

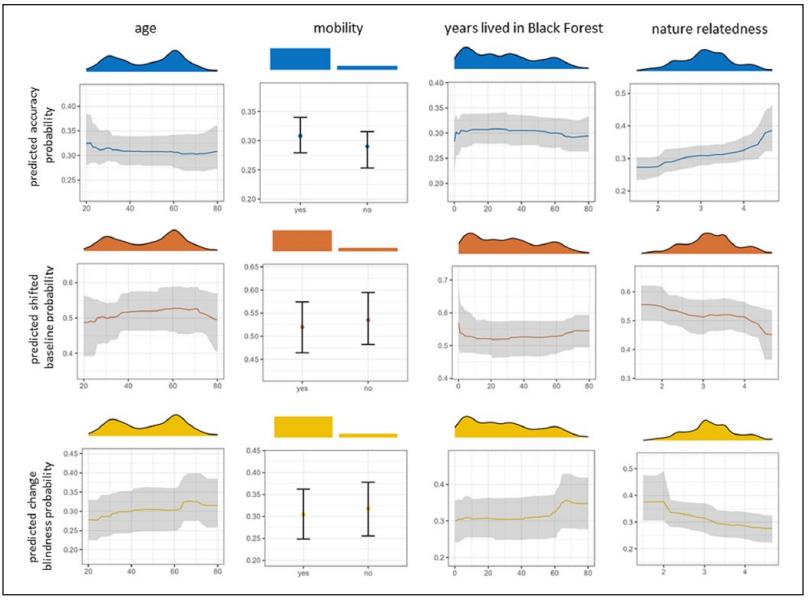


Figure 3. Partial dependence plots showing the effect of age, mobility expressed as whether a person moved house in their lifetime or not and number of years that they lived in the Black Forest region and effect of nature-relatedness index on accurate perception, change blindness and shifting baseline syndrome.
Note. *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.

individuals below 40 and older than 60 are more accurate in their perception. We also observed a slight tendency that older individuals more often experience shifted baselines or change blindness – however, when averaging predictions across model subsets, this effect remains very small (Figure 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 (Figure 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 3%), but we note that the probability of accuracy still lies below 50% in all cases (Figure 3).

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 maple (*Acer sp*) as well as for fieldfare (*Turdus pilaris*) and nuthatch (*Sitta europaea*; Figure 4). 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 (Figure 4c). However, we found a significant difference in probability of occurrence of accurate perception, change blindness and shifted baseline depending on the percentual change in a species population: the probability of accuracy was significantly lower for species with positive population trends species (Figure 4) than for declining species. Similarly, change blindness and shifted baselines were more likely to occur for increasing species than for declining ones (Figure 4b).Overall, respondents were more accurate about species declines and experienced lower rates of change blindness or shifting baseline syndrome when declines happened, bur they tended to display negativity bias when it comes to historical species change (i.e. perceived declines where there are none).

Discussion

Our results on mapping the alignment of environmental monitoring data and self-reported change perceptions of 18 bird and tree species in the Black Forest region of Southern Germany revealed that the two datasets most often do not align, even when it comes to population changes that occurred in the respondents' lifetime (74% of the cases). Here, we highlight that change blindness prevails as a perception phenomenon, especially when monitoring data reports species increases. The accuracy of perception varies greatly among species. Most interestingly, even after accounting for species, sociodemographic factors (age, education, personal mobility, nature relatedness and media reliance) as well as for species preferences, respondents' reported 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

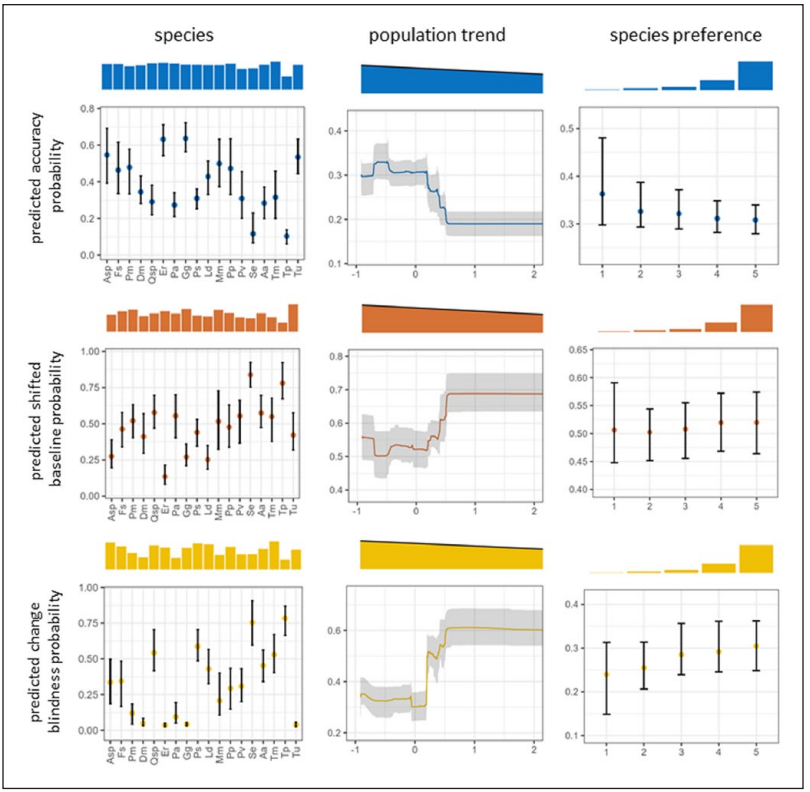


Figure 4. The effect of species, species population trend (percentual, 0 = no change) and species preference (1 strong dislike to 5 strong like) on accurate perception (blue), shifted baseline (orange) and change blindness (yellow).
Note. Color bars indicate data distributions. Species abbreviations: 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.

overall accuracy is higher for declining compared to stable or increasing species.

Contrary to our expectation the perception data did not align with the monitoring data for the most common bird and tree species, even when respondents experienced the change and lived in the area. Our findings reveal a substantial discrepancy between documented and perceived environmental

change (only 26% 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 & 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's willingness to engage in (pro-)environmental and conservation behavior (Mónus, 2021; Soga & Gaston, 2016, 2018).

Despite the majority of reported trends not aligning with environmental monitoring data, 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, 74% 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 in the case of longer-term species changes, when and specifically because attention is focused on other events, people may fail to notice changes that occur in their environment, a psychological phenomenon termed change blindness (Simons & Levin, 1998). Indeed, some 28% of the responses in our sample indicated that, for certain species, no changes occurred when environmental monitoring data actually reported change, leaving the question open toward what drives this change 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 (Buijs & Jacobs, 2021; Kahneman, 2011; Kelsey, 2020), but also in an environmental change context. In environmental contexts, a similar phenomenon has been documented when attention was focused on flagship species (Douglas & 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 increases, we point out that the phenomenon 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 & Sheppard, 2010) but see (Johns & Jacquet, 2018) and to the fact that media coverage for declining species may be dominant, biased toward NGOs, 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, maple). 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; Kappes et al., 2020). 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 & 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 (Supplemental Material S10). Among 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 (Supplemental Material S10). 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. Acknowledging that conservation of most species studied here is not a very controversial topic, 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 (Sáenz-Arroyo et al., 2005; Soga & Gaston, 2018). However, this pattern is often confounded by the fact that older individuals simply experienced more change. With few exceptions (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 & Gaston, 2018). On the other hand, although cognitive aging 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 broadly consistent with psychological research 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 (e.g. Diamond et al., 2020). Furthermore, research showed that both young and older individuals remember their childhood circumstances well (health status and living conditions; Havari & Mazzonna, 2015). This contributes to a growing body of work suggesting that it is not age but rather more subtle psychological phenomena affecting respondents' 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 largely 'forgotten' (Kahneman, 2011; Simons & Levin, 1998). Last but not least, we found a small but positive effect of nature relatedness on perception of historical trends, in line with the hypothesis that higher interaction with nature improves cognitive function (Berman et al., 2008) and confirming that the NR6 scale can capture aspects of human-environment interactions (Nisbet & Zelenski, 2013).

The results of our analysis are unambiguous and consistent across different analysis approaches (Supplemental Material S6). The low overall variance explained by our models (Figure S9) indicates that there are other processes at play that may affect perception. Specifically, it is well recognized that, among 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 oriented 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 & Jacobs, 2021; Jayasinghe & Darner, 2020; Martell & 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 'environmental monitoring 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. Importantly, Red List assessments, such as those used in the bird analyses, are compiled from both territory mapping data and expert knowledge. This means that the ecological monitoring data we used already incorporates a degree of expert knowledge. While the value of expert knowledge is widely recognized in ecological assessments, these data are often misinterpreted in research (Drescher et al., 2013). The presence of expert knowledge in our ecological data can be interpreted in several ways. First, if there is an implicit bias among experts that aligns with public perception, our estimates of mismatch may be conservative. On the other hand, if no such bias exists, our study highlights differences between ecological monitoring data (which includes both empirical and expert-based components) and general public knowledge, providing an example of integration of datasets for ecological monitoring (Brook & McLachlan, 2005; Drescher & Edwards, 2019; Fitzgerald et al., 2021; H. Huntington et al., 2004).

Further, although we specifically asked respondents to report their perception of trends throughout the Black Forest ecoregion between two fixed time points, 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. 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. Although the age distribution of the respondents matches that of the larger geographical region of Baden-Württemberg, our sample may be biased toward individuals who have close work or personal relationships with the natural environment. A randomized respondent-recruitment strategy or nationally representative samples would increase the generalizability of our results. Given this potential bias, we consider our estimates of mismatch here to remain conservative and expect even higher rates of change blindness in the general public.

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 difficult 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 conservation messages framed around recovering species may increase awareness and hence contribute to better align perception with and environmental change processes.

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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, CFD, GS acquired funding, all authors revised and agreed with the manuscript.

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Declaration of Conflicting Interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: We declare that there according to Institutional regulations of the Ethics Commission of the University of Freiburg, there is no legal obligation to seek approval on environmental surveys from the ethics committee outside the field of medicine. Informed consent was granted in writing by study participants.

Supplemental Material

Supplemental material for this article is available online.

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