The role of shifting baseline syndrome in conservation: linking local ecological knowledge and biological datasets

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Declaration of Authorship

I, Lisa (Lizzie) Jones, hereby declare that this thesis and the work presented in it is entirely my own. Where I have consulted the work of others, this is always clearly stated.

Signed: L. Jones

Date: 09/07/2021

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Abstract

Local ecological knowledge (LEK) is increasingly recognised as an important source of information for conservation, especially when long-term scientific datasets are inaccessible or non-existent. However, local knowledge and perceptions of environmental change are fundamentally personal and subjective, due to a variety of social and psychological factors. Cognitive biases and phenomena, such as Shifting Baseline Syndrome (SBS) can threaten the exclusion of valuable anecdotal knowledge in conservation research, practice and policy. Under SBS, perceived environmental baselines used to measure change may not accurately represent the true ecological 'starting point', potentially leading to the consistent downgrading of perceived 'normal' conditions with every sequential generation. SBS is therefore considered an increasingly critical issue in the face of accelerating global change, as people are unable to perceive the true extent of ecological degradation, yet very little empirical evidence for SBS exists.

This thesis provides a thorough review of the SBS literature (Chapter 1), regarding current evidence for SBS and the causes, consequences, and proposed combat methods of SBS in the context of conservation management, participation, education and environmental policy. The review aims to define key terminology from a multidisciplinary perspective and distinguish SBS from other similar phenomena, combining the fields of social science, psychology, and ecology to reveal key gaps in the SBS literature.

Tackling a key research gap identified by the literature review, this thesis provides early empirical evidence for SBS in the context of garden bird population change in the UK (Chapter 3). Following the widely accepted criteria for defining evidence of SBS, social perceptions of local ecological change were statistically compared to long-term biological data to create a measure of paired 'agreement'. Variation in paired agreement was used to identify evidence of both generational and personal amnesia, the two mechanisms thought to drive evidence of SBS. This thesis also offers the first evidence of negative impacts of SBS on public perceptions of conservation priority for species in decline, confirming previous hypotheses regarding the detrimental effects of SBS on conservation support.

In investigating differences in evidence of SBS between the UK and Finland, evidence of the impacts of data range restriction and reduced sample size were identified. Data range restriction (hereafter 'range restriction') is a statistical phenomenon, characterised by weakened statistical relationships due to limited variation in the dataset as the observed

sample data do not represent the full data range of interest. The effects of data range restriction are explored using comparative modelling of variance in experience of biological change across three unrestricted and range restricted samples. The chapter concludes that range restricted sample size increases of up to 45% to achieve power equivalent to an unrestricted dataset.

Combining data in the UK and Finland, areas of agreement and disagreement between perceptions and the biological data are explored across multiple bird species, time points and population parameters (relative abundance and population trends). Patterns in agreement between data sources were identified, revealing situations where the effects of underlying socio-psychological phenomena may be more prominent and where collecting species relative abundance may be more effective than collecting species trends and *vice versa.* This study indicated that agreement was more likely to vary between species, countries and participants when collecting species relative abundance, and when asking for personal perceptions of species relative abundance, agreement tended to be higher for male participants, those recognised a greater number of species from those who reported a greater number of years birding experience. By contrast, trend agreement varied only between species, indicating that for poorly known species, research on long-term trends may be a more reliable measure of species status than relative abundance.

Finally, Chapter 7 provides one of very few studies to investigate the potential implications of SBS on conservation target-setting and decision-making. Previous hypotheses and evidence for SBS in this area are conflicted. There has been speculation as to the presence and impacts of SBS within conservation management since Daniel Pauly's seminal paper on SBS in 1995, however, recent studies have not found evidence for the syndrome. In this study, paired tests investigated experience-related differences in personal perceptions of current, maximum and target abundance (as pairs or territories), long-term trends, and perceived conservation priority for six bird species on participant's local bird or nature reserves. No significant effect of experience was found for all species and power analysis indicated that even if SBS was statistically detectible with a larger sample, the practical implications of the syndrome would be minimal due to small effect sizes, suggesting that SBS may not be as significant a threat in conservation management as first thought.

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Publications

Chapter 3 is published in People & Nature as "Investigating the implications of shifting baseline syndrome on conservation".

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Chapter 5 is prepared as a manuscript to Conservation Science and Practice as "Data range restriction impacts conservation research conclusions".

Chapter 6 is prepared as a manuscript to Biological Conservation as "Integrating local ecological knowledge (LEK) and biological datasets to evaluate bird species abundance and trends in the UK and Finland".

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I led all data collection, analysis and writing for all chapters. Dr Sarah Papworth and Professor Samuel Turvey provided comments and guidance on the design, analysis and writing of all chapters.

Other contributions

Additional publications during PhD:

- **Jones, L.,** Holland, R.A., Ball, J., Sykes, T., Taylor, G., Ingwall-King, L., Snaddon, J.L. and S.-H. Peh, K., 2020. A place-based participatory mapping approach for assessing cultural ecosystem services in urban green space. *People and Nature*, *2*(1), pp.123-137.

- Catford, J.A., **Jones, L.P.,** Gibson, D.J. and Newman, J.A., 2019. Grassland invasion in a changing climate. *Grasslands and Climate Change; Cambridge University Press (CUP): Cambridge, UK*, pp.149-171.

- Archer, L.A., Muller, H., **Jones, L.P.,** Ma, H., Gleave, R., da Silva Cerqueira, A., McMurdo-Hamilton, T., Shennan-Farpon, Y. Towards diverse and inclusive conservation; perspectives and ideas from early career researchers. *People and Nature*. (Under review)

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- Invited author and co-author for The Conversation, author for BBC Springwatch
- Interviewed by the New Scientist, Anthropocene Magazine, I News, and for Forgetting Nature, a documentary on generational amnesia.
- Research featured in BBC Future's *Wise Words* Series
- Primary organiser for a ZSL Evening Symposium entitled, 'The Value of Indigenous Knowledge for Conservation' and co-host of a subsequent ZSL podcast.
- ZSL Biology Week video calls with UK schools about careers in conservation.
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Conference presentations and posters:

- BES PalaeoSIG 2021 Masterclass in R (presentation).
- BES Annual Meetings 2019 (presentation) and 2020 (poster).
- Linnean Society Student Spotlights 2020 (poster).
- UCL Conservation Society Guest Speaker (2020).
- Student Conference for Conservation Biology 2019 (presentation).
- ZSL Annual Science conference 2018, 2019 (presentation) and 2020 (poster).

Definitions

Connectedness to nature (CTN): A measurable construct describing an individual's perception of their own relationship with the natural world (Nisbet et al., 2009; Lumber et al., 2017).

Empirical knowledge: A bank of propositional knowledge gained via subjective, personal experience via the senses through observation or experimentation (Putnam and Compton, 1969).

Episodic (explicit) memory: Place, emotion, context, and experience-based memory of autobiographical events that can be explicitly stated or conjured (Tulving, 2002).

Erosion of knowledge: The *process* by which personal (LEK) or communal (TEK) empirical knowledge of the natural environment is lost (Aswani et al., 2018). Loss is often due to socio-economic or cultural change such as urbanisation or westernisation (Pilgrim et al., 2008).

Extinction of experience: Disconnection from nature due to a reduced daily contact and fewer meaningful interactions (reduced subjective experience) with the natural environment (Miller, 2005; Soga et al., 2016a)

Generational amnesia: A form of SBS in which there is a gradual loss of information regarding past conditions by each subsequent generation due to a lack of intergenerational communication (Kahn and Friedman, 1995)

Learned *(A priori)* knowledge: A store of knowledge gained independent of personal experience through secondary communication or learning.

Local ecological knowledge: Local people's knowledge of local nature, usually gained through individuals' observations over their lifetimes (Gilchrist et al., 2005).

Personal amnesia: A form of SBS in which individuals have no recollection of ecological change over time due to memory loss or allow extreme memories to mask realistic trends (Papworth et al., 2009).

Semantic (implicit) memory: The ability and capacity to recollect facts and general knowledge about the world, independent of experience-based knowledge (Squire and Zola, 1998).

Shifting baseline: A new baseline state which has, over time, significantly diverged from the original state of the system (Klein and Thurstan, 2016).

Shifting baseline syndrome (SBS): A social phenomenon in which people are unable to perceive change in condition of the natural environment due to a lack of past experience, comparing change to only autobiographical experience (Papworth et al., 2009; Soga and Gaston, 2018).

Subjective experience: First-hand, personal knowledge or mastery gained through involvement or exposure with the subject of interest (OED, 1989).

Traditional ecological knowledge: A cumulative body of knowledge, practices and beliefs in relation to the natural world, evolving over time and handed down through generations by cultural transmission (Berkes et al., 2000).

Introduction

Almost all ecosystems exist in a state of shift and change. However, ecological change can go unnoticed by local people as new conditions are readily accepted as the normal state of play (Soga and Gaston, 2018). A lack of historical ecological data can prevent the precise measurement of change from past to present conditions and inhibit informed estimation of effective targets across conservation (Thurstan et al., 2015; Turvey et al., 2015). Shifting baseline syndrome (hereafter SBS) is a socio-psychological phenomenon in which historical environmental information is lost and people do not notice (Papworth et al., 2009; Jones et al., 2020). SBS is thought to occur because people tend to compare current ecological conditions to reference points set within their own autobiographical experience (Rost, 2018). The baseline for what are considered 'normal' current ecological conditions is therefore framed within a single human generation, rather than across multigenerational timescales, preventing accurate perception of long-term change (Pauly, 1995).

In this thesis, multidisciplinary methods are used to investigate evidence of SBS in both the public and management domains of conservation ecology. To provide empirical evidence of SBS, paired or 'matched' data methods are used to statistically compare local perceptions with biological datasets. Public perceptions of bird species population abundance and trends in the UK and Finland provide an effective case study to explore empirical evidence for the existence and potential impacts of SBS. Participant demographics, perceptions of species population change, experience and knowledge were collected via large-scale online questionnaires. Through comparative investigation of SBS in both the UK and Finland, the potential impacts of reduced sample sizes and range restriction are highlighted, which pose challenges to researchers investigating evidence of SBS in any field. Interviews with conservation managers, practitioners and decision-makers further explore the impacts of SBS on conservation decision-making and help to empirically identify the key factors that influencing conservation managers' perceptions of ecological change, to improve the current understanding of SBS and aid future investigation into combatting SBS.

1.1. Introduction to shifting baseline syndrome

The origins of SBS lie in the concept of a 'shifted baseline', which describes a new ecological baseline that is significantly diverged from the original system state, a concept that is widely used in ecological (e.g., Dayton et al., 1998; Knowlton and Jackson, 2008; Kai et al., 2014) and psychological research (Driver and Frith, 2000). It is worth noting that SBS is frequently misidentified as 'shifted or shifting baselines', which refers only to changing biological conditions, discounting the socio-psychological aspects of SBS, or even as 'shifting reference baselines' (e.g., Mihoub et al., 2017).

SBS is thought to occur when perceived environmental baselines do not accurately represent the true environmental 'starting point', leading to downgrading of perceived 'normal' environmental conditions over time (Papworth et al., 2009; Soga and Gaston, 2018). Research to date hypothesises that SBS is indicated when personal perceptions cannot keep pace with rapid environmental change, due to a lack of experience of nature (Soga and Gaston, 2016) or a loss of historical knowledge (Turvey et al., 2010), preventing realistic perception of environmental degradation (Wu et al., 2011). It is thought that if entire generations cannot accurately perceive ecological change, this may be, or become, a significant barrier to support for ecological conservation, restoration, and rewilding initiatives (Soga and Gaston, 2018).

In his seminal essay in 1995, Daniel Pauly coined SBS in the context of fisheries management, in which:

> *"…each generation accepts [as] a baseline…that occurred at the beginning of their careers, and uses this to evaluate changes".*

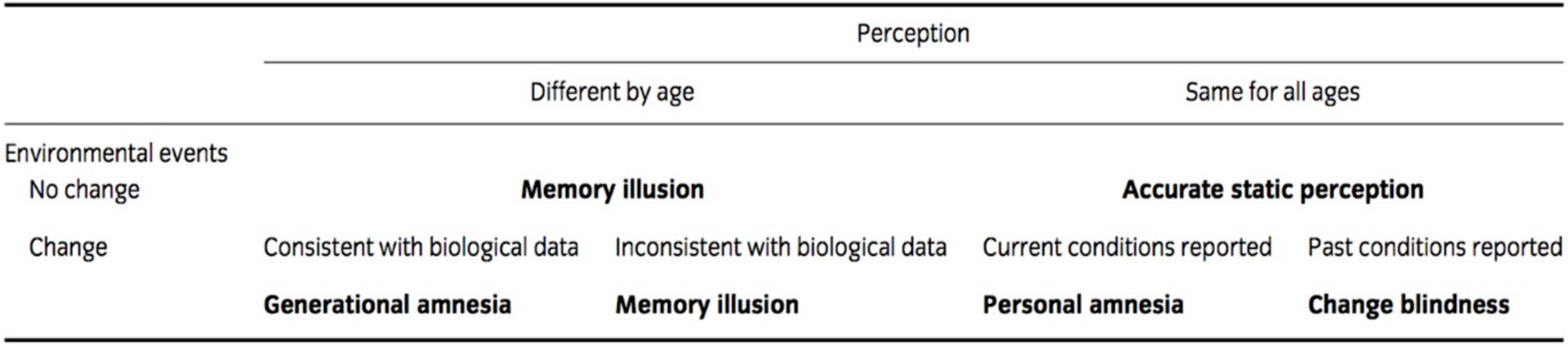
Pauly hypothesised that over multiple generations, SBS could lead to the use of inappropriate biological reference points and a gradual accommodation of species losses. Without long-term and empirical evidence of changing conditions it is difficult to perceive the extent of ecological change, even if the species or system of interest was historically abundant or thriving (Pauly, 1995). SBS has since been defined as a social phenomenon by which individuals or entire generations compare change in the biological system against a recent set of reference points or baselines, often set at the beginning of their life or career (Papworth et al., 2009). The baseline for perceived 'normal', current ecological conditions is therefore framed within a single human generation, rather than across multigenerational time frames, preventing accurate perception of long-term change (Turvey et al., 2010). The 'normal' baseline can shift with each successive generation due to lack of intergenerational communication and the loss of historical information and context (Bender et al., 2013).

In 2009, Papworth et al. built upon Pauly's original hypothesis, to provide a framework for examining evidence of SBS in more detail, defining two key criteria that must be met for SBS to occur (Papworth et al., 2009). In order to find evidence of SBS, first and in all cases, the system must exhibit perceptible environmental change. While most examples in the SBS literature are of negative change (e.g., Turvey et al., 2010; Bender et al., 2013), some are positive, which has been referred to as 'lifting baselines' (e.g., Steen and Jachowski, 2013; Roman et al., 2015). The second criterion depends on the form of 'amnesia' occurring within the population**,** so called for the loss of knowledge that results in perceptual inaccuracy.

References to SBS can be separated into two forms of amnesia; '*generational amnesia'* is the form of SBS most often referred to in the literature, first described in relation to urban children's perceptions of nature (Kahn and Friedman, 1995). Generational amnesia describes a gradual loss of information regarding past conditions by each subsequent generation due to a lack of intergenerational communication, creating bias in interpretations of past ecological conditions in relation to the current (Pauly, 1995). By contrast, *'personal amnesia'* describes a situation in which individuals have no recollection of ecological change over time due to memory loss or allow extreme memories to mask personal experience (Papworth et al., 2009). Under these definitions, for generational amnesia to occur, all individuals must have an accurate perception of the current system conditions, but perception of system change over time must be dependent upon age or experience, i.e., differences per generation. For personal amnesia, individual observers are unaware of any difference in current and past conditions, with no effect of observer age or experience (Table 1). It is important to clarify that SBS is not an umbrella term for 'personal amnesia' and 'generational amnesia' but rather that both forms of amnesia are mechanisms behind SBS (Papworth et al., 2009).

As seen in Table 1, Papworth et al. (2009) also define SBS in the context of other, similar terms in the conservation psychology domain. Memory illusion is thought to occur when perceptions of change vary by age, for example, where older people inaccurately recall past conditions, recalling change over time, or vice versa (Roediger III, 1996). Conversely, when all ages have a similar perception of change within a static biological system, accurate static perception occurs, and under 'change blindness' people indicate an inability to recognise or notice true biological change (Simons and Rensink, 2005).

Table 1. From Papworth et al. (2009). Establishing the key differences between personal and generational amnesia (and similar concepts) in relation to environmental change.



	Perception			
	Different by age		Same for all ages	
Environmental events				
No change	**Memory illusion**		**Accurate static perception**	
Change	Consistent with biological data	Inconsistent with biological data	Current conditions reported	Past conditions reported
	Generational amnesia	**Memory illusion**	**Personal amnesia**	**Change blindness**

1.2. Proposed implications of SBS for conservation

Daniel Pauly's original hypotheses predicted that with each successive generation of researchers, SBS can lead decision-makers to develop unrealistic perceptions of anthropogenically-caused environmental degradation, resulting in an unobserved acceptance of degraded ecological conditions and the setting of less and less ambitious targets by conservation managers (Pauly, 1995 - Figure 1). More recent papers have similarly forecasted the power of SBS to discourage conservation managers and policymakers from implementing ambitious targets (Bonebrake et al., 2010; Plumeridge and Roberts, 2017), yet there is a significant lack of evidence for this issue. Due to a lack of long-term biological datasets, only three previous studies have investigated evidence of SBS in management scenarios (Cook et al. 2014; Plumeridge and Roberts, 2017; Muldrow et al. 2020), representing a significant gap in the SBS literature. Furthermore, all three studies did not meet the criteria identified by Papworth et al. (2009), in which perceptions must be directly compared to biological datasets (see section 1.4. for more details). Even in the absence of SBS this is problematic, as wrongful citation of SBS in a management context may bias the interpretation of historical conditions and the effectiveness of science-based conservation management decisions.

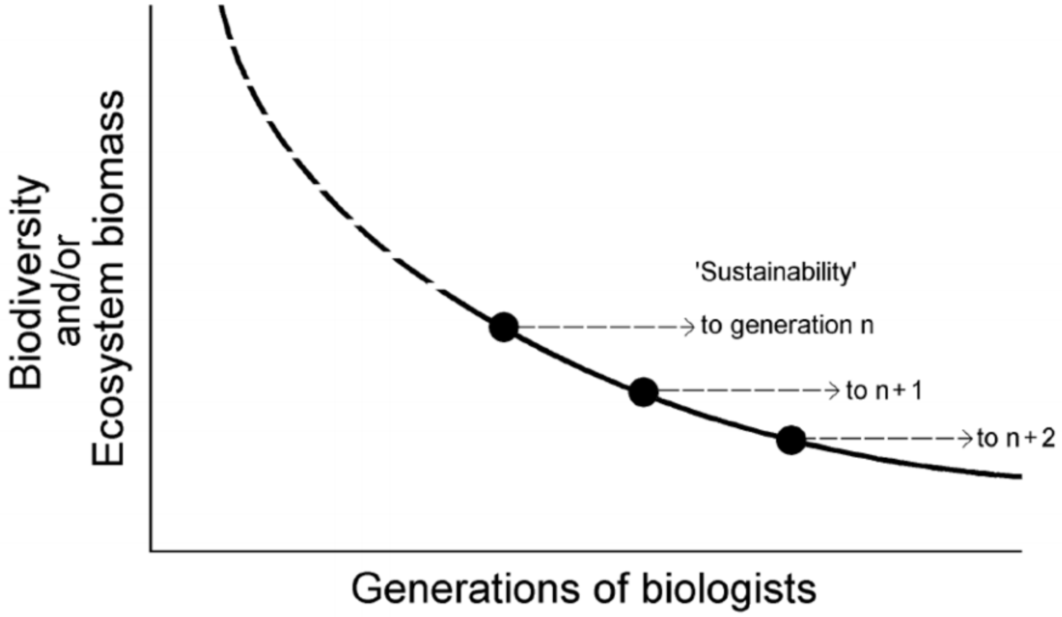


Figure 1. Adapted from Pauly's schematic of shifting baseline syndrome (Pauly, 2001). Each generation of conservationists set their static baseline at the beginning of their career, forgetting previous conditions (dashed line).

In the same year as Pauly's 1995 paper (Pauly, 1995), Kahn and Friedman also identified 'generational amnesia' as a form of SBS with regard to the perceptions of members of the public, after assessing awareness of environmental decline in inner-city children and their perceptions of a 'normal' local environment (Kahn and Friedman, 1995). They identified a higher tolerance for environmental degradation than expected, suggesting an age or experience-related difference in the children's perceptions of degradation compared to the research team. Since then, many reviews and studies have voiced concern over the potential effects of SBS on public perceptions of biological change, and therefore perceptions of the need for conservation interventions in declining ecological systems (Papworth et al., 2009; Turvey et al., 2010; Soga and Gaston, 2018). In her 2018 book 'Wilding', Isabella Tree highlighted the effects of SBS on perceptions of rewilding on the Knepp estate in Sussex, UK. Tree observed that support for rewilding varied significantly by generation, with the eldest welcoming a landscape similar to their youth, while the younger generations were more critical of significant change away from the farmed landscape they grew up with (Tree, 2018, pages 147-149). Although not empirical evidence of SBS, this case study emphasises the significance of the impacts SBS may have on support for restoration and rewilding initiatives, especially those that rely on public volunteers or funding. Likewise, in terms of policy, a lack of public support for conservation issues may lead to less aggressive policymaking. This has been coined 'the policy-placebo effect' in a recent study, where participants believed some species populations to be increasing following the passage of new conservation legislation, without biological evidence for recovery (Lovell et al., 2020). However, due to the limited scope of the study and small sample size it is unclear as to whether this effect is an outcome of SBS, or if SBS and the policy-placebo effect occur in tandem.

1.3. Local ecological knowledge, perceptions and biases

In rapidly shifting biological systems, in which people play a large role in ecological change, understanding the perceptions, knowledge and behaviour of stakeholders and decision-makers is critical for maintaining long-term conservation support and success (Redpath et al., 2013). To inform conservation decisions, researchers require data regarding the occurrence and degree of change in the system, species, or environment to make assessments of change and estimate the action needed to return systems to past conditions (Foley and Lynch, 2020). Yet long-term biological records are often unavailable, highlighting the importance of anecdotal, experience-based information such as local ecological knowledge (LEK) to help understand past conditions (Turvey et al. 2010).

Contemporary studies increasingly look towards the use of historical records, living-memory, and perceptions to provide anecdotal accounts of ecological change on a variety of temporal scales (Turvey et al., 2010; Katikiro, 2014; Fernández-Llamazares et al., 2015; Thurstan et al., 2016). Fazey et al. (2006) were among the first to highlight the value of local, expert knowledge in the conservation literature, recognising LEK as an embedded system, in which community-held knowledge is formed through direct ecological feedback with the local natural environment (Berkes et al., 2000; Fazey et al., 2006). In addition to LEK, traditional ecological knowledge (TEK) emerges over long temporal scales, through complex cultural and social contexts and can be communicated vertically from generation to generation through oral traditions (Aswani et al., 2018). However, as theorised by Polfus et al., (2014), the embedding of LEK in cultural practices makes differentiating LEK difficult when referring to the knowledge of local communities and indigenous peoples (Polfus et al., 2014). In the context of SBS, the term LEK is most often used, especially when investigating empirical evidence of the syndrome (e.g., see section 1.5 for more information). As SBS refers to differences in personal perceptions of ecological change and the impact of that individual’s memories and experiences. However, TEK is extremely important when considering SBS as a generational issue, as historical knowledge, passed down through generations, has been theorised as the key to combatting the effects and consequences of SBS (see section 1.6 for more information).

Other sources of local knowledge include photographic records (e.g., McClenachan, 2009; Chen et al., 2011 - see Figure 2), literature-based archives (e.g. Plumeridge and Roberts, 2017) and scientific or industry-based accounts (e.g., Thurstan et al., 2016). LEK can therefore reveal both current local perceptions of the local environment, and historically perceived baselines, providing a rich socio-ecological history. Furthermore, LEK is increasingly recognised by international research and policy as a valuable conservation tool with great potential to promote sustainable resource use, aid biodiversity monitoring, and achieve conservation enforcement via integration with local cultural systems (Gratani et al., 2011). This is emphasised by Aichi Target 18 of the Convention on Biological Diversity (CBD) which recommends “the full and effective participation of indigenous and local communities” in conservation policy by 2020 (CBD, 2011; Tengö et al., 2017).

Figure 2. Photos of ‘trophy fish’ caught by the same boat in the same areas and displayed on the same board, the left in 1957, the right in 2007 in Florida, USA (McClenachan, 2009). Photographs can provide a long-term, universal language by which to identify ecological change and combat SBS.

However, it is accepted that personal perceptions, based on experiences, are likely to be biased according to the prior knowledge, preferences, cultural beliefs, experiences, and upbringing of each individual. Personal perceptions of past and current ecological conditions can be influenced by numerous factors, including ability to accurately recall memories and information (Blasiman and Was, 2018; Rost, 2018), influence of cognitive biases and heuristics (Tversky & Kahneman 1973), such as SBS and cultural factors shaping the local 'information environment' (Verweij et al., 2010; Daw et al. 2011; Peñaherrera-Palma et al., 2018). Variation in the frequency, means and timeframe over which individuals experience the local environment can lead to differences in perceptions of ecological change between past and current timeframes, and therefore influence predictions for the future (Beaudreau and Levin, 2014). Despite potential 'cognitive biases', defined as systematic deviations from normal rational judgment, which often form recognisable patterns in behaviour or thought (Haselton et al., 2015), the study of LEK can help us learn about the influence of spatial, cultural and temporal factors on perceptions of change.

1.4. The importance of memory, experience and knowledge

A baseline can be defined as 'an imaginary line used as a starting point for making comparisons' (Ureta et al., 2020). SBS describes the fallibility in our ability to perceive change over personal or generational timescales. Perception of time itself is therefore intrinsic to understanding the driving forces behind evidence of SBS. In the case of background environmental change and memory, subjective perceptions of time are likely to influence perceptions of change over time. For example, in 2014, Klincewicz argued that without change or other stimuli it is almost impossible to perceive the movement of time, resulting in 'change blindness' (Simons and Rensink, 2005), and conversely time can 'fly' faster the more changes occur in a situation (Hansen and Trope, 2013). Change is therefore occurring over multiple unit scales; biological or environmental change occurs over time, and personal perceptions of the movement of time can correspondingly develop with age.

Several studies highlight the importance of intergenerational communication for the preservation of long-term LEK (Turvey et al., 2010; Fernández-Llamazares et al., 2015). However, knowledge is also lost through the distortion of personal memories. This can occur due to a lack or loss of personal experience, social-cultural influences, or numerous cognitive biases (Soga and Gaston, 2018; Weber et al., 1996). Rost (2018) provides a comprehensive theoretical review of the psychological mechanisms driving SBS, investigating the relationship between knowledge, experience and memory, at the individual and community scale. Using an interdisciplinary standpoint, Rost recommends the direction of further SBS research lies in understanding the links between personal perceptions of the past and our predictions of future conditions, as "future-related memory functions". In line with Papworth et al. (2009), this indicates that our past experiences and subsequent knowledge are key to understanding current perceptions (Rost, 2018).

Few previous SBS studies have considered the intrinsic links (and significant differences) between experience and knowledge. Assmann (2006) considers personal experience as individual perceptions of the environment, generated first-hand and stored as *episodic memory* within 'empirical knowledge' for long-term retrieval. Autobiographical knowledge has place, emotion, and sensory context, therefore when the observer reflects back upon the experience at a later date, they are thought to consciously 're-experience' episodic memories at an interaction of past and present (Assmann, 2006; Rost, 2018). By contrast, *semantic memory* enables the recall of learned knowledge, which has been memorised independently from personal experience through formal education or from communication, often from the older generation (n-1 in Figure 3). Indirect experience gained through learning and communication are thought to help to foster a connection to nature (CTN) (Lumber et al., 2017). Both forms of knowledge can be retrieved and recalled forming part of our personal perceptions (n), which can then be further communicated to the next generation (n+1) enabling this generation to comprehend and perceive long-term ecological trends. However, there are many potential sources of inaccuracy in each generation's perception of change. In the context of declining biodiversity, each generation experiences a differential 'snapshot' of biological decline. In Figure 3, observation of the overall timeline allows a long-term view of the biodiversity trend over three separate generations. If generational amnesia is in effect, generation n would perceive a stable biodiversity trend, as their baseline is only based on autobiographical experience, but this generation would perceive a negative overall trend, if they knew of the experience of their parents (n-1).

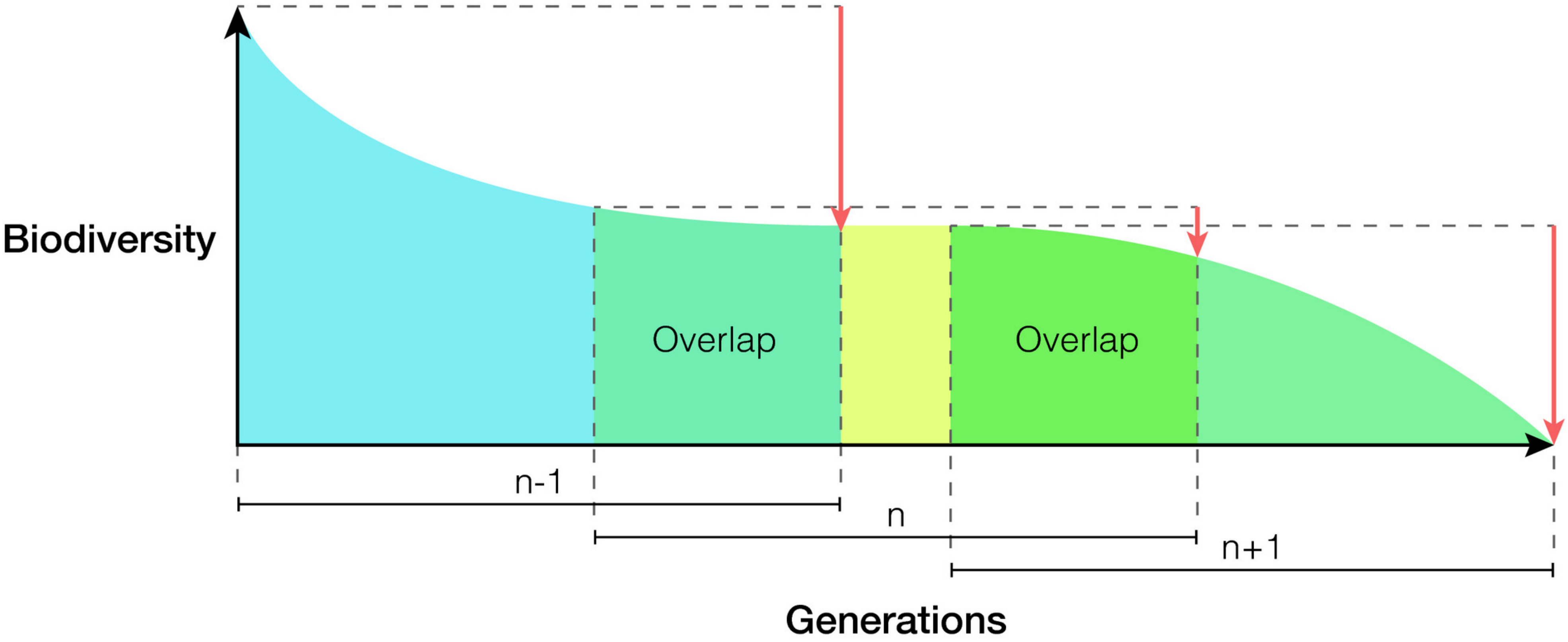


Figure 3. Building on Pauly's original figure (Figure 1) in which each generation is identified by a static baseline point, here each generation (n) inhabits a window of time, which will overlap with previous and successive generations (n-1 and n+1), during which intergenerational communication can pass knowledge between generations.

The temporal overlap of several generations creates many points at which perceptual inaccuracy can be introduced. Some biases occur irrespective of age, such as the Weber–Fechner law which describes a logarithmic relationship between the 'just noticeable difference' in quantities of any stimulus. Under this law, changes to small amounts appear more significant than changes to large amounts, biasing perceptions of compared differences (Weber et al., 1996). Conversely, an individual's ability to store and recall information is not infallible, primarily due to aging, memory loss and cognitive biases. As we age, episodic memory can transition to semantic memory over time, leading to the generalisation of older memories due to a gradual loss of context and to the consistency bias (believing the past as resembling the present). On the other hand, 'reminiscence bumps' enable the recall of memories of youth with unprecedented accuracy, potentially biasing recall to certain time periods (Jansari and Parkin, 1996). This can be partially explained by changes in the perception of time; as the brain experiences fewer novel stimuli, research suggests a disengagement with the present, therefore, time appears to 'pass faster', altering perceptions of change over time and contributing to personal amnesia (Hayes, 1992). Memories can also become distorted, added to, or changed over time, often due to external influences, such as memory conformity, in which information reported by others is incorporated into the individual's memory (Wright et al., 2000).

However, for younger people the detrimental effects of aging on memory and recall have not yet begun (Salthouse, 2009) and inaccurate perceptions of change are therefore most likely due to a lack of experience or the learning of erroneous knowledge from previous generations (Craik, 1992). Recent research suggests that the combination of diminishing nature degradation, reduced CTN and the progressive loss of human-nature interactions may provoke an 'extinction of experience', a term originally coined by Pyle (1993) to describe a lost connection to nature due to a reduced daily contact with the natural environment (Pyle, 1993; Soga et al., 2016a; Gaston and Soga, 2020). Similarly, the nature deficit disorder specifically describes extinction of childhood experience of the natural environment (Louv, 2005). Therefore, without personal experience, younger generations are increasingly dependent upon objective knowledge via education and communication from previous generations, who may themselves suffer from SBS, further exacerbating SBS in a positive feedback mechanism (e.g., Figure 4).

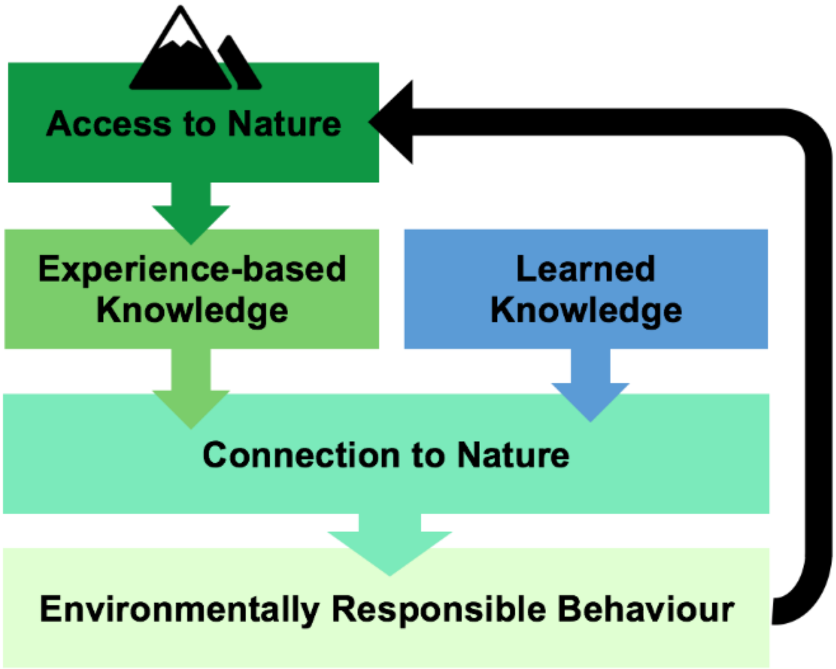


Figure 4. The hypothesised relationship between localised accessibility to nature and greenspace, nature-based experience, learned knowledge and connection to nature, and how impacts conservation success via the encouragement of environmentally responsible behaviour.

It is worth noting that recent research suggests that younger generations experience nature as frequently as previous generations, but the nature of the connection is diminished, due to ecological declines, urbanisation or perhaps SBS itself (Novotný et al., 2020). Pilgrim et al. (2008) attribute significant loss of LEK and TEK in developing countries to social change such as urbanisation, Westernisation of education and the homogenisation of culture, language and beliefs. As rural communities (India, in their example) become less reliant on local, natural resources that require local knowledge to exploit, traditional knowledge that would once have been communicated to the next generation is similarly displaced (Pilgrim et al., 2008). Significant social change in urban communities is likely to lead to a diminished CTN, which, as argued by Thomashow (1996) occurs only through lack of nature-based experience preventing a sense of place, the foundation for a sense of personal responsibility towards the condition of the natural environment (Thomashow, 1996; Wilson, 1997). According to Powers (2004), children must have a clear sense of place, developed via personal experience and knowledge, before positive attitudes of attachment or protectiveness to that place can exist (Powers, 2004). Urbanisation and increasing levels of nature deprivation may also have negative repercussions on personal health and wellbeing, as well as potentially significant implications for environmental conservation due to reduced empathy and concern for ongoing environmental decline (Kellert and Wilson, 1993). Figure 4 conceptualises the proposed links between public access to nature and environmentally responsible behaviour including support for conservation of nature access. However, a barrier to the system at any point may limit nature-based experience, impacting CTN and potentially limiting the development of positive conservation values.

1.5. Empirical evidence of SBS: Methods and barriers

Matching LEK and biological datasets

Matching or pairing LEK and scientific knowledge is a common approach used to analyse ecological observations, identify gaps in the record and reduce uncertainty in conclusions (Huntington et al., 2004; Gilchrist and Mallory, 2007). However, complications arise when combining cultural (LEK) and biological knowledge due to a variety of methodological, linguistic, cultural, and epistemological differences. This can often make collaboration difficult to organise in a field that "lacks the luxury of time" (Drew and Henne, 2006). Furthermore, direct comparison of biological data and LEK is only possible when information is collected on the same or similar spatial and temporal scales. For every study within both science and LEK, spatial and temporal scales tend to be contingent with the specific hypotheses and methodologies of each study, rather than the type of knowledge used. LEK is characterised by locally specific information, developed over longer timescales, so is more suited to providing a longer temporal outlook than recent scientific data (Gagnon and Berteaux, 2009).

Huntington et al. (2004) presented an alternative to the direct comparison of data on non-identical scales, encouraging a focus on "complementarity rather than concordance". Fundamentally, both forms of knowledge are based on observations and analysis, however while scientific data is intended to be collected systematically, via impersonal and unbiased methods, although not all scientific data conforms to these rules, LEK reflects personal experience and is therefore as reliable as the perceived credibility of the informant (Huntington et al., 2004). By concentrating on the areas in which LEK and scientific data overlap and align, information can be matched or 'paired' to strengthen the scientific record and better inform conservation research and policy. Such thinking has been adopted by many recent studies, which aim to compare LEK and biological datasets using holistic methods to better understand the synergies and differences in research conclusions when using each dataset (e.g., Albuquerque et al., 2021; Torrents-Ticó et al., 2021). For example, Torrents-Ticó et al., (2021) compared abundances and trends of threatened carnivore species in Kenya derived separately from camera trap data and local indigenous knowledge. The study identified areas of convergence and divergence between datasets, concluding that the comparison of different data types enriches evidence and understanding of changing ecological systems.

To identify empirical evidence of SBS according to the definitions of Papworth et al. (2009), a paired data approach is required to compare scientific datasets to local knowledge and gain a measure of ‘agreement’. For example, Papworth et al. (2009) found that older residents of a village in Yorkshire, UK, were more conscious of changes in the bird species abundance over the past 20 years than younger village residents by comparing survey data to bird census datasets (Papworth et al., 2009). However, paired data studies have initiated argument between academics. Brook and McLachlan (2005) in response to Gilchrist et al. (2005) warned of using ‘Westernised’ scientific data as ‘truth’ as all information, from any source, may be based upon assumptions and limitations (Gilchrist et al., 2005; Brook and McLachlan, 2005). While not all LEK can be taken at face value, the direct testing of LEK may also be considered “disrespectful” to the local indigenous population as there is inherent value in local perceptions and values, providing rich context for conservation decisions (Huntington, 2000). For example, in Australia, Gratani et al. (2011) involved indigenous co-researchers to examine local management of invasive fish species using complementary methods, finding that a long-term, collaborative relationship forged trust and encouraged cross-cultural data sharing (Gratani et al., 2011).

Data-based limitations and barriers to investigating SBS

As stipulated by Pyhälä et al. (2016), paired data studies provide a more thorough account of long-term ecological change via the combination and cross-referencing of multiple data sources (Marin, 2010; Pyhälä et al., 2016). While the inherent biases in LEK and perceptions are well recognised in the literature (e.g., Turvey et al., 2010), issues relating to the reliability of biological datasets are less discussed. Didham et al., (2020) highlight the need to ‘pause’ and critically compile, analyse and interpret biological datasets, despite haste to provide increasing evidence for biological change. Using insect declines as a case study, the authors discuss seven key challenges in drawing robust inference from biological datasets: site selection biases, detection bias effects, robustness of time series trend estimation, density dependence, phenological shifts, scale-dependence and the establishment and reliance on historical baselines. High levels of inter-annual variability are common in large, long-term ecological datasets, therefore the determination of appropriate baselines is challenging and lengthens the time series required to "separate signal from noise" (Didham et al., 2020).

The process of choosing a historical baseline upon which to measure long-term biological change is of considerable debate in conservation biology. As discussed by Didham et al. (2020), there is a danger to succumb to the 'false-baseline effect', as back-casted (Manning et al., 2006) or post-hoc measured baselines are likely to underestimate historical baselines (e.g., Powney et al., 2019). Several studies, including Campbell et al. (2009), have criticised the use of baselines all-together, emphasising the challenge of identifying the most 'appropriate' baseline as a target for restoration, rewilding, or conservation, while other studies have called for the validation of baseline wherever possible (e.g., Alleway and Connell, 2015). Many recent papers have therefore emphasised the importance of historical and paleo-ecological data to understand the state of ecosystems in relation to past environmental and social-ecological change and validate the use of perceived baselines (Grace et al., 2019; Thurow et al., 2019; Manzano et al., 2020).

Current empirical evidence of SBS

While anecdotal information is well-recognised as a key source of information regarding ecological change, the grounding of management decisions on oral communication and memory opens management decisions up to bias due to phenomena such as SBS (Turvey et al., 2010). Despite this, surprisingly little empirical research has been undertaken to provide evidence the existence or potential threats of SBS, and even fewer studies provide conclusive empirical evidence according to the definitions outlined by Papworth et al. (2009), indicating a significant gap in the present literature (Guerrero-Gatica et al., 2019).

Many SBS studies focus on proving age-related differences in participant's perceptions of local baselines, with a focus on fisheries science. However, as highlighted by Papworth et al. (2009), experience is often independent of age and is more likely to be the active factor influencing perceptions of changes in the natural environment, although the separation of age and personal experience is often difficult (Papworth et al., 2009). It is also critical to note that SBS is not always the correct explanation for age-related differences in perceptions of normal conditions as multiple psychological factors interact. For example, under memory illusion, the prevailing narrative of the local community often replaces personal experience (Roediger III, 1996).

Saenz-Arroyo et al. (2005) conducted surveys across three generations of fishermen (*N*=108) in the Gulf of California, where records suggest a steep decline in fish species abundance in in the past 60 years. The younger generation knew of five times fewer species than the older generation, indicating that many species extinctions had gone unnoticed by the younger fishermen, indicative of generational amnesia. Similarly, older people identified four times the number of fishing sites that would have been considered 'abundant' but were perceived as depleted by the time of the study, than the younger generation of local fishermen (Saenz-Arroyo et al., 2005). Similarly, Ainsworth et al. (2008) found that older fishermen recognised much smaller catches at the time of the interview compared to their childhood. However, as highlighted by Turvey et al. (2010), both studies use fuzzy logic to suggest evidence of SBS, assuming perceptions are implicit with experience and relate directly to participant age (Ainsworth et al., 2008). Furthermore, the second example uses 'catch-per-unit-effort' to normalise participant responses, therefore while these studies providing interesting insight into the potential scope of SBS, neither confirm evidence of SBS.

Papworth et al. (2009) were also first to acknowledge the potential for discrepancy between age and personal experience in many biological systems and recognised the need for parallel biological data to confirm SBS within perceptions of environmental change. Their paper established the importance of SBS research in terrestrial landscapes through three case studies. Two studies investigated the perceptions of bushmeat hunters in rural landscapes but did not prove the existence of SBS as sufficient biological data was not available to indicate statistically significant correspondence between personal perceptions and biological change. However, the final case study, concerning local perceptions of the UK public found evidence of generational amnesia in relation to bird species datasets using paired data techniques, as older, more experienced participants were most able to identify the three most common garden birds in the past state. Personal amnesia was also identified as a second mechanism driving SBS at the personal level, as participants with static perceptions of species population change tended to name currently abundant species as most common rather than those more abundant in the past (Papworth et al., 2009). However, no further evidence of personal amnesia has been identified.

Even after the publication of Papworth et al. (2009), many studies claim to find evidence of SBS, but few studies statistically directly compare perceptions to analogous biological datasets. For example, Plumeridge and Roberts (2017) suggest evidence that SBS leads to the creation of unambitious conservation management targets and the underestimation of the true extent of long-term biological change in the Dogger Bank, UK. However, the biological baseline was 'reconstructed from qualitative and semi-quantitative' unsystematic anecdotal witness testimonies of historical fish stocks and catch effort, therefore direct comparison between data sources was not possible (Plumeridge and Roberts, 2017). Similarly, Muldrow et al., (2020) tested evidence of SBS in coral reef scientists in Florida, successfully quantifying experience as the number of hours diving on local reefs, as previously recommended by Papworth et al. (2009). However, in the case of Muldrow et al. (2020), evidence for biological change was established using respondent's testimonies rather than using independent biological data, indicating evidence of shifting ecological baselines rather than SBS following the definitions outlined above (Muldrow et al., 2020). This is also despite the reiteration of the criteria needed to identify evidence of SBS in many papers in the past decade (Fernández-Llamazares et al., 2015; Soga and Gaston, 2018; Guerrero-Gatica et al., 2019).

Many subsequent studies have since included estimates of participant experience as well as age, while also exploring other factors such as knowledge, level of community cohesion and intergenerational communication. For example, in China, Turvey et al. (2010) investigated the potential extinction of the Yangtze River dolphin or 'Baiji', a charismatic megafaunal species declining due to accidental bycatch, local habitat degradation and resource depletion. A rapid extinction of local knowledge was observed with each successive generation, with younger interviewees (especially those aged < 49) significantly less likely to recognise Baiji from photographic cues. This indicates a form of paradigm shift as a complete loss of personal experience of the species in the younger generation translated into an extinction of knowledge and recognition, highlighting the speed at which LEK can be lost, even in rural communities with strong intergenerational ties (Turvey et al., 2010).

Within the definitions of SBS, methodological choices may also impact the validity of SBS studies. For example, Kai et al., (2014) investigated evidence for SBS in the context of local erosion of LEK in the tropical forests of Southwest China, through participants ability to name a selection of birds and mammals in their local language from pictures. The authors found that older people were more able to identify species, indicative of generational amnesia. However, participants selection was limited to those aged 20-60 years old and "*in a healthy mental and physical state*". This may lead to statistical biases on study conclusions such as range restriction (Bobko, 2001; Bland and Altman, 2011), and limit the discussion of the effect of memory and cognitive biases associated with older age on study. However, no previous study has explored the effect of statistical phenomena such as range restriction, on evidence of SBS.

Fernández-Llamazares et al., (2015) followed the steps required to find empirical evidence of SBS using paired data techniques, and highlighted the importance of intergenerational communication, arguing that a lack of vertical knowledge transfer was implicit in proving the existence of generational amnesia. The authors interviewed 300 adults in 13 villages in Bolivia, to investigate the perceived effects of recorded deforestation and species extinctions. Greater long-term ecological change was recognised by older respondents, compared to younger hunters, further proving the vulnerability of local knowledge systems to SBS (Fernández-Llamazares et al., 2015). However, while LEK and intergenerational communication may shed light on knowledge gaps in recent history, other data sources may be required to assess longer-term ecological declines and produce reliable future projections (Mihoub et al., 2017).

While the prevailing narratives of ecological change focus on decline, rewilding and habitat restoration provide opportunities to investigate SBS regarding positive change. Leather and Quicke (2010) examined the restoration of moorland to traditional woodland in rural Scotland, which was initially passionately opposed by local stakeholders, yet one generation later, the woodland harvest was prevented as local people prioritised the restored woodland (Leather and Quicke, 2010). Steen and Jachowski (2012) similarly found evidence of SBS regarding species that are perceived to be more abundant than biological data would suggest. For example, exotic and invasive species pose one of the biggest worldwide threats to maintaining biodiversity yet their ubiquity outside their native range has led to their tolerance as 'natural' with cultural value to local people (e.g., ring-necked parakeets in the UK - Strubbe and Matthysen, 2009). The authors advise that ecologists must consider the psychological causes and effects of SBS in "both directions" as potential barriers to restoration efforts due to public attachment to new conditions over the past, obscuring the need for ecological conservation and diminishing potential environmental concern (Steen and Jachowski, 2013). Understanding the social and psychological factors influencing personal perceptions of change is therefore crucial to assess the effects of SBS on both conservation management and public support for ecological restoration.

Furthermore, very few previous studies have compared evidence of incidence of SBS between countries and across different cultures (Soga and Gaston, 2018). This represents an important research gap as perceptions of ecosystem resilience and the need for conservation are likely to vary temporally, geographically and by ecosystem, dependent on level on availability of historical information and education, industrialisation, and local reliance on the natural environment (Guerrero-Gatica et al., 2019). In 2008, Pinnegar & Engelhard provided the first and only examination of evidence of the 'shifting baseline phenomena' between countries, with a focus on fisheries science. The authors suggested that local availability of historical ecological data was the primary limiting factor on the time-scales of people's perceptions of ecological change (Pinnegar and Engelhard, 2008). However, it has been hypothesised that in many cultures, even where historical scientific data is available, knowledge of past ecological conditions is passed on in community memory, often via oral communication (Turvey et al., 2010).

Finally, there is also uncertainty as to whether a lack of empirical evidence of SBS may be the result of publication bias, as studies that do not find conclusive evidence of SBS maybe less commonly published. One such example, Pellier et al. (2014), interviewed 247 children in Kalimantan, Indonesian Borneo to understand their perceptions their current and potential future local environment. While this study did not empirically disprove SBS, analysis of drawings by children aged 10–15 years indicated that the children had negative perceptions of the future, in line with ongoing ecological change, suggesting that SBS did not strongly occur within children in the region (Pellier et al., 2014). However, a recent study using systematic review techniques, assume that many gaps in the SBS literature are due to a lack of long-term historical datasets, rather than a publication bias (Guerrero-Gatica et al., 2019).

1.6. Combatting the consequences of SBS

Amongst accelerating ecological degradation and growing discussion regarding the potential negative implications of SBS, including possible impacts on perceptions of ecological change, lack of conservation support and on the ambitiousness of future targets (Papworth et al., 2009; Soga and Gaston, 2018), research into the possible methods to combat SBS continues to grow. Jackson and Alexander (2011) suggested that understanding SBS may help to neutralize the ongoing denial or minimisation of ecological changes, highlighting the pivotal nature of SBS for the future on environmental conservation and restoration.

An evident option for combating the acceleration of SBS is to prevent the three potential causes of SBS, proposed by a lack of data, loss of interaction and loss of familiarity with the natural environment. When visualised as a positive feedback loop (Figure 5) the authors argue that SBS can be combatted by the prevention of further ecological degradation, encouragement of interaction with nature and public promotion of conservation management initiatives, so people are more aware of current change and motivated to learn about conservation education (Morrison et al., 2017). In 2015, Roman et al. introduced the concept ‘lifting baselines’, aiming to raise public and scientific awareness of conservation successes that may otherwise have been forgotten. By promoting success in the context of long-term, historical baselines, perceptions of the extent of biological change can be updated in-line with the current state of the environment to encourage greater conservation support (Roman et al., 2015).

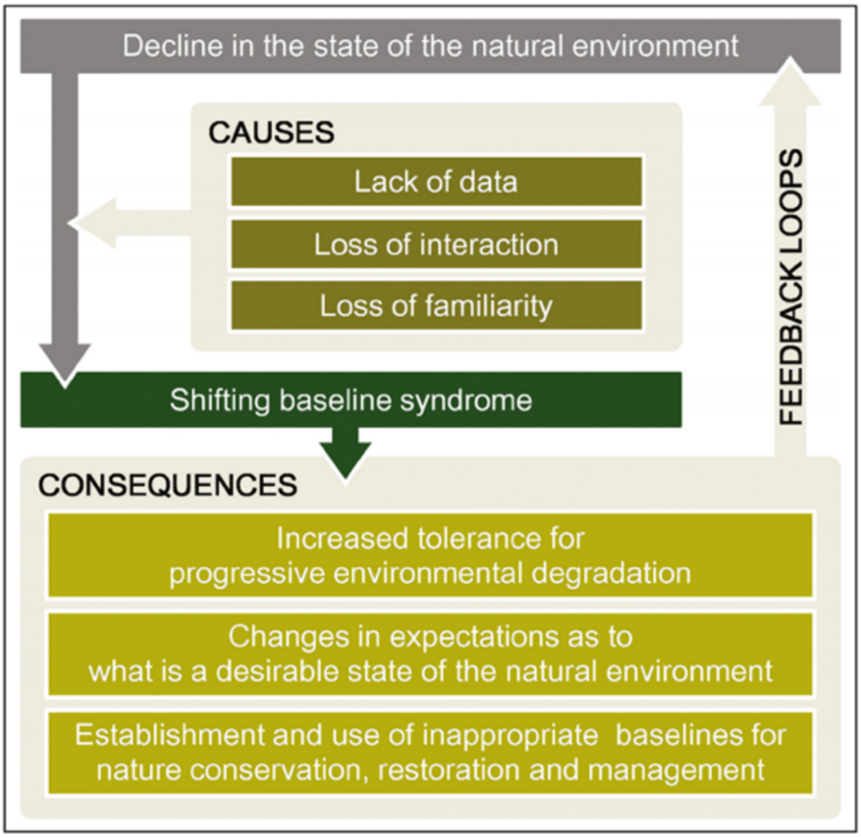


Figure 5. Feedback loops linking the causes and consequences of SBS, from Soga and Gaston (2018).

Moreover, rewilding projects have come to the forefront of recent conservation research, with the aim to restore core wilderness areas as functioning landscapes primarily through the reintroduction keystone species such as large megafauna (Donlan et al., 2006). Rewilding is increasingly endorsed to prevent further degradation through the restoration of previous ecological baselines and help educate the public as to long-term change in the local environment (Corlett, 2013). For example, Rewilding Britain, a campaign to convert at least one million hectares in Britain to pre-anthropogenic conditions, aims to revitalise ecosystems and promote greater connection to nature ("Rewilding Britain," 2018). However, further research should investigate the effect of intergenerational feedback loops, in which intergenerational communication enables the transfer of perceptions from one generation to the next. Also, it is relevant to include the ways to combat SBS in the loop, as accurate diagnosis of the causes and consequences of SBS assists in identifying the most effective combat strategies.

In the absence of historical knowledge, the encouragement of greater public involvement and citizen science data collection provides a double benefit; in the longer term, extra data will be available for future generations to accurately assess historical conditions, providing a scientific base for restorative and rewilding decisions. In the shorter term, personal involvement and experience mitigates the loss of historical ecological knowledge and reduces extinction of experience through increased connection to nature, leading to higher interest and commitment to nature protection and conservation, especially for the younger generation, who may not recognise environmental change (Sandifer et al., 2015; Lumber et al., 2017). Soga and Gaston (2018) highlight the "research-implementation gap", in which scientists and policymakers are less inclined to use citizen science data for policy and decision-making; however, the dual-benefit of extra data and increasing public knowledge should continually improve the quality and reliability of data collected, thus making it more useful for policy as a feedback loop (Soga and Gaston, 2018). Furthermore, research suggests that CTN can be most effectively boosted when benefits arise for both the individual and the natural environment (Pyle, 1993; Soga et al., 2016b). For example, in the UK the RSPB launched a campaign in 2013 to combat childhood nature deficit disorder. The initiative aims to increase local childhood wellbeing by increasing the amount of ecological experience of the natural component of their local area, primarily through the encouragement of outdoor education and play. Greater exposure and connection to nature should also help to combat SBS in the next generation (Nisbet et al., 2009; RSPB, 2013).

Conservation education and intergenerational communication have been proposed to help combat both generational and personal amnesia. The establishment of "accurate narratives” as cross-generational bridges may open untapped sources of traditional and local ecological knowledge regarding past ecological conditions, and help younger, less experienced members of the community to update their perceptions of the current ‘norm’ (Papworth et al. 2009). As outlined by Soga and Gaston (2018), a multitude of methods and media can be used to educate, inspire and invoke memory in order to combat SBS, including citizen science, social communication and the use of existing records and literature. For example, Fernandez-Llamazares et al. (2015) attributed findings of SBS to a lack of intergenerational communication about deforestation and species extinction. Therefore, encouraging narratives or the documentation of knowledge held by older people may aid the prevention of SBS (Fernández-Llamazares et al., 2015). Thurstan et al (2016) emphasise the effectiveness of historical archives such as logbook catch records as cues for combating personal amnesia as this may help individuals to recall lost memories (Thurstan et al., 2016). On a more recent timescale, photographs are also emerging as a key visual resource to assess change over time, especially regarding species size (McClenachan, 2009), or landscape change (Chen et al., 2011), although it is debated that such media could be a replacement for first-hand experience (Mazzoni, 2019). Future studies might look to combine these methods and test the efficacy of different data sources and cues, such as written accounts, photographs, and oral communication, to combat SBS over multiple generations.

In the context of conservation management and decision-making, few studies have suggested ways to mitigate evidence of SBS, most likely due to a lack of conclusive evidence for SBS in this sector. However, emerging research suggests the value of novel statistical techniques to combine paleo-ecological and historical datasets to update and verify the recovery status of threatened species and systems (Akçakaya et al., 2018; Thurow et al., 2019; Foley and Lynch, 2020; Manzano et al., 2020). Thurow et al. (2019) integrated historical, archival counts with contemporary, spatially continuous species counts and spawn timing databases to estimate historical Chinook salmon abundance and provides an earlier baseline against which to compare current populations. However, Foley and Lynch (2020) provided a more comprehensive and innovative framework for integrating historical data of Antarctic fur seal abundance on South Georgia. Using a Bayesian modelling framework, seal harvest data, and a stochastic age-structured population model, they estimated the pre-exploitation abundance of seals, concluding that the current abundance was similar to pre-harvest levels, updating historical baselines and local perceptions of current abundance.

1.7. Conclusions and Research Gaps

The majority of current literature regarding SBS observes evidence of the syndrome on species declines or cites SBS as a potential issue in the study system. However, as evidenced by this literature review, the majority of SBS research does not provide empirical evidence of the syndrome, according to the commonly accepted criteria, defined by Papworth et al. (2009). Of the studies which provide empirical evidence of SBS, most focus on single countries or cultures and single species, as often SBS is identified as a secondary conservation issue, rather than the primary focus of the investigation (e.g., Turvey et al., 2010). Furthermore, no previous study has empirically investigated the effect of SBS on perceptions of species conservation need or priority, and the possible impacts on conservation support despite being frequently cited as one of the most significant possible implications of SBS for conservation (Soga and Gaston, 2018).

Finally, there is also a lack of empirical evidence regarding the effects of SBS on policy making and management decisions, potentially leading to a lack of ambitious conservation targets. At the management level, more research is required to decipher the interrelation explanatory demographic, social and psychological factors influencing the incidence of SBS and exacerbating the consequences of SBS in the context of conservation support and decision-making.

The following PhD thesis chapters further SBS research within conservation in five ways, reflecting the chapters of this thesis:

- Identification of empirical evidence of generational and personal amnesia through a large-scale paired-data study in the UK, statistically analysing the consistency of local perceptions and biological datasets regarding local bird populations. This addresses a major gap in the literature, outlining a methodological framework for SBS investigation, investigating the underpinning demographic and social predictors of SBS, and assessing the impacts of SBS on perceptions of conservation need for species in decline.
- International comparison of evidence of SBS in the UK and Finland and an investigation into the impacts of reduced sample size and data range restriction on study conclusions.

- Exploration of variation in agreement between data collection methods, between countries and between species using mixed effect models. Examine the scope of combining and comparing biological datasets and local knowledge of ecological change, and to identify key areas of agreement and disagreement between datasets.
- Assess the incidence of SBS within conservation management and the possible effects of conservation decision-making and policy using in-depth interviews with managers and practitioners, following Daniel Pauly’s seminal essay on SBS (Pauly, 1995).
- The final discussion concludes the thesis, discusses the wider implications of the data chapters, and recommends areas of future work.

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2. Methods

2.1. Research journey

My research journey began with my BSc in Zoology (2012-15) and Master of Research degree in Advanced Biological Science, at the University of Southampton (2016-17). Fuelled by an interest in the human side of conservation, I focussed my MRes research project on mapping the cultural ecosystem services (CES) provided by an urban greenspace in central Southampton. I used online and in-person surveys to understand differences in the extent and distribution of CES in two contrasting scenarios. The study was published in the journal 'People & Nature' in 2019 (see page 16).

In 2017, I first saw a project investigating shifting baseline syndrome with my supervisor, Dr Sarah Papworth, advertised through a Doctoral Training Programme. I applied but to my disappointment I was not offered an interview for the DTP. Not to be deterred, I attended a Royal Holloway open day and set up a meeting with Dr. Papworth to discuss other PhD options. With support from my future supervisor, I secured funding through the Royal Holloway Reid Scholarship, starting September 2017. With limited knowledge of SBS or background in social science techniques, the first six months of my PhD were spent familiarising myself with the literature, training in survey design and analysis, and researching which biological datasets might be accessible to study empirical evidence of SBS. In the summer of 2018, I secured access to two biological datasets of bird populations in the UK and Finland, through collaborations with specialists at the British Trust for Ornithology and the University of Helsinki and began collecting the questionnaire-based social datasets soon after. Further information regarding the social data collection, biological datasets chosen and the rationale behind these choices can be found below.

In March 2020, the Covid-19 pandemic primarily impacted the data collection of Chapter 7 ("Is there evidence of shifting baseline syndrome in environmental managers? An assessment using perceptions of bird population targets in UK nature reserves"). Under the original timeline, I aimed to conduct in-person interviews with participants from March-April 2020, but I chose to convert all interviews to online video calls due to the first UK lockdown. The full implications of the pandemic on this study are discussed in Chapter 7.

2.2. Rationale for the methods and survey design

Data collection for this thesis was designed to achieve the research aims and fill the gaps in the literature identified in Chapter 1. The survey methodology aimed to achieve the following:

1. Investigate empirical evidence of SBS in the UK and develop understanding of the potential impacts of SBS on public perceptions of conservation priority for species in decline.
2. Provide and compare empirical evidence of SBS in the UK and Finland by comparing the perceptions of large-scale, public social samples to biological datasets using paired data methods.
3. Understand the influence of multiple demographic, experience and knowledge-based characteristics on evidence of SBS and variation in levels of paired data agreement in the UK and Finland.
4. Understand and compare the possible sample size and range limitations of the long-term biological datasets used in paired data analysis, and the effects of limitations on study conclusions and power.
5. Investigate evidence of SBS in conservation management through a case study of reserve managers and staff working in bird and nature reserves in England, and the potential impacts of SBS on target-setting.

The fourth aim was developed in response to the findings of Chapter 4, in which limited sample size and restricted age range of the Finland sample (compared to the UK sample) led to concerns for the effects of range restriction on study conclusions.

To fulfil the above aims, four datasets were collected. For aims 1 to 4 (Chapters 3-6), two large-scale online questionnaires were collected, one each in the UK and Finland, and one in-person survey dataset in Southeast England. Further information is given in section 3.1 below.

To fulfil aim 5 (Chapter 7), one ‘in-person’ survey was collected through video and phone calls. For this study, conservation managers in the UK were interviewed regarding their perceptions of bird species abundance and trends in their local reserve. Video and phone calling provided a safe and effective interview-based data collection method during the

Covid-19 pandemic when travel as not possible. Full details on survey design, participant recruitment and analysis are provided in Chapter 7 and associated supplementary material, so are not described further here.

Ethics

Ethical approval was granted by Royal Holloway, University of London and the Zoological Society of London (ZPD code: IOZ5) prior to piloting and data collection for all studies. Personal data was not collected during the questionnaire process to ensure participant anonymity. When conducting online questionnaires (Chapters 3-6), all participants remained fully anonymous throughout the questionnaire process. When conducting video or phone interviews (Chapter 7) all data was anonymised and contact email addresses and email correspondence were deleted after study completion unless otherwise requested by the participant for future correspondence. However, the lack of personal data prevented direct feedback of results directly to participants. Therefore, to ensure participants have access to the results of this thesis if desired, all publishable studies will be or have been published in an Open Access journal or format (Jones et al., 2020a), and links to the publications have been disseminated via the same social media accounts as used to initially advertise the questionnaire or contact participants.

Free, informed consent was obtained from all participants before starting all questionnaires. Before choosing to begin online questionnaires, all participants read a Participant Information Sheet which explained the study motivation, outlined the questionnaire format and provided my contact details should the participant wish to be removed from the study at a later date. When conducting interviews via video or phone calls, participants were asked to read and accept the Participant Information Sheet before starting the interview.

2.3. Rationale for pairing biological and social datasets

To identify empirical evidence of SBS according to the criteria defined by Papworth et al. (2009), biological and social datasets can be used (Chapter 1), to systematically compare perceptions of biological change to long-term biological datasets (see Chapter 3 & 4). The benefits of statistically matching or ‘pairing’ biological and social datasets (hereafter referred to as ‘paired data methods’) are well known, including the ability to gather wider and more in-depth insights into ecological change and examine variation in perceptions of change in relation to the scientific record (Huntington, 2000; Huntington et al., 2004). Many of the known challenges of these paired data methods link to limited biological data availability on similar temporal and spatial scales to local ecological knowledge (LEK). In this thesis, availability of biological data drove many of the choices and decisions regarding methods and study design, as is described in the following sections.

Biological data availability and region selection

The choice of study locations was primarily based on the availability of long-term biological datasets and potential collaborators in the UK and Finland. Access to long-term biological datasets remains a key limiting factor for many studies aiming to investigate ecological change over time (Magurran et al., 2010). In the UK and Finland, systematic, long-term bird species population monitoring has been conducted for several decades and these datasets are available on request to academics pursuing research questions. Furthermore, visits to collaborating institutions and in-person fieldwork was possible in both countries within the available research budget, and both English and Finnish are languages spoken by members of the student and supervisory team. The use of these datasets was a clear choice for this project however, the possible limitations of both datasets were assessed before the commencement of analyses. At the time of data access, the widely accepted list of seven possible limitations of biological datasets by Didham et al. (2020) was not yet published (see page 32 for further discussion). However, I concluded that the temporal range, and systematic methods used to collect both datasets prevented the influence of several of the possible limitations of biological datasets, including site selection and species detection biases (see next paragraph). Furthermore, as species abundance was to be converted to a relative abundance rank for analysis (see *Biological data analysis* section – page 59), false-baseline effects would be limited (Didham et al., 2020.

In the UK data was available from the British Trust for Ornithology (BTO) in the form of the combined Breeding Bird Survey and Common Bird Census (BBS-CBC) datasets (Freeman et al., 2007). The original Common Bird Census (conducted throughout the UK from 1962-2000) counted the number of territories of common breeding bird species within a standardised plot, most commonly within woodland and farmland habitats. The CBC was replaced by the BTO/JNCC/RSPB Breeding Bird Survey in 2001 after 7 years of overlap to compare results and calibrate future species modelling. The BBS is now conducted annually within randomly chosen 1km^2 plots across the UK, with bird recordings taken for 90 minutes, twice per year in the breeding season (April to June). Volunteers record the abundance of birds in flight and the approximate distance to estimate species detectability and relative population density (British Trust for Ornithology, 2010). Data for the whole of the UK was restricted, however, data for the southeast region of the UK was made available for this thesis, which consisted of eleven contiguous counties in southeast England: Berkshire, Buckinghamshire, Cambridgeshire, Essex, Greater London, Kent, Hampshire and Isle of Wight, Hertfordshire, East and West Sussex, and Surrey. This area was selected based on the availability of biological data using the combined CBC-BBS dataset (Freeman et al., 2007; Gillings et al., 2012). The selected region has consistent land use and similar climate (Dessai and Sims, 2010), hence the species included in this study are annually detected throughout the region.

In Finland, the Linnustonseuranta (the annual monitoring of breeding birds in Finland) dataset provided the annual biological data. Organised by the Finnish Museum of Natural History, monitoring data is collected annually by citizen scientists and volunteers using point counts and line transects for over 140 species (Järvinen et al., 1991; Lehikoinen, 2013). Each observation includes the date, location, species, abundance and behaviour such as movement, direction of travel and nesting behaviour. Finnish data collection was limited to the southern and eastern provinces of Finland (co-ordinate limits 67°N latitude and 34°E longitude), including the states of Uusimaa, Kymenlaakso, Päijänne, North and Southern Karelia and Savonia. Southeast Finland has a relatively consistent habitat type and land use (LUOMUS Team, 2018, *pers comm.*) ensuring that the range of each species was likely to span throughout the study area. The area also has consistently high Linnustonseuranta and Finland Bird Atlas survey effort (LUOMUS Team, 2018). A scoping visit during June 2018 allowed me to create a valuable network of local contacts, identify participant networks and form collaborations in the study area.

National differences in language, educational curricula and connectedness to nature also provided key reasons to collect data in the UK and Finland. Finland has a rich cultural relationship with nature (83% of Finns consider the forest ‘important’ or ‘very important’), especially the nation’s forests (Hiltunen et al., 2020). This is perhaps in contrast to the UK and many other Western countries, where many studies explore evidence of a ‘disconnection from nature’ especially in the younger generations (Bragg et al., 2013; Barthel et al., 2018), which may be due to urbanisation, the use of modern technologies for play and a possible distrust of natural landscapes (Kesebir and Kesebir, 2017; Chawla, 2020). However, many similarities can be found between countries in terms of land-use and habitat in the UK and Finland, resulting in many similar native species (Gosney, 2010; Saurola et al., 2013; Sterry and Stancliffe, 2015).

Both countries have a strong history of studies collecting data through citizen science to understand ecological change. For example, in Finland amateur birders have been collecting data on timing of bird species migration for over 250 years (Dickinson et al., 2010) and more recently, studies have used citizen science to collect a variety of data, from ecosystem services (e.g., Niemelä et al., 2010; Kaartinen et al., 2013) to species population dynamics (Brommer et al., 2017). Many studies in the UK have used citizen science to investigate local people's perceptions of nature and ecological change (e.g., Tweddle et al., 2012; Cox et al., 2017; Jones et al., 2020b), including previous studies investigating evidence of SBS (Papworth et al., 2009).

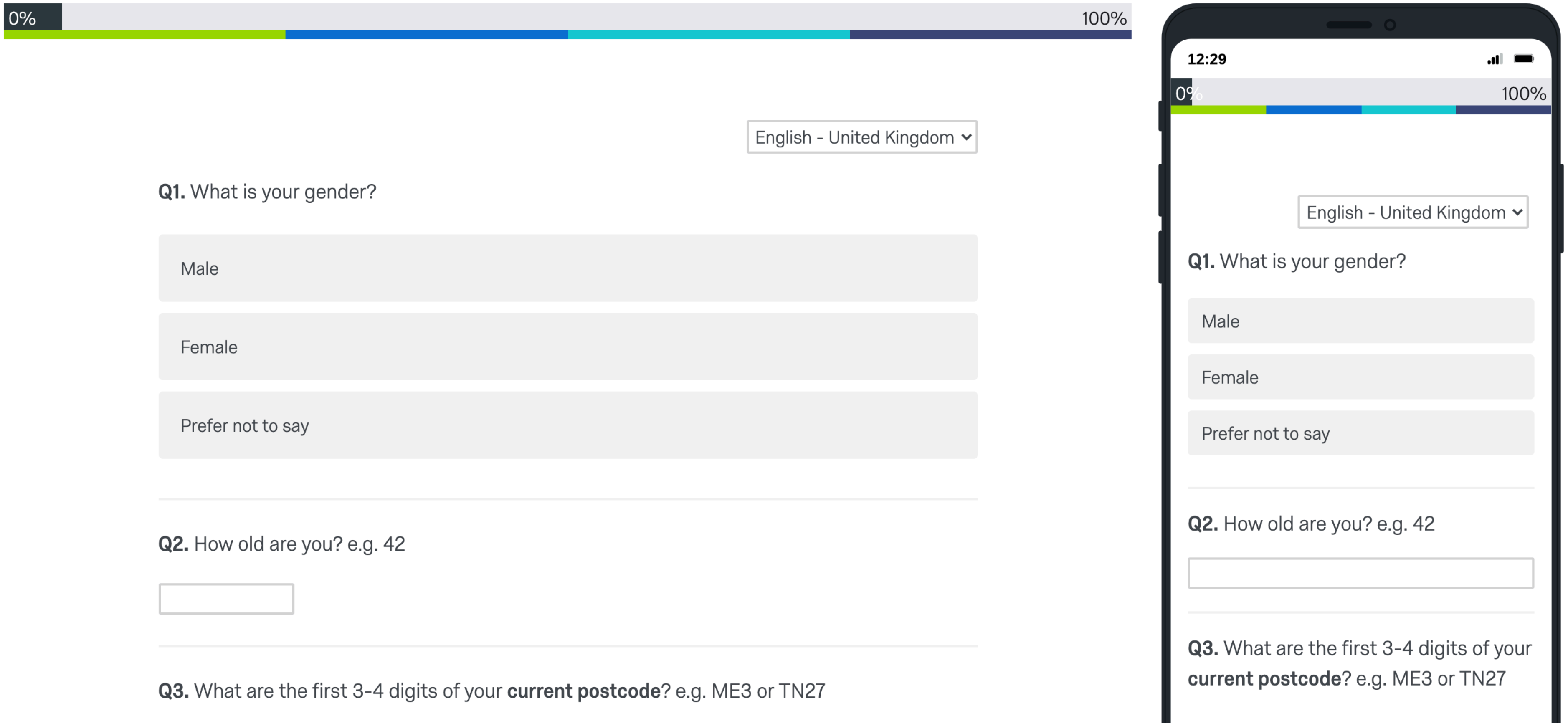
Species selection

Across the UK and Finland, 41 'garden bird' species were initially selected as candidate species to include in the online questionnaires, based on data from open-access, national-scale biological summaries (UK – BTO BirdFacts (Woodward et al., 2018); Finland - Third Finnish Breeding Bird Atlas (Valkama et al., 2011)). For each country, all selected species were ranked in order of abundance (as number of pairs or territories for most recent year available) and population trend (annual % change from first year to last year available) and ten bird species were selected in each country to encompass the full range of abundance and trends, ranging from abundant and increasing, to rare and declining. A focus on bird species seen regularly in garden and urban areas ensured that members of the public in each country were likely to have personal experience of the species, through 'everyday' activities, such as walking, gardening or commuting (Cox and Gaston, 2016). Specifically, the species included in this study were selected because they are generally distinctive and easily recognizable even to non-trained observers, and because the species sets of each country varies in both abundance (as number of pairs or territories) and population trend (% annual abundance change), ranging from abundant and increasing to rare and declining (Woodward et al., 2018; Table 1). For more information on species selection both countries see Chapter 3, and for more details on species characteristics and a full list of species see the supplementary materials for Chapter 3.

Social data collection

The social data samples were collected using online questionnaires through the Qualtrics platform in both the UK and Finland (version XM 2018). Online questionnaires enabled the collection of larger public samples than would be possible using in-person interview techniques with limited time and financial resources (Newing, 2010, page 79). Although online questionnaires may bias results towards younger internet-users, both countries have high mobile and broadband internet coverage (European Commission, 2021), therefore online questionnaires were likely to reach a large and diverse audience in both countries. Furthermore, large potential sample sizes of online surveys limit the potential impacts of high non-response rates (over 50%) on final sample sizes.

Following ethical approval of the project, the UK questionnaire was designed in June 2018 and piloted with 12 participants from 11 to 13 July 2018. These 12 participants included specialist social scientists and members of the target sample population (the UK public) to ensure that the survey was theoretically sound and easily understandable. Alterations were made to the wording and question design in response to feedback from pilot participants, including ensuring that the questionnaire working on desktop computers, laptops and mobile phones (see Figure 1 for examples of the questionnaire aesthetics on computer and mobile). The UK questionnaire was made live on the Qualtrics platform from 16th July to 9th September 2018. The Finnish questionnaire was translated and piloted by two native Finnish speakers and was live from 15th September to 9th December 2018. Data collection was repeated in Finland from 17th July to 2nd September 2019 to maximise sample size.



Q1. What is your gender?

Q2. How old are you? e.g. 42

Q3. What are the first 3-4 digits of your **current postcode**? e.g. ME3 or TN27

Q1. What is your gender?

Q2. How old are you? e.g. 42

Q3. What are the first 3-4 digits of your **current postcode**? e.g. ME3 or TN27

Figure 1. An example screenshot of the first page of the UK questionnaire on a computer/laptop (left) and mobile phone (right).

The questionnaires collected data on personal demographics and interests in nature as well as perceptions of species populations. Knowledge of local bird species was estimated by asking participants to recognise all 10 species using photographs, and knowledge origin was reported as a score from 0 to 100 across eight categories (personal experience, intergenerational communication, friends/other birders, education, books, TV, internet and other). Frequency of nature-based activities, and active birding experience was calculated as proportion of lifetime since year of first birding experience served as measures of nature experience. For the species that were selected as recognised by the participant, perceptions of species abundance (as a rank order from increasing, static or declining) in the past (the year the participant was age 18) and present (the year the questionnaire was taken) were collected, as well as perceptions of trends between the past and present time points. The year participants were 18 years old was selected as a 'memory anchor', a psychological heuristic which aids recall of experience-based episodic memory (Havari and Mazzonna, 2015). Eighteen years old was specifically chosen as a memory anchor for two reasons: first, this marked the youngest possible age of any participant in the sample as only adults were included for ethical reasons. Second, age 18 marks a universally significant year for all participants as the transition period into adulthood, regardless of gender, ethnicity or other demographic factors.

Participant demographics (age and gender) and county and length of time in current and past residence (converted from postcodes - Office of National Statistics, 2018), connectedness to nature score (Nisbet et al., 2009; Nisbet and Zelenski, 2013) and perceptions of relative need for conservation attention were collected per species (Jucker et al., 2018). All data were outputted to a CSV file and analysed using R software (R Core Team, 2019). For questionnaire methodology and transcripts, and further details on paired data analysis for Chapters 3-6 see each chapter and associated supplementary materials.

Biological data analysis

All data and statistical analyses were conducted using R software version 3.6.2. (R Core Team, 2019). For consistency, both the UK and Finland biological data were analysed using rTRIM, an R package built to mimic the monitoring data analysis software 'TRIM' (Trends and Indices for Monitoring Data - Pannekoek and van Strien, 2005). TRIM was recommended for use by my Finnish collaborators, as TRIM is their primary data analysis tool for analysing annual monitoring datasets in Finland (LUOMUS Team, 2018) and models data using the same log-linear Poisson regression techniques as used for bird census analysis by the BTO (Massimino et al., 2019). TRIM is well recognised as a popular approach for analysing bird species population monitoring data (Fewster et al., 2000), as it applies log-linear Poisson regression techniques which are recommended for incomplete census datasets (Ter Braak, et al., 1994). Furthermore, rTRIM is used within the R coding environment (R Core Team, 2019), producing data that can easily be integrated with other data analysis and produce a variety of data visualisations.

As calculated species abundance coefficients are not directly comparable between years and countries due to variation in data collection effort and scale, relative species abundance ranks were produced per year, analogous to the perceived ranks provided by questionnaire participants. In the UK, relative abundance ranks were calculated per year per region (e.g., Southeast England in 1978), and per county in the Southeast region (e.g., Kent in 1978), while in Finland ranks were calculated annually only to the regional level (e.g., Southeast Finland in 1978). Figure 1 shows and example output of regional-scale species relative ranks from 1966 to 2017 for Southeast England and from 1984 to 2017 for Southeast Finland.

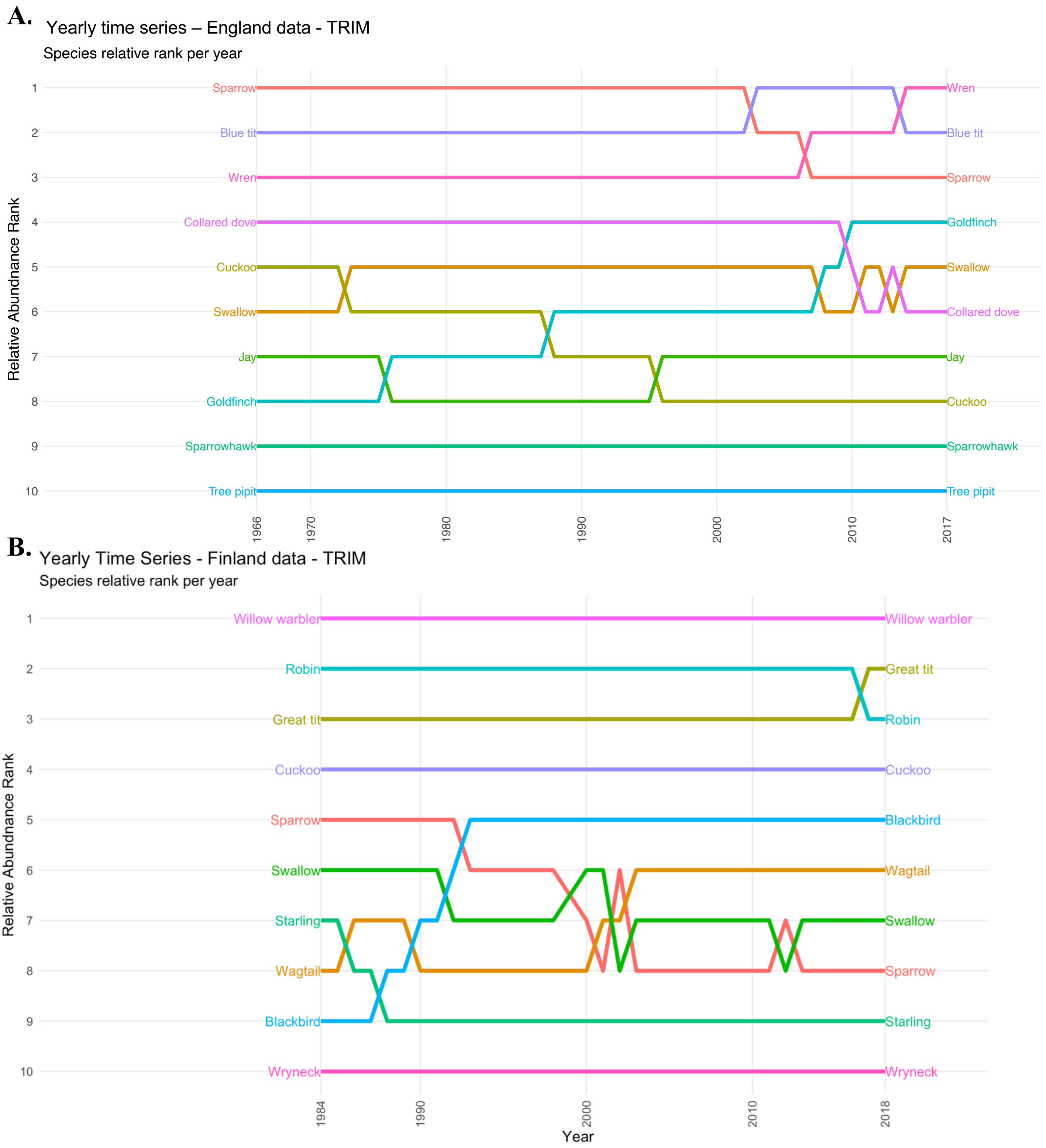


Figure 2. Species relative abundance rank per year for; A. Southeast England, and B. Southeast Finland.

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3. Investigating the implications of shifting baseline syndrome on conservation

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RESEARCH ARTICLE

PEOPLE AND NATURE
BRITISH ECOLOGICAL SOCIETY

Investigating the implications of shifting baseline syndrome on conservation

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Abstract

1. Shifting baseline syndrome (SBS) describes a persistent downgrading of perceived 'normal' environmental conditions with every sequential generation, leading to under-estimation of the true magnitude of long-term environmental change on a global scale. The presence of SBS should be considered when local ecological knowledge and participatory techniques are involved in conservation target-setting. However, despite increasing recognition of the phenomenon, there is little empirical evidence for SBS. Here we provide evidence of SBS, and the first empirical investigation of the impacts of SBS on public perceptions of conservation need.
2. Large-scale online questionnaires were used to collect public perceptions of long-term biological change regarding 10 UK bird species, as well as demographic information and measures of knowledge and experience of the local environment ($n = 330$). A paired data approach compared social perceptions to a large-scale longitudinal biological dataset. Using information theoretic and model selection techniques, we estimate the relative importance of multiple demographic, social and psychological predictors of SBS. We provide a framework for investigating evidence of SBS and its impacts on perceptions of conservation need for species in decline.
3. Evidence of generational amnesia was found as an age-related difference in perceptions of past ecological conditions. The perceptions of older participants had significantly higher agreement with biological data than the perceptions of younger participants. Our results therefore support the expectation that younger, less experienced people are less aware of historical ecological conditions and show greater evidence of SBS. We also present evidence of a negative impact of SBS on future conservation, as older people were more likely than younger people to perceive a greater need for conservation action for three declining species.
4. Our research supports the need to encourage greater intergenerational communication and increase experience of local nature. Discovering evidence of SBS in public perceptions of species experienced within everyday life demonstrates SBS as a pervasive social issue with the potential to impact public perceptions of local nature.

KEYWORDS
change blindness, conservation, generational amnesia, local ecological knowledge, participatory, perceptions, personal amnesia, shifting baseline syndrome

1 | INTRODUCTION

Knowledge of past environments is critical to evaluate current conditions, comprehend change and set effective conservation targets for the future (Soga & Gaston, 2018). There is a wealth of empirical evidence recording our long-term impacts on the natural environment, from species extinctions and habitat loss (Dirzo et al., 2014) to climate change (Steffen et al., 2015). Despite this, conservation baselines are often formed using only recent information (Rodrigues et al., 2018). By focusing on more recent timescales, we may lose perspective on the true magnitude of long-term environmental change (Rost, 2018). This is known as shifting baseline syndrome (hereafter SBS), a socio-psychological phenomenon in which historical environmental information is lost over time and people do not notice changes in biological systems. Without intergenerational communication, it is thought that people tend to compare current ecological conditions to reference points set within their own autobiographical experience, forgetting or ignoring valuable historical information (Papworth, Rist, Coad, & Milner-Gulland, 2009; Pauly, 1995). However, relatively few studies provide empirical evidence for SBS (Papworth et al., 2009; Turvey et al., 2010), often due to a lack of access to longitudinal biological datasets against which to compare perceptions of biological change (Guerrero-Gatica, Aliste, & Simonett, 2019).

According to Papworth et al. (2009), two criteria must be met in order to demonstrate SBS empirically:

1. There must be biological change in the system and,
2. Any perceived change must be consistent with biological data.

The interpretation of these criteria depends on the mechanism by which SBS is occurring: either generational or personal amnesia. Generational amnesia, so called for the unperceived loss of knowledge between generations, occurs when the baseline for 'normal' ecological conditions shifts with each successive generation due to a lack of intergenerational communication, preventing accurate perception of long-term change (Kahn & Friedman, 1995). Therefore, under generational amnesia, individuals must have an accurate perception of current conditions, and there must be age- or experience-related differences in perceptions of change (see Figure 1 for theoretical example). Papworth et al. (2009) also described a second mechanism, personal amnesia, in which age- or experience-related differences are not found; instead, people have an accurate perception of current conditions but believe past conditions to be the same as current conditions. This second mechanism is comparable to the cognitive bias named the 'recency effect' in which people tend to recall more recent information most effectively (Baddeley & Hitch, 1993). By comparison, 'change blindness' or 'anchoring' describes a tendency to remember the past better than recent conditions (Simons & Rensink, 2005).

Numerous studies have envisaged significant negative implications of SBS for conservation (e.g. Papworth et al., 2009; Pauly, 1995; Sheppard, 1995). A recent review by Soga and Gaston (2018) highlighted three potential impacts of SBS on conservation worldwide, at both the public and management level. First, SBS may have significant impacts on stakeholder interest, engagement and support for conservation due to an increased tolerance for degraded environmental conditions (Hayhow et al., 2019; Papworth et al., 2009). For example, in the field of restoration ecology, Wu, Petriello, and Kim (2011) suggested that stakeholders tend to only support environmental restoration efforts if they recognize the difference between past and current conditions, and hence can visualize the potential effectiveness of restorative action. Soga and Gaston (2018) similarly highlighted an ongoing 'extinction of experience' as both a direct driver and impact of SBS. This term was originally coined by

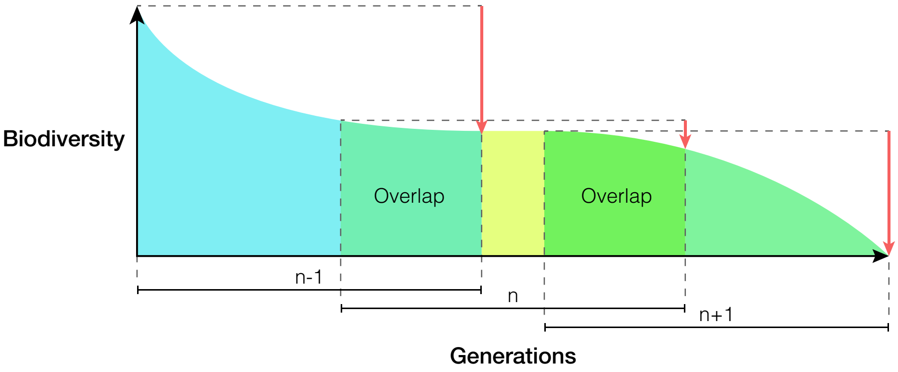

FIGURE 1 Theoretical depiction of generational amnesia occurring over three generations. Each generation (*n*) inhabits a window of time, which will overlap with previous and successive generations (*n* − 1 and *n* + 1) to provide the potential for intergenerational communication about biological condition, although this communication might not occur

Pyle (1993) to describe a lost connection to nature due to reduced daily contact with the natural environment (see also Miller, 2005). Many studies have reviewed the effects of culture and the media on the extinction of experience (Kesebir & Kesebir, 2017; Legagneux et al., 2018), while Soga, Gaston, Yamaura, Kurisu, and Hanaki (2016) evidenced the impacts on willingness to conserve, finding a positive association between children's passive and direct experience of nature and their support for biodiversity conservation in Japan.

Second, degraded expectations of desirable conditions may lead to less ambitious conservation and restoration targets within conservation management. Multiple demographic, cultural and personal traits are known to shape the lens through which change is observed (Bennett, 2016; Turvey et al., 2010). Managers might tend to compare current conditions to baselines set early in their careers, and thus underestimate long-term trends and limit personal perspectives of change to only recent reference points (Pauly, 1995; Vera, 2010).

Finally, the use of inappropriate baselines and unambitious targets alongside diminishing public motivation may lead to an ongoing complacency effect for conservation (Bilney, 2014), as both management and public stakeholders are more easily satisfied with current conditions and see little need for further conservation attention (Soga & Gaston, 2018). The potential effects of SBS should be taken into account when including local ecological knowledge (LEK, experience-based knowledge resulting from interactions with the local environment) in global research and policy (Turvey et al., 2014) due to its possible impact on tolerance for degraded conditions. LEK is increasingly recognized as a window through which to observe local-scale effects of global issues, from climate change (Herman-Mercer et al., 2016; Petheram, Zander, Campbell, High, & Stacey, 2010) to biodiversity loss (Rosa, Carvalho, & Angelini, 2014), and plays a significant role in global environmental assessments (IPBES, 2019; Tengö et al., 2017). There is, however, potential for the introduction of bias and uncertainty in the collection and interpretation of LEK, as poor recollection, reticence and psychological biases such as SBS may influence knowledge or recall of past conditions, highlighting the need to quantify the potential impacts of SBS on questionnaire-based data (Lozano-Montes, Pitcher, & Haggan, 2008; Turvey et al., 2010).

To demonstrate the existence of SBS empirically, scientific data on biological change must also be available and on an equivalent scale to individual perceptions of biological change (Papworth et al., 2009). This requirement necessitates the use of paired data techniques which can statistically compare the level of agreement between biological and social datasets at similar spatial and temporal scales (Gilchrist & Mallory, 2007; Huntington et al., 2004). A significant barrier to diagnosing SBS using this method is a lack of reliable ecological evidence of historical conditions or consistent long-term empirical data documenting change over multiple generations for many biological systems (Bonebrake, Christensen, Boggs, & Ehrlich, 2010; Campbell, Gray, Hazen, & Shackeroff, 2009; Guerrero-Gatica et al., 2019; Pinnegar & Engelhard, 2008). A recent meta-analysis by Guerrero-Gatica et al. (2019) noted that while many studies suggest the existence of SBS, many do not provide adequate empirical evidence of SBS to be conclusive, often because this was not the primary objective of the study (e.g. Ainsworth, Pitcher, & Rotinsulu, 2008; Kai et al., 2014; Lozano-Montes et al., 2008; Thurstan, Buckley, Ortiz, & Pandolfi, 2016). Therefore, often only age-related differences in participants' perceptions of local baselines are reported (Papworth et al., 2009), with little reference to equivalent biological data (Daw, 2010). For example, Saenz-Arroyo, Roberts, Torre, Cariño-Olvera, and Enríquez-Andrade (2005) conducted interviews across three generations of fishermen in the Gulf of California, and demonstrated that the oldest generation knew five times more species and could identify significant declines in four times the number of fishing sites than the youngest generation; these findings are indicative of generational amnesia, but in the absence of statistical comparison between paired biological and social data, they chiefly demonstrate that fisher experience (rather than perceptions) differed with age. On the other hand, Papworth et al. (2009) were first to consider SBS as a social phenomenon and provided the only empirical study to investigate the importance of multiple social and demographic factors influencing the existence of SBS, such as age, experience and birding interest. However, this study was conducted over a small geographical range and was limited by a short-term biological dataset, reducing overall power of the study and the number of explanatory variables used. Fernández-Llamazares et al. (2015) followed Papworth et al.'s (2009) definition framework using a larger sample size over a wider geographical range and provided the first empirical evidence that a lack of intergenerational communication can serve as a driving force behind SBS in local knowledge systems. However, limited availability of local biological data prevented direct geographical and chronological matching with interview-based perceptions of local change (Fernández-Llamazares et al., 2015).

We expand upon these studies using paired data techniques to statistically compare public perceptions of population abundance and long-term trends for 10 UK bird species against an independent long-term biological dataset. Our goal is to build upon previous studies and explore evidence for SBS using a large public sample. Furthermore, while previous studies have maintained a focus on finding evidence of SBS, we additionally aim to investigate the effects of both generational and personal amnesia on perceptions of the need for conservation attention for declining species. Online sampling techniques enabled access to a large sample of people in the United Kingdom, encompassing a wide range of socio-economic and demographic characteristics (Newing, 2010; Szolnoki & Hoffmann, 2013). Access to high-resolution longitudinal biological data spanning multiple generations (1966–2017) allowed focused geographical and chronological matching of individual perceptions and data on biological change. While our focus on birds was primarily driven by access to biological data, birds are a strong proxy for experience of nature in general, as birds and birdwatching are a culturally important and frequently experienced part of nature in the United Kingdom (Cox & Gaston, 2016).

Based on the criteria defined by Papworth et al. (2009), our aims are to:

1. Demonstrate the existence of biological change in a system, and that all participants have experience of this change.

2. Investigate evidence of generational amnesia as age- or experience-related differences in perception of change, and determine the key factors influencing level of agreement between participant perceptions and biological data.
3. Investigate evidence of personal amnesia through static perceptions of the biological system over time and higher agreement with recent biological data.
4. Investigate the effect of participant age and perception of population trend on individual perceptions of species of conservation concern and determine whether experience and personal perceptions of biological change influence conservation choices.

2 | METHODOLOGY

2.1 | Region selection

The combined BTO-JNCC Common Bird Census (CBC) and Breeding Bird Surveys (BBS) constitute a long-term census dataset from 1966 to 2017 (Harris et al., 2018). However, species abundance estimates for the combined census are not uniformly accurate as data collection methods changed after 1994 (transfer from CBC to BBS methodology) and survey effort varies both spatially and temporally according to surveyor availability (see Figure S1). Southeast England was selected as the area of highest density of BTO data (quantified using the number of BBS survey squares) and most reliable species population estimates in the United Kingdom (Gillings, Pearce-Higgins, Baillie, & Fuller, 2012). The study area consisted of 11 contiguous counties in Southeast England: Berkshire, Buckinghamshire, Cambridgeshire, Essex, Greater London, Kent, Hampshire and Isle of Wight, Hertfordshire, East and West Sussex and Surrey. These counties have similar land use and climate (Dessai & Sims, 2010), and most of the species included in this study are present throughout the region.

2.2 | Species selection

Eight regionally widespread bird species found in gardens and urban environments (sparrowhawk *Accipiter nisus*, goldfinch *Carduelis carduelis*, blue tit *Cyanistes caeruleus*, Eurasian jay *Garrulus glandarius*, barn swallow *Hirundo rustica*, house sparrow *Passer domesticus*, collared dove *Streptopelia decaocto*, Eurasian wren *Troglodytes troglodytes*) and two additional bird species present in non-urban environments across much of the study region (tree pipit *Anthus trivialis*, common cuckoo *Cuculus canorus*), were selected. The focus on the UK bird species seen regularly in garden and urban areas ensured that participants would be likely to have personal experience of the species. Species were selected because they are generally distinctive and easily recognizable even to non-trained observers, and

TABLE 1 Biological long-term population data extracted from the Woodward et al. (2018) dataset used to inform selection of the 10 bird species included in this study. Species listed in order of long-term species percentage population change, from most decreasing to most increasing. Data gathered from BTO BirdTrends (Woodward et al., 2018) and BTO BirdFacts (Robinson, 2005) representing all counties in England

UK common name	Scientific name	UK abundance (pairs in 2009)	Long-term change		Short-term change %	UK conservation status (2009)
			Time period	%	(2011–2016)	
Tree pipit	*Anthus trivialis*	88,000	1967–2016 (49 years)	−86	−4	Red
Common cuckoo	*Cuculus canorus*	15,000	1967–2016 (49 years)	−77	−11	Red
House sparrow	*Passer domesticus*	5.1 million	1977–2016 (39 years)	−70	−6	Red
Eurasian jay	*Garrulus glandarius*	170,000 (territories)	1967–2016 (49 years)	6	−5	Green
Swallow	*Hirundo rustica*	860,000 (territories)	1967–2016 (49 years)	4	−21	Green
Blue tit	*Cyanistes caeruleus*	3.6 million (territories)	1967–2016 (49 years)	24	−10	Green
Sparrowhawk	*Accipiter nisus*	33,000	1975–2016 (41 years)	98	−17	Green
Goldfinch	*Carduelis carduelis*	1.2 million	1967–2016 (49 years)	120	16	Green
Eurasian wren	*Troglodytes troglodytes*	7.7 million (territories)	1967–2016 (49 years)	128	47	Green
Collared dove	*Streptopelia decaocto*	980,000	1972–2016 (44 years)	306	−13	Green

because this species set varies in both abundance (as number of pairs or territories in 2014) and population trend (% annual change from 1970–2014), ranging from abundant and increasing to rare and declining (Woodward et al., 2018; Table 1).

2.3 | Questionnaire design and dispersion

A large-scale online questionnaire was conducted using the Qualtrics platform (version XM 2018), piloted with 12 participants from 11 to 13 July 2018 and live from 16 July to 9 September 2018. Ethical approval was granted by the Zoological Society of London (ZPD code: IOZ5) and Royal Holloway, University of London prior to piloting and data collection. All participants were asked to read a Participant Information Sheet before starting the online questionnaire and gave informed consent to participate in the study by choosing to begin the online questionnaire. Participants were acquired with non-random sampling methods, using emails and newsletters, blog posts and social media focused at academics, conservation charities and ornithological groups. Non-random sampling was used as the aim of the study was not to estimate population parameters but investigate relative differences in perceptions of bird populations, requiring a large participant sample size. The questionnaire was not incentivized and was advertised as a nature-orientated conservation study lasting up to 20 min, and so we assume that all participants had a prior vested interest in nature, environmental issues, ornithology or environmental research in general. As the geographical range of the biological dataset was limited to Southeast England, only participants from the same 10 counties were used in subsequent analyses. These participants were further subset based on residency (Table 4): those living in the region at the time of the survey (current), those living in the region at age 18 (past), and those living in the region in both periods. Results from all other participants (non-Southeast sample) and an additional Offline Southeast sample ($n = 79$) are available in Supporting Information.

Online questionnaires were used to collect data on personal perceptions of species abundance (as a rank order from most to least abundant across all species recognized) and trends (each species categorized as increasing, static or declining) between the past and present. Participation restrictions, instructions and a definition of 'local area' were included in the first page of the survey. Questions regarding 'the past' asked participants to remember environmental conditions when they were 18 years old. This age serves as a 'memory anchor', enabling easier recall of experience-based episodic memory (Havari & Mazzonna, 2015). Multiple explanatory variables were also collected (Table 2) including participant demographics (age and gender) and county (converted from postcode) of current and past residence (Office of National Statistics, 2018). Length of residency in past and current home county was collected to estimate consistency of experience and exposure to the same local bird population. Postcodes were also used to estimate current urbanity per county using the 2011 Rural-Urban Classification for Output Areas in England (Office of National Statistics, 2011). Bird species knowledge was estimated by testing participant ability to recognize all 10 species using photographs, and origin of knowledge was collected as a self-reported score from 0 to 100 across eight categories (personal experience, intergenerational communication, friends/other birders, education, books, TV, internet and other). Passive experience of nature was estimated using Likert-scale questions regarding the frequency of nature-based activities, and active birding experience was calculated as proportion of lifetime since year of first birding experience. Connectedness to nature was measured using a combination of two verified Nature Relatedness (NR) sub-scales, the NR-6 and NR-experience (Nisbet & Zelenski, 2013; Nisbet, Zelenski, & Murphy, 2009; Shanahan et al., 2017). Limiting the CTN section to 10 Likert-style questions minimized survey length but ensured valid measurement of nature connectedness. To assess participant perceptions of conservation concern for each species that was recognized by the participant, participants were asked to give a conservation attention score for each species between 0 and 5 for each species, in which species considered to be of highest priority gained a score of 5 (Jucker et al., 2018).

2.4 | Data analysis

Analyses were conducted using R software version 3.5.1 (R Core Team, 2019). Annual abundance and population trend per species per county were calculated from 1966 to 2017 using the RTRIM package (Pannekoek & van Strien, 2005; see Supporting Information for further details). For each participant, biological data were subset to include only the local county and year range from the year the participant was 18 years old to 2017, in order to create a paired biological and social dataset. Only species that were recognized by the individual participant were included.

To calculate agreement between individual perceptions and biological data for species abundance ranks, the perceived species abundance rank and ranked biological abundance were correlated using the Spearman Rank coefficient (Table 3). A scoring system was created to measure the degree of agreement between biological trends and perceived trends, with scores summed across all species to produce an overall score per participant (Table 3).

An information theoretic model selection and averaging approach was used to compare the significance of multiple predictors in explaining the incidence of SBS, explained by the response variables in Table 3. Predictors are: age, gender, connectedness to nature, proportion of life in current and past postcode, urbanity of current postcode, proportion of life as a birder now and at age 18, number of species recognized and correctly named, and frequency of walking in local area (see Table 2 for list of predictors in each model). Predictor variables were selected a priori for each model to represent original expectations from the literature and to prevent overparameterization. Predictor collinearity was evaluated using variance-inflation factor (vif) values (Zuur, Ieno, & Elphick, 2010). Where one or more terms in the unweighted global model had more than 1 *df*, the correlated predictor variables were identified using the generalized variance inflation factor ($\text{gvif}^{(½\ df)}$). In all cases, all variables had a vif or $\text{gvif}^{(½\ df)}$ value smaller than 2, indicating a very low

TABLE 2 Participant-specific predictor variables used to create candidate global models to determine participant ability to perceive current and past bird species abundance and long-term species trends

Predictor category	Predictors	Response variable Current	 Past	 Trend	Data format	Trait measured	Literature support/example(s)
Demographic/ personal	Age	✓	✓	✓	Continuous (years)	Cumulative exposure/ experience throughout lifetime	Saenz-Arroyo et al. (2005) and Thurstan et al. (2016)
	Gender	✓	✓	✓	Categorical—Male/Female/NA	N/A	Stern, Dietz, and Kalof (1993) and Aswani, Lemahieu, and Sauer (2018)
	Connectedness to nature	✓		✓	Combined NR-6 and NR-Experience (score range: 0–50)	Current connectedness to nature using NR scales	Nisbet et al. (2009) and Shanahan et al. (2017)
Location	Proportion of life in current postcode	✓		✓	Proportion of total age (0–1)	Measure of exposure to current local bird populations	Papworth et al. (2009) and Thurstan et al. (2016)
	Proportion of life in past postcode		✓		Proportion of age before 18 years old (0–1)	Measure of exposure to past local bird populations	
	Urbanity of current postcode	✓		✓	Score adapted from ONS 2011 Rural Urban Classifications (1 = mostly rural, 5 = urban city)	Experience of local bird populations Access to nature	Papworth et al., (2009) and Soga and Gaston (2016)
Active experience/ knowledge	Proportion of life as a birder	✓		✓	Proportion of total age (0–1) Non-birders = 0	Measure of cumulative active experience of birds and interest in birding	Thurstan et al. (2016)
	Proportion of life as a birder by age 18		✓		Proportion of age by 18 years old (0–1) Non-birders at 18 = 0	Measure of interest in birding and birding experience by the age of 18	
	Number of species recognized	✓	✓	✓	Number of species recognized from photographs (score range: 0–10)	Measure of current interest in birds and a proxy for cumulative learned experience	Tulving (1989a, 1989b)
	Number of species correctly named	✓	✓	✓	Number of species named by matching name to photo (score range: 0–10)	Measure of current knowledge of bird species and proxy for level of interest	
Passive experience/ exposure	Frequency of walking in local area	✓		✓	Likert scale (0 = never, 5 = everyday)	Measure of recent exposure to local birds as passive experience	Braun and Dierkes (2016)

TABLE 3 Methods used to match and analyse biological and social data for the three response variables (current abundance rank, past abundance rank and trend score)

Response variable	Biological data	Questionnaire data	Comparison method
1. Current abundance rank agreement	Ranked current abundance of all recognized species	Perceived current ranked abundance of all recognized species from questionnaire	Spearman's rho
2. Abundance rank agreement at age 18	Ranked abundance of all recognized species in year participant was 18 years old	Perceived ranked abundance at age 18 of all recognized species from questionnaire	Spearman's rho
3. Trend agreement score (past to current)	Each species classified as increasing (positive trend, *SE* not including 0), decreasing (negative trend, *SE* not including 0) or static trend (falling between positive and negative *SE*) per county	Species classified as increasing Species classified as static Species classified as declining	Scoring system: 2, biological trend in county matches participant reported trend; 1, reported trend is incorrect by one level (e.g. increasing vs. static); 0, opposite trend reported

level of collinearity, so all variables were retained (Zuur et al., 2010). Correlation matrices were also performed to assess the multicollinearity for each sample, specifically for age and multiple measures of experience (see Supporting Information for full results).

Linear models were executed for the current and past rank abundance response variables, and a generalized linear model (GLM) with a Poisson transformation and log-link was selected for the trend accuracy response (St-Pierre, Shikon, & Schneider, 2018; Zeileis, Kleiber, & Jackman, 2008). Unstandardized predictors were used in all cases to directly examine the relationships between each predictor and the response variable (see Supporting Information for full model selection and averaging methods). Results were compared to the non-Southeast England sample to ensure that the main sample was representative of the UK in general, and to the Offline sample to ensure that online questionnaire methods gained the same result as traditional methods (see Tables S8–S18). The effect of SBS on perceptions of conservation need was investigated for the three most declining species included in the study (house sparrow, common cuckoo and tree pipit). Ordinal logistic regression was used to investigate the effect of age and perceived trend on perceived need for conservation attention (Agresti, 2018). To check the proportional odds ratio assumption, a Chi-square test was used to test for a significant difference in the AIC value for a multinomial logit model and the ordinal logistic regression model for each species (Fox & Monette, 2002).

3 | RESULTS

A full overview of the size and demographic and geographic distribution of participants is given in Table 4. A heat map showing the distribution of participants within the study region is given in Figure S2.

3.1 | Section 1: Demonstrating environmental change in the system

For each participant, the correlation coefficient (rho) across all species was calculated between the relative rank abundance from BTO data when they were 18 and the relative rank abundance from current BTO data (Figure 2). Two participants, both aged 18–30, did not experience biological change (Rho = 1), and were therefore excluded from all subsequent analyses. For the remaining participant sample, a correlation of participant age against biological change shows that older people experienced more biological change than younger people (Spearman rank, rho = −0.75, $p < 0.001$; Figure 2).

3.2 | Section 2: Evidence for generational amnesia

In order to demonstrate generational amnesia, individuals must have a similar, accurate perception of current conditions and show an age- or experience-related difference in perceptions of change in the system. We found no evidence of an age-related difference in current abundance rank agreement (−0.002 ± 0.002, $p = 0.288$; Figure 3a), as all age groups were found to have similar perceptions of current ecological conditions. Participants with a greater personal knowledge of bird species, measured as an ability to recognize a greater number of species, showed higher current rank agreement (0.085 ± 0.02, $p < 0.001$).

However, perceptions of past conditions (at age 18) did vary significantly with age. Our results indicate that older respondents have greater abundance rank agreement at age 18 than younger participants (0.007 ± 0.002, $p = 0.002$; Figure 3b), despite older participants experiencing greater levels of biological change during their lifetimes (Figure 2). We can therefore infer that, even though older participants had a longer time over which to remember, they recall past conditions that are more consistent with the biological dataset than those recalled by younger people.

Trend agreement scores did not vary significantly with age (−0.001 ± 0.002, $p = 0.62$). Higher trend agreement scores were only significantly explained by a greater number of species recognized (0.106 ± 0.022, $p < 0.001$), as trend scores were limited by the number of species each participant recognized. However, linear regression analysis found a significant positive interaction between number of species recognized and amount of knowledge gained

TABLE 4 Sample size, demographics and location information for participants residing in the study region, which is further subset into participants living in the region at the time of the survey (current), at age 18 (past) and in both time periods. For these participants the upper age limit is limited to 70 years old, in line with the available biological data

		Age distribution		Gender ratio (%)			Years in postcode (*M* ± *SD*)	
Sample	*n*	Range	*M* ± *SD*	Male	Female	N/A	Current	At age 18
Main sample—Southeast England								
All ages	330	19–81	49.3 ± 15.2	39.1	60.9	0	16.0 ± 13.5	14.8 ± 8.6
Current	308	19–70	48.2 ± 13.8	37.7	62.3	0	14.8 ± 12.4	—
Past (age 18)	282	20–70	48.8 ± 14.0	40.8	59.3	0	—	14.8 ± 8.5
Both current and past	201	19–70	46.8 ± 14.6	37.8	62.2	0	16.1 ± 13.2	14.8 ± 8.9

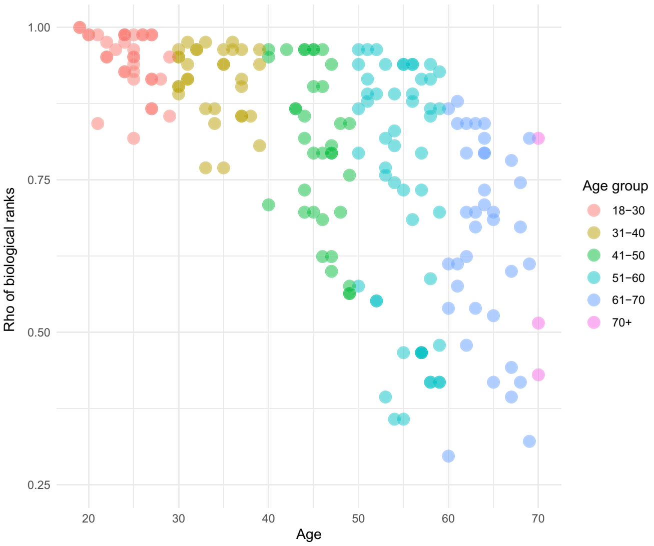

FIGURE 2 Participant age against the correlation of biological abundance rank at time of survey and at age 18 per participant across all species. Only participants living in the study region at age 18 and at the time of the survey are included (*n* = 201)

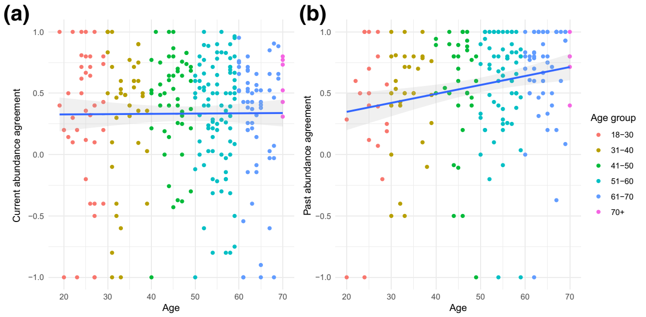

FIGURE 3 Agreement between species relative rank in participant perceptions and biological datasets: (a) in the present; (b) at age 18

from personal experience (5.68 ± 1.40, *p* < 0.001) and from books (3.77 ± 1.40, *p* < 0.001).

3.3 | Section 3: Evidence for personal amnesia

Personal amnesia was investigated for participants who experienced biological change and lived in the study region both at age 18 and at the time of the survey (*n* = 199). Of this subset, 37 participants (18.6%) had a static perception of species abundance ranks, ranking species in the same order of relative abundance at both age 18 and in the present (Spearman's rho = 1; Figure 4). The mean age of these participants was 45.1 years, and 73% had some experience of birdwatching. These participants were separated into two categories representing two contrasting cognitive biases: anchoring and recency effect. Four participants (aged 18–40) showed signs of personal amnesia (a form of recency effect) as they reported a static perception of species abundance in both time periods, and their perceptions of current conditions showed complete agreement with the current biological data (rho = 1).

3.4 | Section 4: Effect of SBS on perceptions of conservation attention

Analyses included only participants living in the study region both at age 18 and at the time of the survey, and that had experience of biological change (*n* = 199). Participants were only asked about species selected as recognized earlier in the questionnaire. The effect of SBS on perceived need for conservation (measured as conservation attention) was investigated for the three most declining species in the study (house sparrow, common cuckoo and tree pipit), which vary in relative abundance (see Table 1: house sparrow > tree pipit > common cuckoo). In all cases, the proportional odds assumption was met. Results for all species can be found in Table S20.

The house sparrow was awarded a mean conservation attention score of 3.71 out of 5. Higher scores were significantly predicted by increasing age, with the predicted odds of awarding a higher score increasing by 3.6% for each year of increasing participant age, independent of perceived trend (odds ratio = 1.036, *p* = 0.031, *n* = 170; Figure 5). However, despite an age effect appearing more evident for participants perceiving a declining or increasing trend (Figure 5), no significant interaction effects of age and trend were found. The

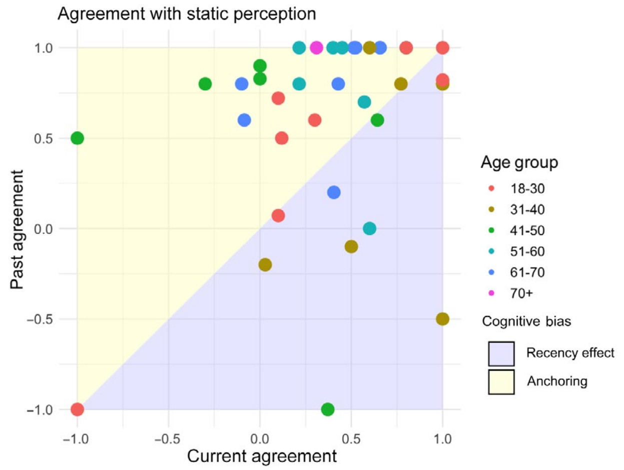

FIGURE 4 Participants with a static perception of species abundance ranks from age 18 to the present ($n = 37$). Participants within the blue area demonstrate the recency effect, reporting higher agreement with current biological conditions and which they also believe to have been the same in the past. Participants within the yellow area show signs of anchoring, in which people show higher agreement with past biological conditions and which they believe are still the same in the present

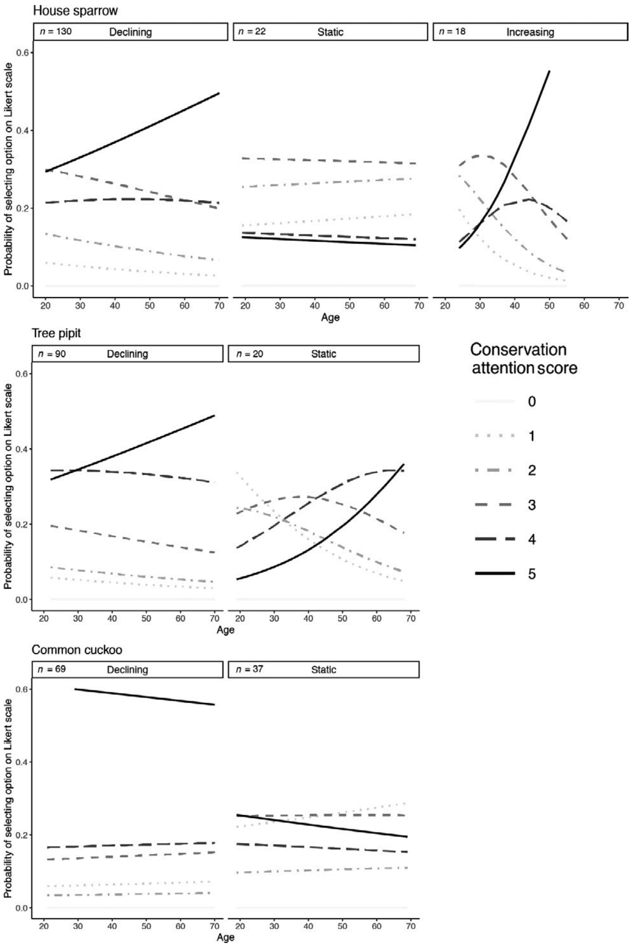

FIGURE 5 Interaction effects of perceived species trends and participant age on perceptions of conservation need, represented by conservation attention score

tree pipit was awarded a mean score of 3.62. The odds of awarding a higher score increased by 3.1% for each year of increasing participant age, independent of perceived trend (odds ratio = 1.031, $p = 0.028$, $n = 110$). Perceived trend also had a significant effect (Figure 5), as participants who perceived a declining population trend were 85.0% more likely to award a higher score than those who perceived a static population trend (odds ratio = 0.150, $p = 0.048$, $n = 110$). However, no significant interaction effects of age and trend were found. For the common cuckoo, mean score was highest at 3.83, but there were no significant effects of age or perceived trend.

4 | DISCUSSION

According to the conceptual framework defined by Papworth et al. (2009), two criteria are essential to find evidence of SBS: biological change must be present in a system, and differences in perceptions of change must be in line with biological data (Papworth et al., 2009). In this study, we substantiate both of these criteria, and provide empirical evidence for generational amnesia and limited evidence for personal amnesia in the study sample. Generational amnesia was identified as we found an age-related difference in perceptions of past ecological conditions, as older participants recall past conditions which are more consistent with the biological dataset than younger people. Therefore, the baseline against which participants perceive bird species abundance appears to be shifting with each successive generation. Evidence of personal amnesia was found in some younger participants, characterized as an accurate perception of current conditions which are believed to have been the same in the past. Our results therefore support the expectation that younger, less experienced people are less aware of historical ecological conditions and show greater evidence of SBS. Most importantly, we find evidence of SBS in relation to perceptions of conservation need, demonstrating a negative impact of generational amnesia on conservation support for species in decline. Older people were found to give significantly higher conservation attention scores than younger people for two out of three declining bird species included in this study, representing potential negative impacts on future conservation support for these species.

The first criterion required for SBS is to ensure that every participant is exposed to, and has experience of, biological change in the system (Papworth et al., 2009). We restricted analyses to the 99% of participants who had experienced change in local bird populations since they were 18 years old, and found that older people had experienced more biological change than younger people in the study region (Figure 2). The second criterion for SBS is to provide evidence that any perceived change is consistent with these biological data. Furthermore, in order to demonstrate the existence of generational amnesia, perceptions of change must be related to age or experience. First, we confirmed that all age groups reported similar current rank abundance agreement, representing no significant age-related difference in perceptions of current conditions

(Figure 3a). However, with regard to perceptions of past ecological conditions, older people reported significantly higher abundance rank agreement at age 18 than younger people (Figure 3b), despite having to recall information from further in the past. This finding provides empirical evidence of generational amnesia, as the perceptions of younger, less experienced participants had significantly lower agreement with biological data than did perceptions of older participants. This is especially significant, as it would generally be expected that a person's ability to remember the past accurately should diminish with age, a process known as cognitive ageing (Salthouse, 2004; Tulving, 1989a).

One explanation for our findings may be generational differences in cultural backgrounds during childhood, including varying levels of contact with nature. These differences may have caused different awareness of the natural world, although at the time of the study we found no age-related difference in frequency of experience of nature or connectedness to nature scores (see Supporting Information). However, we also found that across all age groups, participant perceptions generally had higher agreement with biological data in the past than the present, contrary to what might be expected given the relative clarity of recent episodic memories (Murre & Dros, 2015). While the acute mechanisms of human memory are still intensely debated, evidence suggests that long-term memory has higher capacity and can be more resilient to decay as it is contextualized and reinforced by cumulative experience and understanding (Cowan, 2008). Increased past agreement may also be the result of so-called ‘reminiscence bumps’ which are thought to enable the recall of older memories with greater accuracy (Jansari & Parkin, 1996). Building upon the review by Rost (2018), further research into the psychological mechanisms driving SBS are needed with focus on differences in the storage, decay and contamination of long- and short-term memory.

Following the original definition and investigation of personal amnesia by Papworth et al. (2009), we are the only subsequent study to suggest evidence of the phenomenon. However, personal amnesia is very rare across our study system, occurring in only four participants, or 2% of those living in the study region at both survey time points who experienced biological change, suggesting that it may constitute an individual rather than a wider-scale collective phenomenon (cf. Papworth et al., 2009). If subsequent studies suggest that personal amnesia is a greater problem than indicated here, it could be combatted using increased communication and education within the community, as well as with historical records and photographs (Papworth et al., 2009; Thurstan et al., 2016).

While the definition of SBS describes an age- or experience-related degradation of ‘normal’ expected conditions, arguably the most discussed aspect of SBS is the consequential threat posed for conservation support, uptake and long-term success (Pauly, 1995; Soga & Gaston, 2018; Soga et al., 2016). In other words, if people do not realize the extent of ecological decline due to SBS, does this negatively influence their conservation choices in the present? Our study is the first to explore this theory empirically, identifying a species-specific difference in the impacts of SBS on perceived need for conservation for two declining species, the house sparrow and tree pipit (see Figure 5). The potential for a negative impact of generational amnesia was identified as we found an age-related difference in the perception of a need for conservation action for both of these species, with older people significantly more likely to perceive a greater need for conservation attention than younger people. This result seems logical in the context of an ongoing extinction of experience, in which younger people are increasingly disconnected from nature (Soga & Gaston, 2016; Soga et al., 2016); however, this is contrary to the increasingly common media portrayal of younger people as pro-environmental advocates around the world (Gardner, Struebig, & Davies, 2020; Sullivan & Syvertsen, 2019). Bickford, Posa, Qie, Campos-Arceiz, and Kudavidanage (2012) emphasized that while environmental literacy may be improving, a lack of formal environmental education in school curricula may continue to widen the gap between people and nature, and prevent the development of long-term pro-environmental behaviour. However, no age-related effect was found for the common cuckoo, despite this species earning the highest mean conservation attention score of the three declining species. Furthermore, looking across all species included in this study, a similar age-related trend was found for the blue tit and goldfinch, indicating that perceptions of conservation need vary by age irrespective of species' population trend (see Table S20). This result may indicate that the impacts of SBS on conservation attention are species-specific, an area to be explored in further research.

Our results also indicate a possible conservation impact of species-specific personal amnesia, as participants who perceived a static population trend for the tree pipit awarded lower conservation scores, even though all three species show continuous population decline throughout the study period. In this case, an effect of personal amnesia on perceptions of conservation need was only identified for the tree pipit, as participants who perceived a static trend were significantly less likely to award higher conservation attention scores than participants who perceived a declining trend. Further study is also needed to elucidate whether biological factors such as charisma, distinctiveness and residency influence the incidence and impacts of SBS at the species-level (Courchamp et al., 2018).

Evidence of the presence and impacts of SBS within a large public sample highlights the potential magnitude of SBS as a widespread concern, holding the power to impact conservation understanding, uptake and support on a global scale (Bonebrake et al., 2010; Guerrero-Gatica et al., 2019; Humphries & Winemiller, 2009). In terms of conservation management, our study emphasizes the potential impacts of SBS on the strength of conclusions for conservation decision-making, especially when informed by anecdotal perceptions of long-term biological change (Anadón, GimÉnez, Ballestar, & Pérez, 2009; McClenachan, 2009; Thurstan et al., 2016). SBS has been cited among biases impacting LEK, which must be considered when LEK is utilized as a source of data for conservation research and management (Fernández-Llamazares et al., 2015; Kai et al., 2014). For example, Turvey et al. (2010) emphasized the potentially rapid loss of cultural and linguistic knowledge across an entire community due to SBS, even for charismatic megafaunal species such as the Yangtze River dolphin *Lipotes vexillifer*.

However, as recommended by Soga and Gaston (2018), identification of the cause(s) of SBS enables the development of strategies to combat its negative impacts. Although neither current rank agreement nor trend agreement score was explained by age, results of model selection highlighted the role of species knowledge (measured as the ability to recognize a greater number of species from photographs) as the most important variable for predicting both current abundance agreement and ability to perceive long-term trends. As a measure of retained visual knowledge, higher species recognition is likely to originate from personal experience or intergenerational communication. However, we found a significant positive relationship between number of species recognized and knowledge gained from personal experience and from books. Our evidence of generational amnesia across an entire ecological community highlights a need for a shift of focus towards the promotion of intergenerational communication and knowledge-sharing about the UK bird species declines (Fernández-Llamazares et al., 2015; Kai et al., 2014). The importance of knowledge for accurate perception of long-term trends indicates the potential role of active involvement of LEK in combating SBS, through opportunities such as citizen science (Schuttler et al., 2018) or wildlife-based tourism (Ballantyne, Packer, & Hughes, 2009; Powell, Brownlee, Kellert, & Ham, 2012). Public involvement not only aids in preventing the extinction of experience (Louv, 2005; Soga & Gaston, 2016), another proposed cause of SBS, but also provides the dual-benefit of gathering extra data and increasing public knowledge to continually improve the quantity and quality of available biological datasets for further SBS research (Soga & Gaston, 2018).

There are three key limitations in this study that could be addressed in future research. First, although we present a case study of SBS, this is constrained to the United Kingdom and focuses only on birds; this is primarily due to the limited availability of long-term longitudinal biological datasets required to assess perceptions of change spanning multiple generations, a limitation highlighted by previous studies (e.g. Fernández-Llamazares et al., 2015; Thurstan et al., 2016). Wider availability of high-resolution biological datasets on an international scale could provide broader evidence for SBS, providing scope for more paired studies comparing cultural and ecological data. Further studies should look towards large-scale, broad-topic investigations of SBS spanning multiple aspects of environmental concern (e.g. perceptions of climate change; urbanization) in order to gain a full picture of the effects of SBS on environmental concern. Second, our study design used non-random sampling methods. However, the aim of this study was to investigate the processes and relationships between individuals, rather than attempting to estimate population-level parameters, and our methodology ensured the geographical and chronological matching of a large social sample against a consistent long-term biological dataset. Finally, while many previous SBS studies used face-to-face interview techniques, which can provide lower non-response rates (Heerwegh & Loosveldt, 2008) and more representative results than online surveys (Szolnoki & Hoffmann, 2013), the use of online questionnaires is increasingly recognized as a fast, cheap and convenient method to collect data (Wright, 2005). In the case of this study, we found the results of the online survey were in agreement with a smaller face-to-face sample (see Tables S2–S19 for results of model selection and averaging for all samples). However, the face-to-face sample in this study had a small sample size ($n = 79$), and further studies should aim to use a large interview sample to ensure data quality.

As several previous studies have recommended (Papworth et al., 2009; Thurstan et al., 2016; Turvey et al., 2010), caution must be taken when using retrospective accounts of change to investigate evidence of long-term change. We provide evidence to suggest that SBS can impact personal and generational perceptions of past, present and future biological conditions, and confirm previous concerns that SBS can negatively impact perceptions of conservation need for species in decline (Soga & Gaston, 2018). In the current era of rapid ecological degradation, the potential implications of SBS are momentous for many disciplines interested in perceptions of change over time, from conservation (Papworth et al., 2009) to climate change (Moore, Obradovich, Lehner, & Baylis, 2019). Looking toward environmental restoration, we must also recognize the issue of 'lifting baselines', which equally threatens our ability to recognize positive change and learn from the past, as previously degraded conditions are forgotten and improved conditions are considered normal (Roman, Dunphy-Daly, Johnston, & Read, 2015). Empirical evidence of the prevalence and impacts of SBS within the general public highlights the scope of the issue and the urgent need to promote greater awareness throughout conservation science. Future efforts to explore and unearth new, reliable data sources are needed to enable a better understanding of long-term change and allow the setting of more appropriate restoration targets. Meanwhile, further research into species-related and cultural variation in evidence for SBS is critical to improve and shape the work of conservationists, educators and policy- and decision-makers alike to improve frameworks for combatting the continuation of the phenomenon (Soga & Gaston, 2018). As a generational phenomenon, SBS is likely to continue as a pervasive issue in conservation. However, by understanding the extent, pattern and rate at which our own actions are degrading the natural environment, and by communicating this knowledge, we might hope to tackle SBS in the future.

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CONFLICT OF INTEREST

The authors declare no conflict of interests.

AUTHORS' CONTRIBUTIONS

L.P.J., S.K.P. and S.T.T. conceived the project idea, developed methods and discussed results; D.M. provided biological data and analytical advice; L.P.J. collected questionnaire data and performed analyses. All authors contributed to and authorized the final manuscript.

DATA AVAILABILITY STATEMENT

All biological data (provided by the British Trust for Ornithology) and anonymized social data collected using online questionnaires are available from Royal Holloway Digital Repository (https://doi.org/10.17637/rh.12640244.v1; Jones & Papworth, 2020). Please contact corresponding authors for more information.

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SUPPORTING INFORMATION

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

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4. Comparing international evidence and impacts of shifting baseline syndrome: a case study in the UK and Finland

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4.1. Introduction

With global environmental change accelerating at an unprecedented rate, it is increasingly difficult to perceive the magnitude and extent of ecological degradation, even at the local scale (Dirzo et al., 2014). Such unparalleled change results in variation in psychological perceptions of the natural world, as people are unable to accurately perceive the extent of ecological change (Petheram et al., 2010). However, despite recent increases in research regarding the social dimensions of ecological decline (Bennett et al., 2017; Cinner and Barnes, 2019), surprisingly few studies investigate how and why there might be discrepancies between perceptions and the biological data, and how local perceptions of biological change might vary around the world (Papworth et al., 2009; Kai et al., 2014; Fernández-Llamazares et al., 2015; Jones et al., 2020). In a systematic review, Pyhälä et al. (2016) argue that cognition, culture, knowledge and local adaptive capacity are the most important factors shaping the lens through which individuals perceive environmental change. Yet, the social facets of environmental change are often overlooked by scientific research due to a focus on the biophysical aspects from a predominantly top-down perspective (Pyhälä et al. 2016). Understanding social perceptions of change has known benefits to conservation science, from revealing previously unknown gaps in scientific datasets (Marin, 2010), to providing deeper understanding of the key factors driving support for environmental conservation, restoration and adaptation (Engels et al. 2013).

However, when perceptions diverge from the biological reality, individuals are likely to become less aware of the extent of biological decline, potentially introducing bias to local ecological knowledge (LEK), community-based and participatory conservation, and environmental education (Papworth et al., 2009). Specifically, shifting baseline syndrome (SBS) describes a psychological phenomenon in which people only recognise biological change within their own experience, effectively forgetting the historical conditions of the past (Papworth et al., 2009, State of Nature Report, 2019). Over multiple generations the use of only recent baselines is thought to lead to a gradual acceptance of degraded ecological conditions as ‘normal’ and the use of inappropriate reference points for evaluating ecological trends or identifying restoration targets (Soga and Gaston, 2018). According to Papworth et al., (2009), two mechanisms have been identified which may lead to evidence of SBS: generational amnesia and personal amnesia. Generational amnesia describes a gradual shift in perceptions of ‘normal’ ecological conditions, primarily due to loss of ecological knowledge between successive generations (Papworth et al., 2009). Generational amnesia is therefore thought to prevent accurate perceptions of long-term change, in both the public (Kahn and Friedman, 1995) and in conservation management (Pauly, 1995). In 2009, Papworth et al. defined a second form of SBS, termed personal amnesia, in which people believe past conditions to be the same as current conditions. This is comparable to ‘the recency effect’, a cognitive bias in which we remember recent events more clearly than the past (Baddeley and Hitch, 1993) and change blindness (or anchoring) which describes a tendency to remember the past better than recent conditions (Simons and Rensink, 2005).

To provide empirical evidence of SBS, three criteria must be met, as outlined by Papworth et al. (2009), yet only a small proportion of previous SBS studies adhere to these criteria (Guerrero-Gatica et al., 2019). These criteria are; all individuals must have experienced biological change in the system, all individuals must have an accurate perceptions of current conditions and that differences in perceptions of change are dependent on age or experience (indicating generational amnesia) or that individuals believe current conditions also occurred in the past (indicating personal amnesia). Very few previous SBS studies have sought to systematically compare evidence of incidence of SBS on an international scale and across different cultures (Pinnegar and Engelhard, 2008; Soga and Gaston, 2018). This represents an important research gap as perceptions of ecosystem resilience and the need for conservation are likely to vary temporally, geographically and by ecosystem, dependent on level on availability of historical information and education, industrialisation and local reliance on the natural environment (Guerrero-Gatica et al., 2019). Previous SBS studies have been conducted in various countries, from the United Kingdom (Papworth et al., 2009; Jones et al., 2020), to China (Turvey et al., 2010) and Bolivia (Fernández-Llamazares et al., 2015), but most studies focus on a single study country or region. In 2008, Pinnegar & Engelhard reviewed the ‘shifting baseline phenomena’ within fisheries science on a global scale. The review suggested that the time-horizons over which people are likely to perceive change are limited primarily by the scope of the known historical biological record (Pinnegar and Engelhard, 2008). However, in many cultures, even where historical scientific data is available, knowledge of past ecological conditions is passed on in community memory, often via oral communication. For example, in 2010, Turvey et al. presented a significant relationship between evidence for SBS and the loss of local community memory with regard to the extinction of the Yangtze river dolphin or baiji. Age was found as a significant predictor of species knowledge and recognition of the species' rapid decline. Older respondents (over 40 years old) were significantly more aware of the species' past existence, indicating that community knowledge of ecological conditions can be lost within just two generations (Turvey et al., 2010). In ecological research, community memory can therefore be used as measure of time, as a specific common memory might be a 'trademark of a generation' (Funkenstein, 1989). Similarly, Fernandez-Llamazares (2015) provided the first study investigating the links between decreased intergenerational communication and evidence of SBS in the Tsimane peoples of Bolivia. Free-listing techniques revealed that gradual movement away from traditional farming practices and religious traditions provided barriers to the passing of traditional ecological knowledge between generations, highlighting that the stability and resilience of community memory regarding past ecological conditions is likely to vary culturally (Fernández-Llamazares et al., 2015).

In a recent review of the causes, consequences and implications of SBS, Soga and Gaston (2018) called for further investigations into the importance of factors influencing the presence and magnitude of SBS in a range of contexts, cultures and scales (Soga and Gaston, 2018). While previous studies have investigated the importance of several socio-demographic factors including age, knowledge and experience of biological change (Papworth et al., 2009; Turvey et al., 2010), as well as interest and connectedness to nature (Jones et al., 2020) on the incidence and consequences of the syndrome, as yet, no previous study has directly compared empirical evidence for SBS in multiple countries using equivalent paired data methods. The comparison of such factors across cultures would reveal important information required to map the incidence of SBS on a global scale and in future, point towards possible mechanisms to combat the impacts of SBS. It would enable the opportunity to identify cultures with less evidence of SBS and investigate which factors prevent both forms of amnesia occurring. This information could be used to inform future research and policy to target future research towards certain 'at-risk' countries or cultures and combat the consequences of the syndrome on conservation on a global scale (Soga and Gaston, 2018).

The primary limiting factor currently preventing empirical SBS research is the availability of longitudinal biological datasets against which to statistically compare social perceptions using paired data techniques (e.g., Huntington et al., 2004). Papworth et al. (2009) was first to explore evidence for SBS using case studies from contrasting cultures using a standardised set of definitions, comparing evidence in Gabon and Equatorial Guinea, alongside perceptions of bird populations in the UK, but conclusive evidence of SBS was only found in the UK. More recently, Jones et al. (2020) were the first to provide empirical evidence of the impacts of SBS on public perceptions of conservation priorities for species in decline, using a case study of UK garden bird species. However, the majority of SBS literature focuses on a single country or culture (Jones et al., 2020), within a context of exploitative, degenerating systems such as species extinction (Turvey et al., 2010), species abundance declines, biodiversity loss (McClenachan, 2009; Rosa et al., 2014; Thurstan et al., 2016; Francis et al., 2019) or climate degradation (Lyytimäki, 2013).

Following the criteria defined by Papworth et al. (2009), we aim to provide the first comparative investigation into evidence for SBS on an international scale. The availability of long-term ornithological census datasets in the UK and in Finland provide a unique opportunity to compare evidence on the incidence and possible mechanisms behind SBS in countries with cultural similarities and differences. The similar climate, diversity of bird species, socio-economic status of the UK and Finland provide a foundation for comparison of SBS in differing cultures. Nature and the natural environment are strongly embedded in the Finnish culture and language, and Finland is well-known for promoting nature-based schooling (Jeronen et al., 2009) and high participation in citizen science programmes, while a strong connectedness to nature is thought to foster a strong conservation ethic (Tikka, 2003). By comparison, the prevailing narrative in the UK often highlights a disconnect from nature (Cox and Gaston, 2016), especially in the younger generation and a sharp decline in native wildlife stemming from rapid urbanisation (RSPB, 2015).

The primary aim of this study is to systematically compare evidence for SBS in both the UK and Finland, through both generational and personal amnesia, following the criteria outlined by Papworth et al. (2009). We therefore aim to:

- Test for differences in interest in- and connectedness to nature between countries,

- Ascertain that all participants from both countries have experience of biological change in the study system,
- Explore age- or experience-related differences in the level of agreement participant's perceptions of biological change in the current and past, in order to investigate and compare evidence of generational amnesia in both countries.
- Explore and compare evidence for personal amnesia, characterised as static perceptions of biological change, with higher agreement with the biological data in the present than in the past.
- Finally, to understand the key factors influencing level of agreement between participant perceptions of biological change and the biological data, including key demographic, experience and knowledge-based factors in the UK and Finland, connectedness to nature (CTN) scores, frequency of birding experience and visitation to local natural environments, knowledge of garden bird species.

Strong cultural affiliations with nature in Finland, including nature-based recreation and nature-based schooling from a young age, may result in higher connection to nature scores and more frequent experience of nature in Finland (Jeronen et al., 2009). We therefore hypothesise that Finland will show little evidence of SBS compared to that found in the UK (Jones et al., 2020), however differences in data availability may influence evidence of SBS. Our results will provide the first study to directly compare evidence of SBS between countries and explore variation in the drivers of SBS, highlighting potential methods for combatting the impacts of SBS on a global scale.

4.2. Methods

Data sources

In the UK, the British Trust for Ornithology (BTO) combined Common Bird Census (CBC) and later Breeding Bird Survey (BBS) dataset formed the biological dataset. The original CBC methodology and BBS methods are comparable, allowing the datasets to be combined to create a long-term census dataset from 1966 to 2017. For more details see Jones et al. (2020).

The Linnustonseuranta (the annual monitoring of breeding birds in Finland) collects bird species occurrence across a network of 3,848 10x10km^2 grid squares covering 99.7% of Finland’s total land area. Annual data is collected via citizen science and submitted electronically using the standardised BirdLife Tiira system by an extensive registered volunteer network. Every observation registers the date, location, species, abundance and observations such as type of movement, direction of travel, nesting behaviour and nest safety.

Region selection

The study area in the UK consisted of eleven contiguous counties in Southeast England: Berkshire, Buckinghamshire, Cambridgeshire, Essex, Greater London, Kent, Hampshire and Isle of Wight, Hertfordshire, East and West Sussex, and Surrey. This area was selected based on the availability of biological data using the combined BTO-JNCC Common Bird Census and Breeding Bird Survey datasets (Freeman et al., 2007). However, species abundance estimates for the combined census are not uniformly accurate as data collection methods changed after 1994 and survey effort varied both spatially and temporally according to surveyor availability (Figure S1). Southeast England was selected as the area of highest density of BTO data (quantified using the number of BBS survey squares) and most reliable species population estimates in the UK (Gillings et al., 2012). The selected region has consistent land use and similar climate (Dessai and Sims, 2010), hence the species included in this study are annually detected throughout the region.

Finnish data collection was limited to the southern and eastern provinces of Finland (co-ordinate limits 67°N latitude and 34°E longitude), including the states of Uusimaa, Kymenlaakso, Päijänne, North and Southern Karelia and Savonia. Southeast Finland has a relatively consistent habitat type and land use (LUOMUS Team, 2018), ensuring that the range of each species was likely to span throughout the study area. The area also regularly has high Finland Bird Atlas survey effort (Figure S2). A scoping visit during June 2018 allowed us to create a valuable network of contacts, identify participant networks and form collaborations in the study area (LUOMUS Team, 2018).

Species selection

For full details regarding UK species selection see Jones et al. (2020). In the UK, ten bird species were selected to encompass the full range of abundance and trends, ranging from abundant and increasing, to rare and declining (Woodward et al., 2018 - see Table S1). The species are; house sparrow (*Passer domesticus*), tree pipit (*Anthus trivialis*), common cuckoo (*Cuculus canorus*), Eurasian jay (*Garrulus glandarius*), barn swallow (*Hirundo rustica*), blue tit (*Cyanistes caeruleus*), Eurasian wren (*Troglodytes troglodytes*), sparrowhawk (*Accipiter nisus*), goldfinch (*Carduelis carduelis*) and collared dove (*Streptopelia decaocto*), plus one control species not endemic to Southeast England, the Scottish crossbill (*Loxia scotica*).

In Finland, national-scale data were extracted from the Third Finnish Breeding Bird Atlas (Valkama et al., 2011) for 41 'garden bird' species. Species were ranked in order of abundance (as number of pairs or territories in 2010) and population trend (annual % change from first data to 2010). Ten bird species were selected to encompass the full range of abundance and trends, ranging from abundant and increasing, to rare and declining. The ten species are; wryneck (*Jynx torquilla*), starling (*Sturnus vulgaris*), barn swallow (*Hirundo rustica*), common cuckoo (*Cuculus canorus*), house sparrow (*Passer domesticus*), blackbird (*Turdus merula*), white wagtail (*Motacilla alba*), great tit (*Parus major*), willow warbler (*Phylloscopus trochilus*) and Eurasian robin (*Erithacus rubecula*) plus one control species not regularly found in Southeast Finland, the Siberian jay (*Perisoreus infaustus*).

In both countries, a focus on species seen regularly in garden and urban areas ensured participants would have personal experience of the species as they can be seen passively in everyday life. Using garden birds also enabled inclusion of species with both increasing and decreasing trends, to control for dominant narratives of native bird species declines (Newton, 2004; Woodward et al., 2018). The species also vary according to several co-variates such as body mass, detectability, charisma, longevity and migration status (Tables S1 and S2). In both the UK and Finland, one control species not endemic to the study region was included (Scottish crossbill in the UK and Siberian jay in Finland) as a non-local independent baseline for comparing perceptions to identify participants with local birding knowledge.

Questionnaire design and dispersion

The methodologies and dissemination strategies for both questionnaires are the same as described in Jones et al. (2020). Described below are key methodological decisions for both questionnaires and an outline of where the Finland methodology deviated from the original UK questionnaire methods.

Large-scale online questionnaires were designed, operated and distributed using the Qualtrics platform (version XM 2018). The UK questionnaire was piloted with 12 participants from the 11th-13th July 2018 and was live from 16th July to 9th September 2018. The Finland questionnaire was translated from English by a native Finnish speaker and piloted by two trusted proof-readers. The Finnish questionnaire was live from 15th September to 9th December 2018 and repeated from 17th July to 2nd September 2019. Full ethical approval was granted from ZSL (ZPD code: IOZ5) and RHUL prior to piloting and data collection (see Supplementary materials S1 & S2 for full questionnaires).

The questionnaires collected personal perceptions of species abundance (as a rank order from most to least abundant across all species recognised) and trends (each species categorised as increasing, static or declining) in the past and present (see Table 1 for analysis). Participation restrictions, instructions and a definition of ‘local area’ was included in the first page of the questionnaire. Questions regarding ‘the past’ asked participants to remember when they were 18 years old. This age serves as a ‘memory anchor’, enabling easier recall of experience-based, episodic memory (Havari and Mazzonna, 2011) and has been found as a key change-point in connectedness to nature scores (Hughes et al., 2019). Multiple explanatory variables were also collected (see Table S3) including; participant demographics (age and gender), and county of current and past residence (in the UK, postcodes converted to county (Office of National Statistics, 2018) and in Finland, postal codes were converted to regional districts (“List of postal codes in Finland,” 2019). Length of past residency in both countries was collected to estimate consistency of experience and exposure to the same local bird population. The Finnish questionnaire had three additional questions regarding personal access to holiday cottages. We asked whether participants had access to a holiday cottage, and if so, in which area/postcode and for how many years. Other questions quantified bird species recognition, the origin of birding knowledge, frequency of passive experience of nature through nature-based activities, and years of active birding experience, perceptions of conservation concern and connectedness to nature (CTN) scores

(Nisbet et al., 2009; Nisbet and Zelenski, 2013; Shanahan et al., 2017). For further details see Jones at al. (2020).

To ensure that participants in the 'Southeast' samples were representative of the wider population, results from these samples were statistically compared to the rest of the national sample, named the 'non-Southeast' subsets in both countries. These samples were further broken down according to the time of residency in each area; those living in the Southeast regions at the time of the questionnaire (current), those living in the Southeast at age 18 (past) and those that lived in the Southeast in both time periods. In the UK, the online sample was compared to an additional offline sample (n = 79), collected in Kent, UK in August 2018. However, due to the nature and length of the questionnaire, most participants were older and had a prior interest in nature.

Data Analysis

Analyses were conducted using R software version 3.6.2. (R Core Team, 2019). Annual abundance and population trend per species, per county was calculated from 1966 to 2017 in the UK and from 1984 to 2018 in Finland using the 'rTRIM' package (Pannekoek and van Strien, 2005). For further information please refer to Jones et al., (2020).

In the UK, biological data were available per county therefore geographical matching for biological data and participant perceptions was possible to the county-scale. For each participant, biological data were subset to include only the local county and year range from the year the participant was 18 years old to 2017 (producing a participant age range of 18 to 70 years old), to create an analogous biological and social dataset. This dataset is referred to as the 'UK unrestricted dataset'. In Finland, the biological data were available only at the regional scale (i.e., Southeast Finland and non-Southeast Finland), therefore for each participant, the biological data was matched spatially to the regional scale but was matched temporally on an annual scale, from the year the participant was 18 years old to the year of the questionnaire. However, as the earliest available data date to 1984 in Finland, it was not possible to temporally match biological data to participant perceptions for participants who turned 18 earlier than 1984 (participants over 53 years old). For direct comparison between countries, an additional UK subset (named the 'UK restricted dataset') was therefore created, restricted to the same age range as Finland.

Only species that were recognised by the individual participant from photographs were included for all subsequent analyses (see Table 3; Jones et al. (2020)). To calculate abundance agreement between individual perceptions and biological data, the perceived species abundance rank and ranked biological abundance were correlated using the Spearman Rank coefficient (see Jones et al. (2020), Table 3). For species trends, a scoring system was created to assess the level of agreement of each participant's perception of species abundance and trends and the biological data per species. Trend agreement scores were summed across all species to produce an overall score per participant.

Participant demographics and years of experience of biological change were similar between the Southeast and non-Southeast regions of both the UK and Finland (Table 1). Therefore, we only present results from the restricted Southeast samples here (see Tables S4-24 for all results). For results using the UK unrestricted dataset see Jones et al. (2020). An information theoretic model selection and averaging approach was used to compare the significance of multiple predictors in explaining the incidence of SBS (Zuur et al., 2010; Harrison et al., 2018). In both countries, global models were created using predictor variables selected *a priori* to represent the original hypotheses to prevent overparameterization. Predictors included: age, gender, connectedness to nature, proportion of life in current and past postcode, urbanity of current postcode, proportion of life as a birder in the current state and by age 18, number of species recognised and correctly named, and frequency of walking in local area. Additional predictors in Finland included: access to summer cottage and proportion of lifetime with access to a summer cottage.

Predictor collinearity was evaluated using a variance-inflation factor (vif) values calculated using the 'Performance' package (Zuur et al., 2010; Lüdecke et al., 2021). Where one or more terms in the unweighted global model had more than one degree of freedom, the correlated predictor variables were identified using the generalized variance inflation factor (gvif$^{(\frac{1}{2}\,\mathrm{df})}$). Where, vif or gvif$^{(\frac{1}{2}\,\mathrm{df})} < 2$, a low level of collinearity was accepted and all variables were retained (Zuur et al., 2010). If not, the residuals of the global models were evaluated for overdispersion using an iterative predictor removal, plot and transformation approach until vif < 2 (see selected models in Supplementary materials for final predict lists per model). Linear models were executed for the current and past abundance response variables and a generalised linear model (GLM) with a Poisson transformation and log-link was selected for the trend accuracy response (Zeileis et al., 2008; St-Pierre et al., 2018). In the UK, results from Southeast sample were compared to the Offline and non-Southeast samples while in Finland, the Southeast sample was compared to the non-Southeast sample.

Multiple candidate models were compared using an information theoretic approach using MuMIn package in R (Bartoń, 2019). The small sample size correction of the Akaike

Information Criterion (AICc) was used to rank candidate models and models with a ΔAICc < 2 were retained as a 'confidence set' of models, for which Akaike Weights were calculated (Burnham and Anderson, 2002; Zuur et al. 2009). The confidence set was verified against a second selection method in which all models with a cumulative Akaike Weight of ≥0.95 from the top model were included as a '95% confidence set' (Harrison et al., 2018). All three response variables had multiple candidate models with similar levels of support leading to model uncertainty so a model averaging approach was taken (Grueber et al., 2011).

Averaging was conducted on all models where Δ_i <2, to consider an effective combined multi-model inference. Selected models and model averaged estimates including standard errors, confidence intervals, z-and P-values are shown (see Tables S4 – S24). Model averaged estimates indicate the probability of observing participant perceptual agreement in relation to the biological datasets, as the value for a continuous predictor variable increases, or compared to the baseline (intercept) value for categorical predictors (Harrison et al., 2018). Positive estimates indicate positive effects on agreement, while negative estimates indicate negative effects on agreement. Model averaged estimates were not calculated for variables that did not occur in the confidence set of models.

4.3. Results

In the UK, a total of 912 participants completed the questionnaire. Participants aged 18 to 70 years were included in the 'full UK sample'. This sample was restricted to 458 participants ('UK restricted' sample) to match the age-range of the Finland sample. This subset ranged in age from 19 to 52 years (mean [SD]= 38.8 years [9.6]). In Finland, 293 participants were surveyed, but once matched to the biological data this was restricted to 166 with an age range from 18 to 52 years (mean [SD]= 38.3 years [8.3]). Both countries had a similar gender ratio, with more female participants than male. A full overview of the size and demographic and geographic distribution of each sample can be found in Table 1 below.

Table 1. Sample size, demographics and location information per sample and subset.

Sample name		**N**	**Age Distribution**		**Gender ratio (%)**			**Mean no. of years in postcode**	
			Range	**Mean ± SD**	**M**	**F**	**N/A**	**Current**	**At age 18**
National Finland sample (all participants)		293	18-78	48.8 ± 14.1	43.0	55.3	1.7	16.8 ± 14.5	15.4 ± 12.7
Southeast Finland sample (Southeast)		166	18-52	38.3 ± 8.3	38.0	60.2	1.8	10.8 ± 10.5	14.4 ± 8.2
SE Finland	Current	92	18-52	38.4 ± 8.0	37.6	60.2	2.2	11.6 ± 10.9	
	Past (at age 18)	73	18-52	39.0 ± 8.0	35.6	63.0	1.4		14.7 ± 8.7
	Both current and past	54	25-52	39.5 ± 7.5	35.2	62.9	1.9	14.5 ± 12.4	15.9 ± 9.0
Non-SE Finland	Current	73	18-52	38.2 ± 8.7	38.4	60.3	1.4		9.8 ± 9.7
	Past (at age 18)	93	18-52	37.8 ± 8.5	39.8	58.1	2.2	14.1 ± 7.7	
	Both current and past	58	18-52	38.9 ± 8.5	37.9	62.1	0	10.4 ± 10.3	14.4 ± 8.6
National UK sample (all participants)		912	19-85	50.4 ± 14.6	38.3	60.9	0.9	15.5 ± 12.8	15.3 ± 8.4
Restricted Southeast UK sample		458	19-52	38.8 ± 9.6	36.9	62.2	0.9	10.5 ± 10.0	15.5 ± 7.5
Restricted SE England	Current	170	19-52	37.1 ± 10.0	33.5	66.5	0	9.8 ± 9.2	
	Past (at age 18)	146	19-52	37.7 ± 10.0	36.3	63.7	0		15.1 ± 7.8
	Both current and past	102	19-52	37.1 ± 10.0	35.3	64.7	0	10.8 ± 9.9	15.6 ± 8.0
Restricted Non-SE England	Current	288	20-52	39.8 ± 9.2	31.9	67.4	0.7	10.8 ± 10.4	
	Past (at age 18)	306	20-52	39.3 ± 9.3	31.0	68.3	0.7		15.7 ± 7.4
	Both current and past	237	20-52	39.6 ± 9.4	31.6	67.5	0.8	11.2 ± 10.8	15.9 ± 7.4

Using the Southeast Finland and Restricted Southeast UK samples (see Table 1), unpaired two sample t-tests revealed no significant difference between the UK and Finland with regard to multiple demographic variables (age distribution, t = 0.61, df = 335, p-value = 0.54; time living in current postcode, t = -0.41, df = 279, p-value = 0.68; and time living in past postcode, t = 1.56, df= 291, p-value = 0.12) and other social predictors, such as mean connectedness to nature (CTN) score (t = -0.46, df = 371, p-value = 0.65), mean proportion of lifetime with birding experience (t = -1.04, df = 289, p-value = 0.30).

However, t-tests did reveal a significant difference in the mean number of species recognised from photographs (t = -4.44, df = 258.92, p-value <0.001) with participants in Finland recognising on average 9.56 species (86.9% of all species) compared to 8.79 (79.9%) in the UK. To investigate whether this result was the product of differences in charisma and recognisability between species selections in the UK and Finland, the number of species recognised was investigated using the three species included in both questionnaires: house sparrow, common cuckoo and barn swallow, indicating a similar pattern between countries (proportion of participants that recognised all three species; UK = 84.3%, Finland = 91.8%).

Demonstrating experience of biological change

Biological species abundance rank at the time of the questionnaire across the species included in the questionnaire was correlated with biological species abundance ranks for these species when each participant was 18, to test whether participants had experienced biological change. Two participants in the unrestricted UK and age-restricted UK sample (both aged 19), and one participant in the Finnish sample (aged 18) did not experience biological change as the abundance rank of species at age 18 and in 2018 were identical (Rho = 1). As these participants did not experience biological change they were excluded from all subsequent analyses.

A negative relationship between age and degree of biological change experienced (correlation of current and past species ranks) was found for all three datasets (Figure 1), indicating that older participants experienced greater biological change than younger participants in both countries (Spearman rank tests: Full UK - rho = -0.71, p-value < 0.001; Age-restricted UK - rho = -0.56, p-value < 0.001; Finland - rho = -0.88, p-value < 0.001).

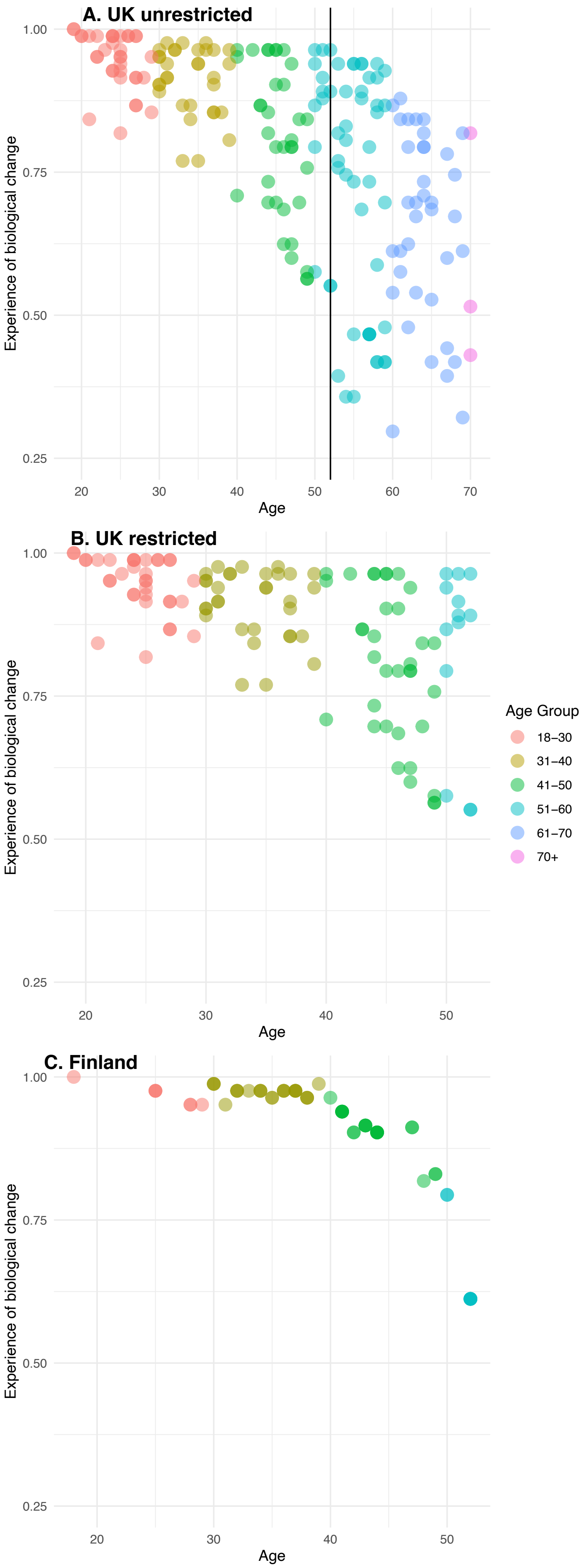

Figure 1. Participant age plotted against the correlation of biological abundance rank in the current and biological abundance rank at age 18 per participant across all species for **A.** the UK unrestricted dataset, **B.** the UK age-restricted dataset and **C.** Finland. Only participants living in the Southeast region of both countries in both the current and the past were included. The vertical line in Figure 1A represents the restricted data cut-off at 52 years old.

Exploring evidence for generational and personal amnesia

Model selection and model averaging results for the Southeast and non-Southeast samples in both the UK (age restricted sample) and Finland can be found in the supplementary materials (Tables S4 – S24). All results for the UK unrestricted sample can be found in Jones et al. (2020).

In both countries no significant relationship was found between age and current agreement between participant perceptions of species relative ranks and biological datasets (UK current - lm, 0.002 ± 0.004, z=0.423, p=0.673; Finland current - 0.009 ± 0.006, z=1.635, p=0.106 – Figure 2A), in line with the criteria required to identify evidence of generational amnesia. Instead, agreement between current participant perceptions and the biological data in the UK was explained by number of species recognised by each participant, with greater species recognition from photographs resulting in greater current rank agreement (lm, 0.086 ± 0.026, z=3.282, p<0.001). However, for Finland, none of the predictors significantly predicted current participant agreement with the biological data. Similarly, none of the predictors collected for this study significantly predicted agreement between participant perceptions at 18 and the biological data in either country, including age (UK past - lm, 0.007 ± 0.005, z=1.395, p=0.163, Finland past - lm, -0.011 ± 0.007, z=1.605, p=0.108).

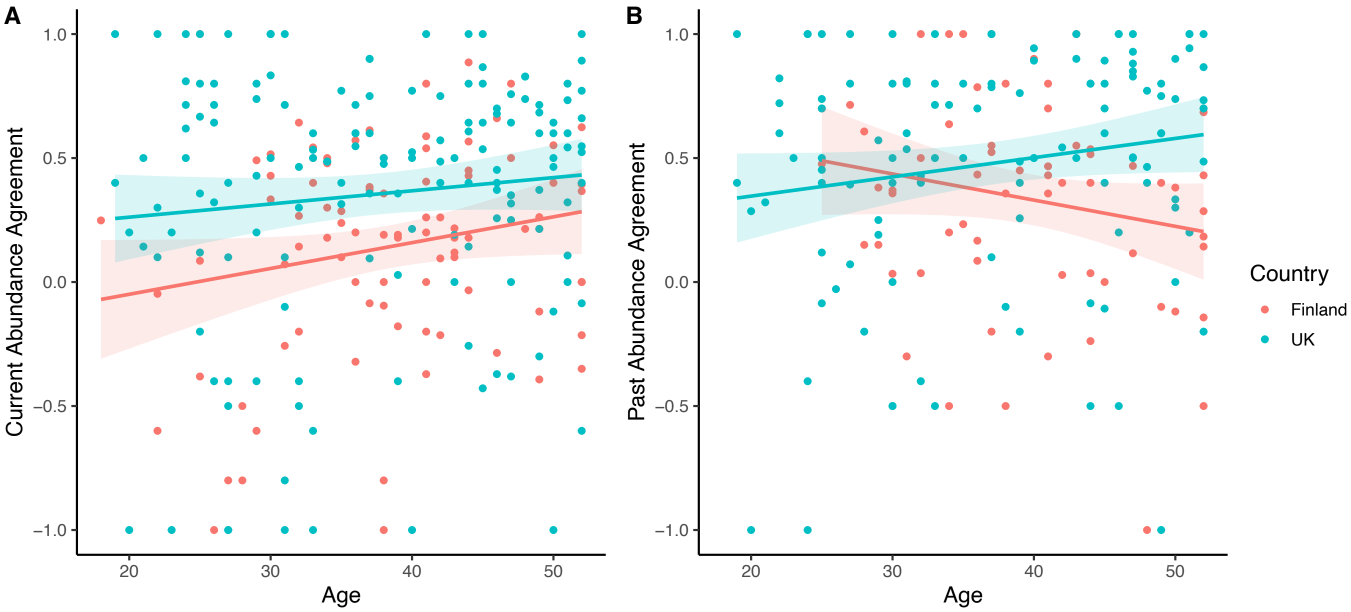

Figure 2. Agreement between participant perceptions of species relative ranks and biological datasets (**A**) in the present and (**B**) at age 18 age in both countries. The lower age range in Finland is reduced as the youngest participant was removed (age 18) due to a lack of experience of biological change.

Regarding perceived trend agreement scores, older participants in Finland showed greater agreement with biological data (Figure S4 - lm, 0.022 ± 0.009, z=2.49, $p<0.01$) as did participants that recognised a higher number of species from photographs (Figure S4 - lm, 0.214 ± 0.056, z=3.80, $p<0.001$). However, in the UK, none of the predictors collected for this study significantly predicted trend score agreement with the biological data.

Investigating evidence for personal amnesia

Evidence for personal amnesia was explored for those living in the Southeast region of Finland or the UK in both the past and current timepoints. Participants with a static perception of species abundance ranks were identified as ranking species in the same order of relative abundance at both age 18 and at the time of the questionnaire (Spearman's *rho* = 1). In Finland 19% of the Southeast Finland sample (12 of 63) showed a static perception, while in the UK, 20% of the original sample (23 of 115) had a static perception. We found no significant difference between countries in the mean of the correlation between perceptions of species rank (two sample t-test, t = -0.12, df = 128.81, p-value = 0.91). Participants who perceived no change in species rank were separated into two categories representing two cognitive biases: anchoring and the recency effect (Figure 3). In Finland, one participant (1.6% of the original sample) and 4 in the UK (3.5% of the original sample) showed signs of personal amnesia (recency effect) as their static perception of species ranks correlated perfectly with current biological data (Figure 3, rho = 1 for 'current agreement').

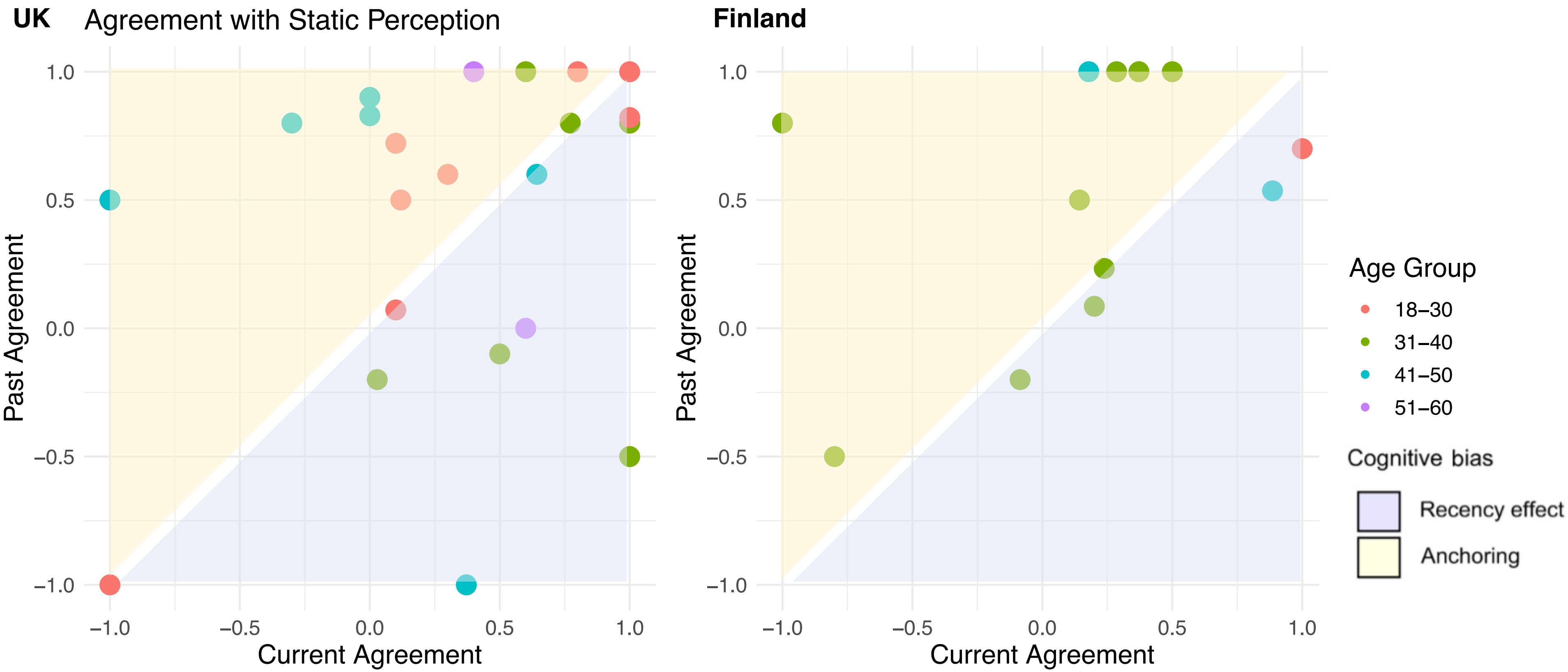

Figure 3. The extent to which participant perceptions agree with past and present relative bird abundance, for participants who perceived no change in species abundance ranks between age 18 and the present.

4.4. Discussion

In 2009, Papworth et al. proposed that two criteria were required to find evidence of the occurrence of SBS: biological change must be present in the system, and any differences in perceptions of change must be in line with biological data (Papworth et al., 2009). We examine and compare evidence of SBS in the UK and Finland according to these criteria, to provide the first investigation into possible variation in the incidence of SBS between countries. Initial comparison of predictor variables using two-sample t-tests revealed no significant differences between UK and Finnish participants in demographic, experience or knowledge predictors. Following confirmation that all participants had experience of biological change since age 18, regression modelling and averaging was used to predict the effect of multiple demographic and socio-cultural factors on agreement between perceptions and the biological data. We found no evidence of generational amnesia in either country as age was not a significant factor in predicting differences in perceptions of past ecological conditions. Evidence of personal amnesia was found to be twice as likely in UK than in Finland, characterised as an accurate perception of current conditions which are believed to have been the same in the past. However, incidence of personal amnesia was very low in both countries (<4% of the original sample), therefore, further research is needed to distinguish whether this is a personal or cultural phenomenon (Papworth et al., 2009). Comparison of these results to those gathered from the unrestricted UK sample (see Jones et al. 2020) reveals range restriction of participant age, combined with limited sample size, may provide a misrepresentation of the variation in perceptions of biological change occurring in a system, and therefore potentially bias evidence of SBS.

Contrary to our original hypotheses, no significant difference was found between the UK and Finland regarding almost all demographic predictors, or measures of birding interest and nature connectedness. Two sample t-tests revealed a significant difference between countries only in the mean number of species recognised by participants from photographs, with participants in Finland recognising on average 7% more species than participants in the UK. While this result may also be due to variation in the charisma or recognisability of the species chosen for this study, a similar result was found when comparing the UK and Finland for the three species included in both questionnaires, indicating that Finnish participants held greater knowledge of local bird species.

Participant experience of biological change was tested by correlating participant age against the correlation coefficient of past (when the participant was 18) and current biological species abundance ranks for the species covered in the questionnaire (10 non-control species per country). A similar proportion of participants in both countries (~2%) did not experience change and were removed from subsequent analyses. However, Figure 1 indicates that the Finland, unrestricted UK and restricted UK samples all show a similar negative trend, with older participants experiencing greater biological change than younger participants in both countries within the study period. Spearman correlations indicate a stronger negative correlation in Finland than either of the UK samples, however, this may the result of lower spatial resolution of the biological data in Finland. Furthermore, correlation analysis also highlights the possible effects of range restriction within the UK samples, as the restricted UK sample shows a weaker correlation than the unrestricted sample (Bobko, 2001).

As all participants have experience biological change, and older participants have experienced more biological change, the first criteria outlined by Papworth et al. (2009) is met and there is the potential for generational amnesia in both study systems. Evidence for generational amnesia was explored through the relationship between participant perceptions of biological change and age. In line with the criteria to find evidence of SBS, age had no significant effect on agreement between perceptions and the biological data in the present, in both the UK and Finland (Papworth et al., 2009). Instead, in the UK, agreement between participant perceptions and the biological data in the present was explained by number of species recognised by each participant, with greater species recognition from photographs resulting in greater current rank agreement. By contrast, as seen in Jones et al. (2020) the same analysis using the unrestricted UK dataset indicated a significant positive effect of higher species recognition on agreement, similar to the results for Finland. None of the predictors, including age, significantly predicted agreement between participant perceptions at age 18 and the biological data for either country. Therefore, participants of all ages were equally accurate in their ranking of bird species by abundance when they were 18. We therefore find little evidence to suggest that generational amnesia is occurring in these samples as there are no significant age-related differences in perceptions of past ecological conditions (Papworth et al., 2009).

These findings contrast with those found by Jones et al. (2020), using the unrestricted UK sample, in which empirical evidence of generational amnesia was indicated. Therefore, in this study, the lack of evidence of generational amnesia in both the UK and Finland could be due to range restriction and Type II error caused by a combination of limited sample size and restriction in the range of participant age, potentially masking the significance of the relationship between age and past abundance agreement. Especially in the case of generational amnesia, even small restrictions range of years of age or experience within a sample may result in the sampling of fewer generations over which to compare perceptions of change (Papworth et al., 2009). Meanwhile, in Finland, lack of evidence of generational amnesia could be caused by limited data granularity in Finland as data was only available at the regional scale, rather than by local area or county, as in England. Further research investigating evidence of SBS in Finland, and in other countries with high connectedness with nature, (see Beery (2013) and Braun and Dierkes (2016)), ideally with higher resolution biological data and a larger sample size, is therefore especially relevant to further understand the impacts of culture, education and language on evidence of SBS.

By contrast, our results suggest that personal amnesia may be present in both the UK and Finland, although at very low levels. Interestingly, the likelihood of participants reporting a static perception of ecological change between age 18 and the time of the questionnaire across all species was similar in the UK and Finland (approximately 20%). However, of those that perceived static biological conditions, participants in the UK were approximately twice as likely to show evidence of personal amnesia than in Finland (1.6% of the original sample in Finland and 3.5% of the original sample in the UK). This may indicate that people in the UK are comparatively more likely to focus on current conditions, and less likely to recall or remember the past. However, similar to the conclusions made by Jones et al. (2020), these results indicate that the prevalence of personal amnesia is very low. Further research, across multiple regions and cultures, preferably with very large sample sizes may would help to conclusively quantify the prevalence of personal amnesia and optimal suggest combat methods, such as education and communication about the past using multiple media types (McClenachan, 2009; Chen et al., 2011; Jones et al., 2020).

However, according to Guerrero-Gatica et al. 2019, only 5% of previous SBS studies (8 publications) find empirical evidence of SBS using both social and biological datasets (paired data methods). Adding two additional studies to this list (Fernández-Llamazares et al., 2015; Jones et al., 2020), a total of 10 studies show evidence of SBS, however not all studies adhere to the widely accepted criteria developed by Papworth et al. (2009) (see Soga and Gaston, 2018; Guerrero-Gatica et al. 2019). We argue that only four studies show empirical evidence for the phenomena (Papworth et al. 2009, Turvey et al. 2010, Fernandez-

Llamazares et al. 2015 and Jones et al. 2020). Of these studies, the sample sizes vary significantly, from 50 participants (Papworth et al. 2009), up to nearly 600 (Turvey et al. 2010), however all studies include participants across a wide age range. Especially when compared to the age ranges seen in previous studies, a key limitation in this study was the need to restrict the range of both the UK and Finland samples to a maximum age of 52, to match the available range of biological data in Finland. Range restriction is a known statistical issue, often discussed in psychological research, in which the observed sample data do not represent the full data range of interest, weakening statistical relationships due to limited variation in the dataset (Bobko, 2001; Miciak et al., 2016). Compared to significant evidence for SBS found by Jones et al., (2020), using the unrestricted UK sample our results may highlight the negative effects of range restriction and limited sample size on study power, limiting our ability to identify significant evidence of SBS. Statistical modelling and power analysis is needed to compare model fit and effect size between the restricted and unrestricted datasets, to understand the impacts of limited sample size and range restriction on study conclusions. For discussion of other methodological limitations, see Jones et al. (2020).

Investigation into the effects of socio-psychological influences on perceptions of ecological change, including shifting baseline syndrome, change blindness and other cognitive biases, is key, to understand the factors driving agreement between local perceptions and biological datasets (Soga and Gaston, 2018). Factoring in known patterns in agreement and potential biases into our interpretations of LEK is important, not only to ensure that conservation managers and practitioners base decisions on data that effectively represent ecological conditions, but to ensure that the interpretation of LEK is representative of local thoughts and perceptions (Aswani et al., 2018). Although our study indicates that both the UK and Finland do not show evidence of generational amnesia, by comparison with previous studies (Jones et al. 2020), we highlight the potential impacts of range restriction and limited sample size on the validity of our study conclusions.

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5. Data range restriction impacts conservation research conclusions

Short title: Data range restriction in conservation

Keywords: conservation methods, local ecological knowledge, power, publication bias, range restriction, sample size, shifting baseline syndrome, social science, Type II error

Abstract

We explore the implications of range restriction and limited sample size on data interpretation and statistical power using correlative and linear modelling techniques within multiple biological and social-science case studies. Range restriction occurs when the observed sample data do not represent the full data range of interest, weakening statistical relationships due to limited variation in the dataset. This represents a major hidden issue in conservation, limiting statistical conclusions and leading to publication bias through Type II error. Non-linearity and heteroscedasticity limited the utility of correlation correction formulas for both social-science and ecological datasets examined in this study. Range-restricted social-science datasets demanded sample size increases of up to 45% to achieve power equivalent to an unrestricted dataset but power was falsely inflated with small sample sizes. Our results provide a cautionary tale for future conservation studies, and we advise the prevention of range restriction by minimising barriers to data collection and maximising sample breadth.

Introduction

The scope and effectiveness of conservation decision-making is often limited by data availability, especially for species and systems of conservation concern, with nearly one in six species assessed as Data Deficient on the IUCN Red List (Tulloch et al., 2018). The effectiveness of standard field techniques can be limited by a lack of economic resources, time limits, insufficient planning or training and unpredictable environmental conditions, resulting in a lack of robust biological data. These issues are often exacerbated with species of very low abundance or density, for which standard monitoring methods often do not exist or produce limited data due to low levels of detectability, preventing the collection of a fully representative sample of the study population (Anadón et al., 2009).

Range restriction occurs when observed sample data do not represent the full range of variability in a population of interest, meaning that statistical relationships are weakened due to limited variation in the dataset as the tails of the distribution are underrepresented (Ghiselli et al., 1981; Bobko, 2001; Schmidt and Hunter, 2015). For example, range restriction in bivariate correlative analysis can weaken or artificially strengthen correlation coefficients, reducing estimated correlation values and increasing between-study variability (Figure 1; Bland and Altman, 2011; Nie and Haitao Chu, 2011). When potential range restriction is unaccounted for, reduced sample size can also limit statistical power, leading to Type II errors (Miciak et al., 2016). Range restriction can therefore mask the simpler underlying reality of the data, leading researchers to ‘overanalyse’ seemingly complex relationships using surface-level analysis, overlook scientific parsimony, and draw false conclusions (Schmidt, 2010).

Range restriction can occur by one of two mechanisms. Indirect range restriction occurs when data or participant selection is based on an uncontrolled secondary measure (e.g., a study on perceived impacts of climate change in Nagchu Prefecture, Tibet was restricted to male participants as female respondents reportedly felt unable to participate; Klein et al., 2014). Direct range restriction occurs through direct analytical truncation, such as restriction to identify a specific pattern or hypothesis (e.g., Brito et al. (2017) presented an age-related difference in medicinal plant knowledge, but a significant relationship was only found when restricting the upper age limit to 50 years old).

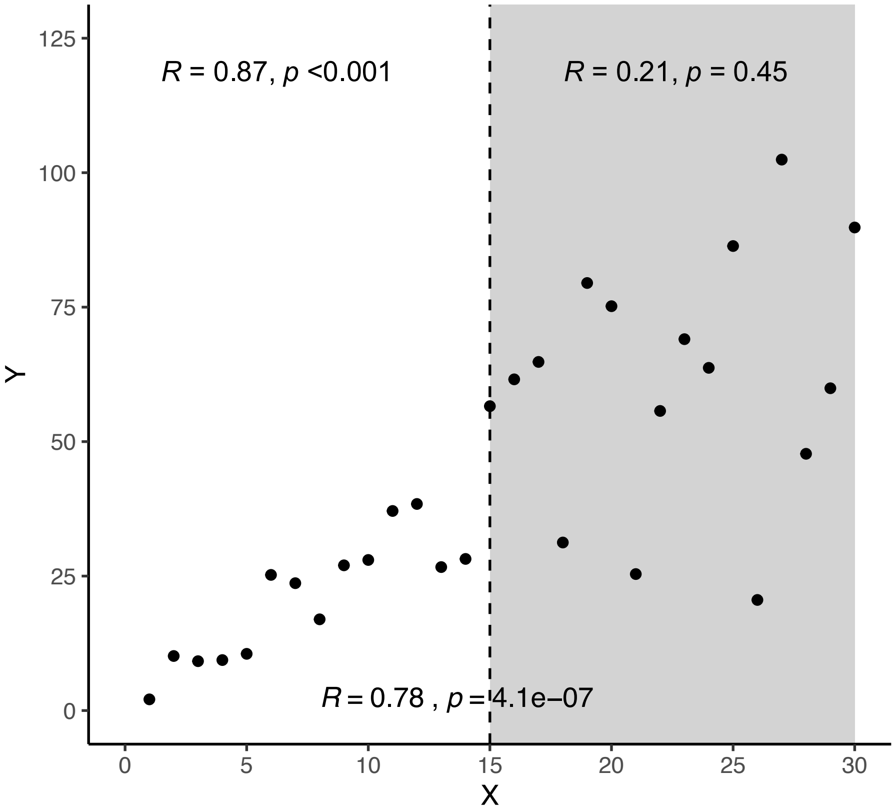

Figure 1. Example of impact of range restriction on Pearson's correlation coefficient between two hypothetical variables, X and Y, following Bobko (2001). The correlation between X and Y in this population is 0.78. Restricting to the lower half of the range (x-axis) gives a rho value more similar to the unrestricted value (r =0.87), while restriction to the upper half of the range reduces the r value to 0.21.

Range restriction is a well-known statistical problem, investigated extensively in the fields of psychology and psychometrics (e.g., Schmidt et al., 1976; Sackett and Yang, 2000; Bobko, 2001; Le and Schmidt, 2006) potentially impacting any sampling dataset, yet there has been little discussion of its potential implications in the conservation literature. The potential for range restriction is especially high for social science studies due to multiple potential barriers while sampling. Social science methods and data such as local ecological knowledge (LEK) are increasingly recognised as a valuable alternative to standard field techniques for the estimation of biological and anthropogenic parameters required to inform evidence-based policy and practice (CBD, 2011; Nash et al., 2016; Cross et al., 2017). LEK describes personal, experience-based knowledge gathered over time in a relationship with local natural environments (Newing, 2010; Aswani et al., 2018). LEK can be relatively inexpensive to collect over large spatial scales (Anadón et al., 2009), span multiple generations of knowledge (Turvey et al., 2010), and reveal information and perceptions beyond the scope of traditional scientific observations and otherwise unknown to the scientific community (Martinez-Levasseur et al., 2017). However, numerous direct and indirect barriers can hinder systematic data collection using social science methods, potentially limiting data range and sample size. For example, epistemological, value-based, and cultural differences (e.g., St John et al., 2019), and language barriers, can represent direct obstacles to data collection, especially in older participants (Nash et al., 2016; Barnes et al., 2019). Conversely, self-selection of participants and post-hoc selection criteria (e.g., pre-determined score thresholds for inclusion in analysis) can indirectly restrict data usage. Therefore, while in many cases social science methods may hold the statistical power to provide high-quality longitudinal data, practical considerations can limit sampling which may lead to data range restriction, low power, and unpublished results (Haddaway, 2015; Hickisch et al., 2019).

The lack of range restriction research in conservation, especially for studies grounded in social science, remains a significant research gap, given the recent rapid increase in studies using LEK as a key data source in conservation (Aswani et al., 2018). We use paired or 'matched' data methods to address this research gap, exploring the effects of range restriction on evidence for shifting baseline syndrome (SBS) in the UK and Finland. As a psychological phenomenon occurring over multigenerational timescales (Pauly, 1995; Papworth et al., 2009), evidence of biological change is required over a wide age range to demonstrate SBS. We have already established evidence for biological change and associated SBS across a multi-decadal population trend dataset of garden bird species in the UK (Jones et al., 2020). However, the temporal range of comparable garden bird population trend data is more restricted for Finland, leading to concerns that range restriction could impact study conclusions.

Awareness of the issues posed by range restriction in other fields, especially concerning the magnitude of relationships, has led to the development multiple formulas to correct data-based estimates of the magnitude of correlation coefficients. In this study, we investigate the effects of direct range restriction (and consequential reduced sample size) on estimated correlation coefficients in the UK and Finland using paired social and biological datasets. We investigate the effectiveness of range restriction correction techniques in this context using Thorndike's case II correction formula (Thorndike, 1949; Wiberg and Sundström, 2009), and discuss our results in the context of multiple fields of conservation research. As range restriction is inherently tied to a reduction in sample size, the combined implications of both issues for inferred statistical power are explored using comparative linear regression modelling. We use our findings to discuss possible wider impacts of range restriction on the validity of research conclusions, with the goal of providing guidance to researchers and policymakers when using biological and social science datasets in conservation research.

Methods

Biological data preparation

Biological data were available for paired data analysis in the form of annual abundance indices and population trends for 10 garden bird species in both the UK and Finland. Annual population indices were calculated for 1966 to 2017 from the combined BTO-JNCC Common Bird Census (CBC) and Breeding Bird Surveys (BBS) datasets in the UK (Harris et al., 2018) and from 1984 to 2018 for southeast Finland using the common bird monitoring annual datasets (see Supplementary section S1 for more details on data collection and S2 for full species lists).

In both countries, species were selected to encompass the full range of abundance and trends, ranging from abundant and increasing, to rare and declining. As ‘garden bird’ species, all are regularly seen passively in domestic gardens and urban or suburban areas and include a selection of relative abundances and trends, to control for dominant accounts of decline in many European bird species (Newton, 2004; Woodward et al., 2018). The species also vary according to several perceived and life history co-variates such as body mass, detectability, charisma, longevity, and migration status.

Participant data collection

Participant data were collected using an online questionnaire conducted using the Qualtrics platform (version XM 2018) from 16 July to 9 September 2018 in the UK and from 15th September to 9 December 2018 and 17 July to 2 September 2019 in Finland. The Finnish questionnaire was directly translated from the UK questionnaire to create an analogous final dataset and was checked by two trusted proof-readers (see Supplementary section sS3 & 4 for full UK and Finnish questionnaires). Ethical approval was granted by Royal Holloway, University of London prior to piloting and data collection. Participants were acquired with non-random sampling methods (see Jones et al., 2020), reflecting the original study aim to investigate differences in perceptions of biological change, which required a large participant sample size. Only participants from the same geographical range as the biological dataset were included in subsequent paired-data analyses.

Following a declaration of informed consent, participants were asked a series of demographic questions regarding age, gender, current and past (at age 18) location at the level of county (UK) or region (Finland, i.e., southeast versus non-southeast Finland), and length of residency in each location. Participants were also asked a series of questions designed to assess personal perceptions of biological change (see Jones et al. (2020) for more details). Details of sample size and participant demographics are provided in Table S1.

Pairing biological and social data

Annual abundance and population trend per species per county (or region in Finland) were calculated using the rTRIM package (Pannekoek & van Strien, 2005). For each participant, biological data were subset to include only the local county or region and the year range from the year the participant was 18 years old to 2017, to create a paired biological and social dataset.

In the UK, biological data and participant perceptions were matched spatially at the county-scale and temporally from the year the participant was 18 years old to 2018, creating an analogous paired biological and social dataset spanning 52 years. As the earliest available biological data in Finland for all species were from 1984, temporal matching of biological and social data was not possible for participants who turned 18 before 1984, restricting maximum participant age to 52 and the paired dataset to a range of 34 years (Table 1). A comparative restricted UK dataset was generated by removing participants from the unrestricted UK dataset who were 18 before 1984, which represents 65.4% of the unrestricted range.

The following analyses were conducted separately in the UK and Finland. To calculate a measure of biological change, the full set of 10 bird species were ranked in order of biological abundance in the year of the survey and the year each participant was 18 years old, creating an abundance rank per participant. Spearman's correlation coefficient (*rho*) was then calculated between the relative biological rank abundance across all species when participants were 18 (past) and at the time of the survey (current). The impacts of range restriction and sample size reduction were investigated for the UK by comparing range-restricted and unrestricted UK datasets.

Statistical analyses

Thorndike's Correlation Correction

All data manipulation and statistical analyses were conducted using R software version 3.6.2 and all plots are made using the 'ggplot2' package (R Core Team, 2019).

To explore the practicality of correlation correction methods, Spearman rank correlation coefficients were used to investigate the strength of the relationship between participant age and experienced biological change. Range correction was conducted using Thorndike's case 2 formula (psych package; Revelle, 2020). Correction requires an analogous unrestricted sample, as the restricted correlation value and standard deviations (*SD*) of restricted and unrestricted samples are used to estimate the corrected correlation (Supplementary S5). There are therefore two key assumptions: a similar, linear distribution in each sample, and homoscedasticity in both samples (Holmes, 1990). Smaller sample sizes can also reduce the accuracy of Thorndike's correction (Bobko, 2001).

Regression analyses

As the assumptions for correlation correction methods were violated, multiple regression models were used to summarise differences in the relationship between variables for each dataset. One-inflated beta regression models (gamlss package; Rigby and Stasinopoulos, 2005) were fitted to each dataset, as beta distributions are most appropriate when the response variable is restricted within a 0-1 range including endpoints. For comparison, additional linear, quadratic, and exponential models were fitted per dataset, with three variance structures of generalised least square (GLS) models to account for heterogeneity: fixed, exponential, power and constant plus power of the variance. GLS structures were chosen as the top three for all datasets using AIC values.

Models were compared using a combination of Akaike weights, AIC, R^2 and 95% confidence limits to determine the model of best fit (Table 2, Figure 2). Akaike weights provide the relative merits of each model, calculated as the relative probability for each model to be the top or best model in each set based on AIC values, i.e., the model in each set with the smallest Kullback–Leibler distance (Wagenmakers and Farrell, 2004). For GLS and beta regression models, a pseudo-R^2 measure was calculated based on methods in Nakagawa and Schielzeth (2013). The linear model served as a linear baseline against which to compare other models. Power analysis was used to investigate the combined effect of range restriction and reduced sample size on inferred sample size for future research on the same system using the ‘pwr’ package (Champely et al., 2018). The inferred sample size for age to be a significant predictor of biological change was calculated using the optimal model at the 80% statistical power threshold (Miciak et al., 2016). The impact of range restriction on expected power was simulated for different sample sizes, producing predictive power curves for each dataset.

Results

Thorndike’s Correlation Correction

For both the UK and Finland restricted datasets, the application of Thorndike’s Case 2 restriction correction on the restricted Spearman rank correlation value failed to correct the restricted correlation coefficient in line the UK unrestricted correlation coefficient (Table 1).

Table 1. Correlation values for unrestricted and restricted samples of each dataset and results of Breusch-Pagan tests for heteroscedasticity.

Dataset	**Years of data**	**Unrestricted**		**Restricted**		**Corrected**	**Breusch-Pagan test**	
		rho	**SD**	***rho***	**SD**	***rho***	**BP value**	**P-value**
UK Unrestricted	52	-0.71	14.56	▨	▨	▨	43.67	p<0.01
UK Restricted	34	▨	▨	-0.56	10.10	-0.70	37.61	p<0.01
Finland	34	▨	▨	-0.89	7.97	-0.96	9.60	p<0.01

Comparison of correlation coefficients of participant age against biological change for unrestricted UK, restricted UK and Finland datasets indicates a similar negative trend for all three datasets, with older people experiencing more biological change than younger people in both countries (Figure 2). The range-restricted UK dataset represents the only successful application of restriction correction, as the UK restricted dataset shows a very similar corrected correlation to the unrestricted UK dataset’s correlation coefficient. Conversely, for the Finland dataset, the correct value diverges further from the unrestricted UK correlation, rather than correcting towards it.

Also, all datasets violate assumptions of linearity and homoscedasticity (Breusch-Pagan test for heteroscedasticity of $p<0.05$), suggesting that these data are not suitable for range correction.

Regression analyses

Differences in model fit for linear, quadratic, exponential and GLS models were compared between the three datasets (Table 2). The unrestricted UK and range-restricted UK datasets share the same optimal model (one-inflated beta regression), while a quadratic model with constant plus power of the variance covariates best-fits the Finland dataset (using AIC). Comparing between datasets, the unrestricted and restricted UK datasets had non-overlapping confidence intervals for 43.8% of models (Table 2), indicating a statistically significant difference between means and distribution of data at p=0.05. For the Finland dataset, non-overlapping CIs were found for 18.8% and 12.5% of models for the unrestricted and age-restricted UK datasets, respectively. For all models, the Finland dataset achieves significantly higher R^2 values compared to the UK datasets, likely due to smaller sample size and lower spatial scale of biological data overinflating the R^2 value and reducing the distribution of the residuals. While the oldest participant in Finland appears to disproportionately influence model fit, this participant is not statistically an outlier (Grubb's test: G = 2.75, U = 0.88, p-value = 0.14)

Table 2. Comparison of model fit for linear, quadratic and exponential models and three variance structures of generalised least square (GLS) models (fixed variance, exponential of the variance, power of the variance, and constant plus power of the variance covariates) and a one-inflated beta regression using R^2 (or pseudo R^2 for GLS), AIC, residual standard error, intercept estimates, and 95% confidence intervals for unrestricted and restricted UK datasets and Finland dataset. Optimal model for each dataset highlighted in dark green; best model per model category highlighted in light green.
Column abbreviations: AIC_i = Akaike Information Criterion; w_i(AIC) = rounded Akaike weights; CI = confidence intervals; Est. = estimate; Res.SE = standard error of residuals.

Model	**UK unrestricted**							**UK restricted**							**Finland**						
	Est.	**CI**		**R^2**	**AIC_i**	**w_i(AIC)**	**Res. SE**	**Est.**	**CI**		**R^2**	**AIC_i**	**w_i(AIC)**	**Res. SE**	**Est.**	**CI**		**R^2**	**AIC_i**	**w_i(AIC)**	**Res. SE**
		2.5%	**97.5%**						**2.5%**	**97.5%**						**2.5%**	**97.5%**				
One-inflated beta regression	**3.62**	**3.17**	**4.08**	**0.42**	**-276.63**	**0.99**	**0.23**	**3.74**	**3.15**	**4.32**	**0.27**	**-256.69**	**0.99**	**0.29**	**9.02**	**8.19**	**9.84**	**0.82**	**-256.29**	**0.00**	**0.42**
Linear model	**1.20**	**1.12**	**1.27**	**0.41**	**- 170.46**	**0.00**	**0.16**	**1.05**	**1.05**	**1.18**	**0.31**	**-207.65**	**0.00**	**0.10**	**1.31**	**1.23**	**1.40**	**0.59**	**-153.63**	**0.00**	**0.07**
GLS Fixed	1.17	1.12	1.23	0.41	-194.40	0.00	0.02	1.11	1.05	1.16	0.31	-211.68	0.00	0.01	1.24	1.17	1.32	0.59	-140.53	0.00	0.01
GLS Exp.	1.13	1.10	1.17	0.41	-248.45	0.00	0.02	1.09	1.05	1.13	0.31	-238.20	0.00	<0.01	1.04	1.03	1.06	0.59	-205.11	0.00	<0.01
GLS Power	1.13	1.10	1.16	0.41	-248.94	0.00	<0.01	1.09	1.05	1.13	0.31	-235.32	0.00	<0.01	1.05	1.04	1.06	0.59	-196.19	0.00	<0.01
GLS ConstPower	1.13	1.10	1.16	0.41	-248.41	0.00	<0.01	1.09	1.04	1.13	0.31	-237.80	0.00	<0.01	1.05	1.04	1.06	0.59	-194.19	0.00	<0.01
Quadratic lm	**0.78**	**0.76**	**0.80**	**0.43**	**- 173.80**	**0.00**	**0.16**	**0.88**	**0.86**	**0.90**	**0.32**	**-206.63**	**0.00**	**0.10**	**0.91**	**0.90**	**0.92**	**0.86**	**-220.61**	**0.00**	**0.04**
GLS Fixed	0.77	0.76	0.80	0.43	-207.77	0.00	0.01	0.88	0.86	0.90	0.32	-217.02	0.00	0.01	0.91	0.90	0.92	0.86	-203.37	**0.00**	<0.01
GLS Exp.	0.78	0.76	0.80	0.43	-263.02	0.00	0.02	0.88	0.86	0.90	0.32	-242.88	0.00	0.01	0.92	0.91	0.93	0.79	-209.87	**0.00**	<0.01
GLS Power	0.80	0.76	0.80	0.43	-263.04	0.00	<0.01	0.88	0.86	0.90	0.32	-239.75	0.00	<0.01	0.91	0.90	0.92	0.85	-201.40	**0.00**	<0.01
GLS ConstPower	0.80	0.76	0.80	0.43	-263.09	0.00	<0.01	0.88	0.86	0.90	0.32	-242.84	0.00	<0.01	0.93	0.92	0.94	0.84	-268.78	1.00	<0.01
Exponential lm	**2.12**	**1.88**	**2.36**	**0.38**	**- 159.62**	**0.00**	**0.16**	**1.65**	**1.43**	**1.87**	**0.30**	**-205.33**	**0.00**	**0.10**	**2.15**	**1.82**	**2.48**	**0.48**	**-138.55**	**0.00**	**0.08**
GLS Fixed	1.98	1.80	2.17	0.38	-190.25	0.00	0.02	1.60	1.42	1.79	0.30	-217.63	0.00	0.01	1.87	1.59	2.14	0.48	-135.42	0.00	<0.01
GLS Exp.	1.71	1.58	1.84	0.38	-241.95	0.00	0.02	1.50	1.35	1.65	0.30	-244.12	0.00	0.01	1.18	1.14	1.22	0.48	-212.47	0.00	<0.01
GLS Power	1.72	1.60	1.85	0.38	-240.90	0.00	<0.01	1.51	1.37	1.66	0.30	-241.27	0.00	<0.01	1.19	1.16	1.22	0.48	-203.67	0.00	<0.01
GLS ConstPower	1.72	1.59	1.85	0.38	-241.24	0.00	<0.01	1.49	1.37	1.66	0.30	-243.76	0.00	<0.01	1.19	1.16	1.22	0.48	-201.67	0.00	<0.01

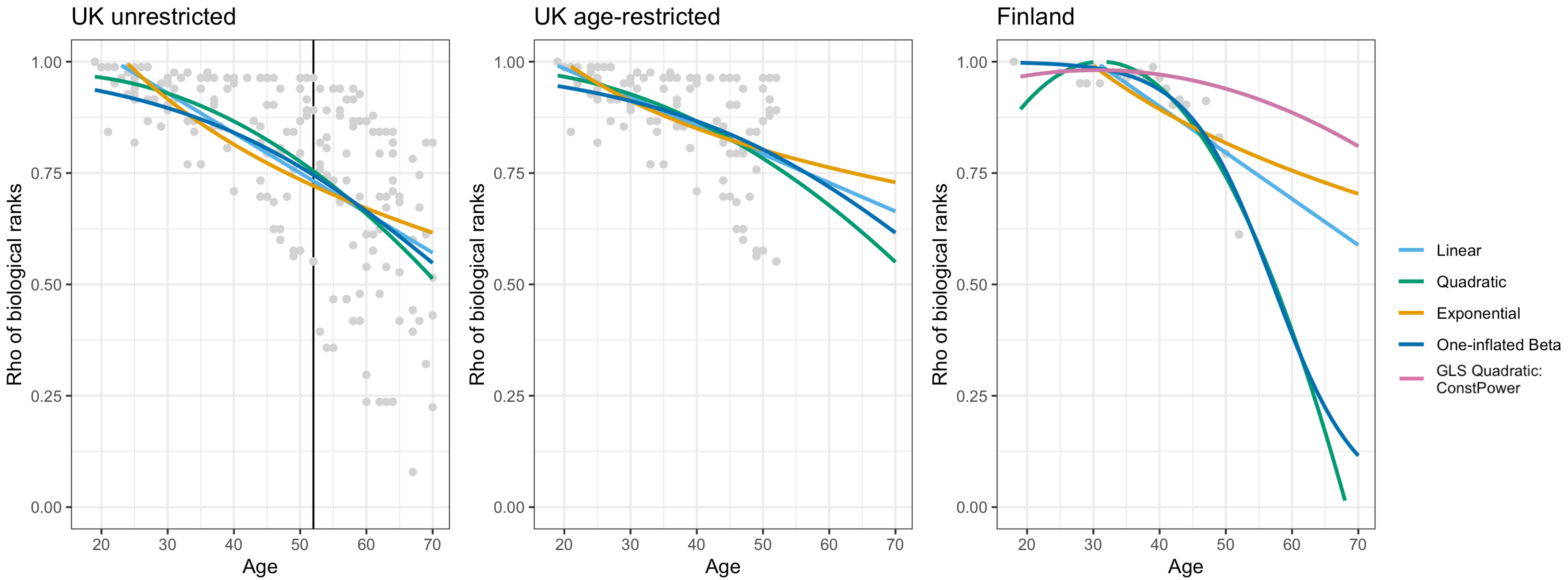

Figure 2. Comparison of model fit for one-inflated beta regression, the linear, quadratic and exponential regression models and optimal model (if not already listed) for participant age against experience of biological change for each dataset.

Implications of range restriction for calculations of statistical power

Statistical power analysis was used to investigate the effect of range restriction on statistical power by using the optimal regression models identified in Table 2 to calculate the suggested sample size for age to be a significant predictor of experience of biological change in a follow up study. The unrestricted UK dataset suggested lower sample sizes than the restricted UK dataset using both correlative and regression techniques, demonstrating the negative impact of range restriction on model statistical power. The opposite effect was seen in the Finland dataset, as lower sample size was needed for correlative analysis, and it was not possible to estimate sample size for this dataset due to a high effect size (Table 3).

Table 3. Sample sizes required for age to be a significant predictor of biological change for each dataset at a power of 0.80 and 95% significance threshold, and percentage increase in sample size needed in comparison to the unrestricted dataset. Abbreviations: Cor. = correlation; f2 = Cohen's f2 measure of effect size.

Model type	**Sample**	**Cor (r)**	**f2**	**N**	**% increase**
Correlation	Unrestricted UK	-0.71	▨	12	0
	Restricted UK	-0.56	▨	22	+ 45.5%
	Finland	-0.89	▨	7	- 41.7%
Optimal linear model	Unrestricted UK	▨	0.74	13	0
	Restricted UK	▨	0.47	19	+ 37.5%
	Finland	▨	5.29	NA	NA

The effect of range restriction on study power was modelled along a gradient of increasing sample size to test for an optimal scenario using the optimal model for each dataset. Statistical power is lower for the restricted UK model compared to the unrestricted UK model, up to approximately n=55 (Table S2). However, at all sample sizes the Finland models require lower sample sizes than the unrestricted UK model (Figure 3).

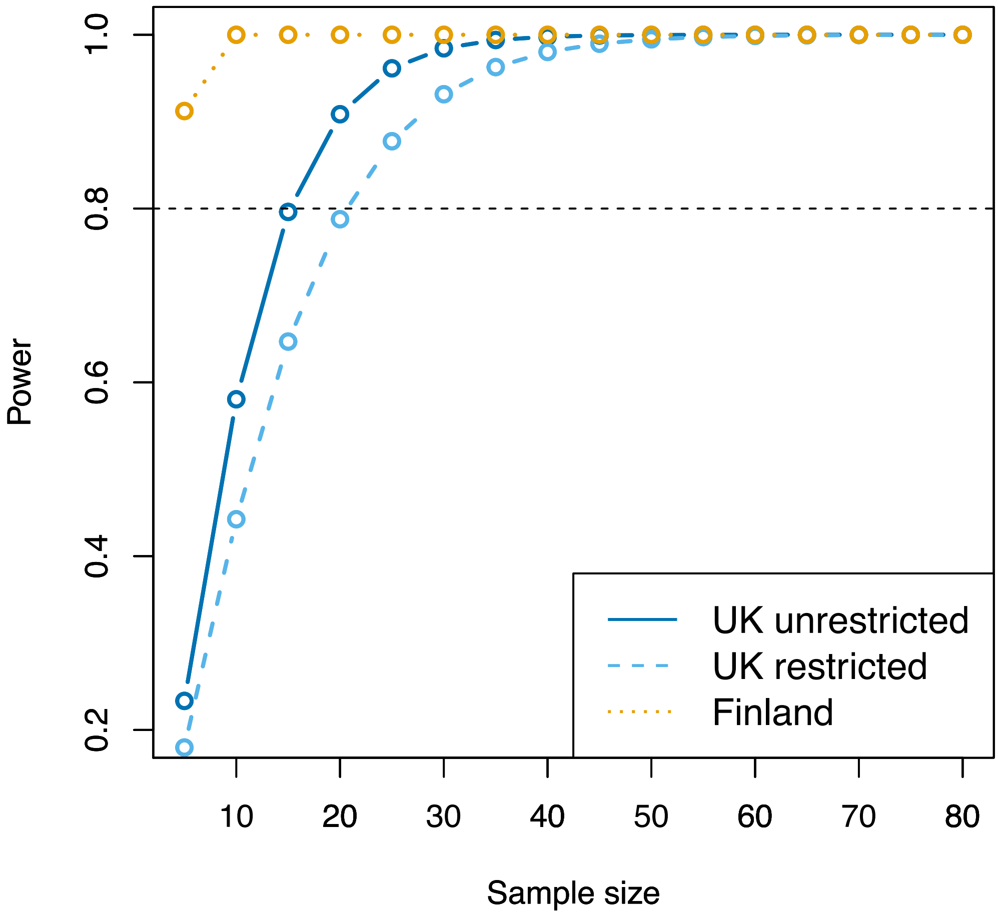

Figure 3. Plot of inferred statistical power to detect a significant relationship between age and experience of biological change at alpha = 0.05 along a gradient of increasing sample size. The optimal model for each dataset was used (Table 2).

Discussion

Investigation into the effects of direct range restriction and limited sample size on study inferences in conservation research was conducted a case study of social science data collected in the UK and Finland. Correlative and regression modelling techniques were then used to assess the relationship between age and experience of biological change in the UK and Finland.

Correlation analyses indicated that for all datasets, range restriction did not change overall directionality of the relationships in the data. For only the range-restricted UK dataset, the application of Thorndike's Case 2 restriction correction was appropriate due to normality and homoscedasticity and but still did not effectively correct the restricted correlation coefficient. This indicates that although the method is well cited and often worth testing before exploring regression-based techniques (Wiberg and Sundström, 2009), correlation correction techniques may be inappropriate for some ecological or social science datasets. This limits the available options to control the effects of range restriction using correlative analysis (Bobko, 2001). Furthermore, our results suggested a sample size increase of 45.5% for the age-restricted UK dataset to obtain the same statistical power as the unrestricted UK dataset, demonstrating the impacts of range restriction.

Regression-based modelling presented differences between samples in the strength and direction of relationships in the data, using a beta regression model and three linear models with multiple variance structures. The beta regression was the optimal model for both the unrestricted UK and restricted UK datasets, and both shared a similar steepening negative relationship between age and experience of biological change. However, the optimal model for the Finland dataset predicted a more pronounced curve with higher predicted values at all ages. Lower R^2 values were also estimated for the restricted UK dataset for all models compared to the unrestricted UK dataset, demonstrating the potential for range restriction through sample size to impact conclusions about model fit. Using regression modelling, the potential for range restriction to impact inferences is also demonstrated by a 37.5% increase in sample size inferred for the range restricted UK dataset to achieve a statistical power of 0.8 using optimal models, compared to the unrestricted UK dataset. Such an increase may jeopardise a study if range restriction is unaccounted for in *a priori* analyses of statistical power, potentially increasing Type II error and publication bias if studies are wrongly discounted, or possibly even preventing studies from even taking place if initial, range restricted pilot data suggest logistically infeasible sample sizes are required.

However, opposing results were found for the Finland dataset in both correlation analysis and linear models, with far lower sample sizes needed to reach adequate statistical power. This result is suggestive of a stronger negative relationship between age and experience of biological change than the UK datasets (Table 1), and that range restriction can prevent a reliable inference using correlative techniques. However, the combined effects of range restriction, reduced sample size and lower-resolution spatial data in the Finland dataset might have introduced bias through model overfitting, as shown by the tight fit of residuals to the line of best fit. In this case, limited sample size prevents a reliable conclusion being drawn, highlighting the risk posed by unaccounted-for range restriction and the limitations of frequentist power analysis methods (Figure 2). This may point to the need for wider exploration into the use of Bayesian regression alternatives and probabilistic power estimation methods. However, these methods are not yet widely used or taught in social science, ecology or conservation, and so our study focusses on the use and limitations of more traditional frequentist methods (Baker and Hirudayaraj, 2019).

Comparable examples of range restriction can be found in other studies of SBS, such as Kai et al. (2014), which excluded participants above 60 years old over concerns that mental and physical ill-health could negatively bias results. If inclusion of older participants significantly strengthens or weakens evidence for SBS, this may have significant implications for study conclusions. Likewise, many ecological datasets used to understand both biological states and human impacts document relatively short periods compared to species and landscape relevant timescales for conservation (Soga and Gaston, 2018), and this range restriction could have similar implications for study conclusions. In our study, range restriction and overfitting suggest the introduction of Type II error in terms of overestimation of the relationship between age and experience of biological change. The perception of more rapid biological change seen in our results could therefore lead to southeast Finland being incorrectly prioritised as of higher conservation concern, potentially misallocating time and resources on the ground or at the policy-level (Bissonette, 1999).

Our research illustrates the susceptibility of conservation studies to range restriction and outlines the potential negative impacts of range restriction and limited sample size on the validity of conservation research conclusions. If fundamental data relationships are hidden by range restriction, and the conclusions that researchers construct do not conform to their original hypotheses, they may use inappropriate statistics to tease out significant relationships (Schmidt, 2010) or wrongly dismiss and not publish their studies (Miciak et al., 2016), potentially increasing the publication bias already known to negatively influence conservation decision-making (Hickisch et al., 2019). This is particularly significant for species and systems of conservation concern, as such studies are more likely to experience indirect range restriction due to limited data availability. For example, calls have been made to remove the IUCN Red List's Data Deficient category and assume a higher level of threat to ensure adequate consideration and funding from policymakers (Parsons, 2016). Furthermore, outside academic research, knowledge of range restriction is important more widely across conservation, from grant writing to policymaking, to ensure that potentially critical but understudied species and systems are appropriately recognised and prioritised (McKinney, 1999).

A key solution to preventing range restriction lies in thorough experimental planning. With any conservation study using social or biological data, a well-considered experimental design stage can help to identify the largest and most diverse possible sample, and thus allow the most appropriate statistical investigation (Bissonette, 1999). For example, when collecting LEK as a primary data source, sampling should aim to include a diverse range of participants and minimise potential barriers to data collection such as cultural and age restrictions, as well as technological, geographical and language barriers (Newing, 2010; Mistry and Berardi, 2012; Aswani et al., 2018). Additional solutions depend on the analytical methods used, for example, in ecological datasets, researcher could ensure as wide a temporal and geographical range is sampled. When using correlation analyses, Thorndike's correction provides a potential solution to range restriction (Thorndike, 1949; Bobko and Rieck, 2016). However, as in this study, ecological and social science data are often non-normal, heteroscedastic, and non-linear, and therefore violate the assumptions of such range correction techniques. Expectation Maximisation (EM) algorithms provide an alternative approach, calculating maximum likelihood estimates for missing data using iterative unsupervised clustering methods based on range-restricted datasets (Wiberg and Sundström, 2009). Previous studies have found both correction methods equally accurate for direct range restriction when data meet the assumptions of Thorndike's correction (Pfaffel et al., 2016).

Based on the findings in this study, we advise researchers concerned about the effects of range restriction to follow the following guidelines where possible, regardless of the type of data collected: 1) *a priori* modelling of restricted range and reduced sample size to identify the optimal sample size for resource and time efficiency and increase power of conservation studies; 2) acknowledgement and minimisation of barriers around data collection to maximise sample size and breadth; and 3) application of range correction techniques when range restriction cannot be ‘designed out’ of a study. If unaccounted for, range restriction may bias research conclusions through unrepresentative samples and inappropriate statistics, with potentially significant impacts on conservation practice and policy.

Ethics statement

Ethical approval was granted by the ethical committees of Zoological Society of London (ZPD code: IOZ5) and Royal Holloway, University of London prior to piloting and data collection. All participants of the social science study in the UK and Finland were asked to read a Participant Information Sheet before starting the online questionnaire and gave informed consent to participate in the study by choosing to begin the online questionnaire.

Data availability statement

All biological data (provided by The Finnish Museum of Natural History and the British Trust for Ornithology) and anonymised social data are available from the Royal Holloway FigShare Repository (https://doi.org/10.17637/rh.12640244.v1). Please contact corresponding authors for more information.

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6. Evaluating congruence between local ecological knowledge and biological datasets in assessing bird species abundance and trends

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Abstract

The comparison of local ecological knowledge (LEK) and biological datasets is increasingly recognised as a key strategy to provide robust conclusions for biodiversity monitoring and assessment, while recognising the attitudes, values and behaviours of local people for more inclusive conservation outcomes. Measuring agreement between data sources can inform future conservation studies by investigating the most effective measurement of population parameters in different situations and for different species. In this study, we matched long-term biological datasets with public perceptions of bird species relative species abundance and trends in the UK and Finland. Social data, collected using large-scale online questionnaires, and biological data were matched spatially and temporally to create a measure of paired agreement. Variation in agreement was explored between population parameters, countries, species and time periods, while controlling for the influence of multiple demographic and experience-related factors. Our results indicate that variation in agreement between datasets is more likely for species relative abundance, than for long-term trends. Agreement was found to be higher for past relative abundance, higher in the UK than in Finland and influenced by multiple socio-demographic variables. By contrast, trend agreement only varied between study species, indicating that for poorly known species, research on long-term trends may be a more reliable measure of species status than abundance.

Introduction

Species abundance and trends are essential population parameters for assessing the need for conservation interventions. However, in practice, accurate assessment of species population status is often limited by data availability, quality, or consistency, especially in the case of rare and threatened species (Turvey et al., 2010; Nash et al., 2016). Didham et al. (2020) identified seven key challenges in drawing robust inference about species population declines, including a reliance on historical baselines, the robustness of long-term species estimation, short-term or phenological changes, and difficulty in accounting for density- and scale-dependence at the population-level (Didham et al., 2020). These challenges, combined with common fieldwork limitations on resources and unpredictable environments, can result in a lack of robust biological data using standard field techniques (Aswani et al., 2018; Giovos et al., 2019). For example, standard surveying techniques in marine ecology (e.g., SCANS technology) are cost-intensive to cover large areas, leading to extrapolation of values over larger areas or limitation to short time-series (Saavedra et al. 2018; Rodrigues et al. 2019). Additional barriers to data collection such as lack of funding or regional capacity are likely in much of The Global South, which holds many of the world's current biodiversity hotspots (Magurran et al., 2010). In such cases it is especially challenging to establish baseline data upon which to monitor population change and predict the need for future conservation interventions, which can lead to the adoption of inappropriate conservation management plans (Parry and Peres, 2015; Peñaherrera-Palma et al., 2018).

Local ecological knowledge (LEK) describes personal, experience-based knowledge gathered over time in observation of local natural environments and developed in co-evolution with social and ecological changes (Gilchrist et al., 2005; Aswani et al., 2018). Local and traditional knowledge offer not only a means to collect perceptions of current ecological conditions, but also a lens through which to observe past species abundance and trends (Turvey et al., 2010), often beyond the scope of traditional scientific observations (Castellanos-Galindo et al., 2011; Martinez-Levasseur et al., 2017). It is now widely recognised as a critical information source for conservation (Tengö et al., 2017), used in species population assessment (Turvey et al., 2010; Ziembicki et al., 2013; Nash et al., 2016), monitoring (Parry and Peres, 2015), the development of local and global policy (Robert et al., 2005), and increasingly in neighbouring environmental fields such as geoscience (Galloway and Patterson, 2019) and ethnobotany (Shrestha and Medley, 2017). The rise of innovative data collection methods such as citizen science, crowd-sourcing and online questionnaires has further highlighted LEK as a diverse knowledge system with which to efficiently collect large, detailed datasets on ecological change (McKinley et al., 2017; Callaghan et al., 2019).

As LEK represents anecdotal information, biases and heuristics can be introduced at any stage during the collection, interpretation, and analysis of LEK datasets (Turvey et al., 2010), which can lead to the misinterpretation and marginalisation of local and traditional knowledge (Albuquerque et al., 2021). Personal perceptions of current and past ecological conditions can also be influenced by a variety of factors, including: personal ability to accurately recall memories and information (Blasiman and Was, 2018; Rost, 2018), willingness to share personal perceptions with 'outsiders' (Huntington et al., 2004), the influence of cognitive biases and heuristics (Tversky and Kahneman, 1974), and cultural factors shaping the local 'information environment' (Verweij et al., 2010; Peñaherrera-Palma et al., 2018). Variation in the frequency, means and timeframe over which individuals experience their local environment can lead to further differences in perceptions of ecological change between past and current timeframes (Beaudreau and Levin, 2014). The recall of past conditions is achieved via a particularly wide variety of cognitive and memory-related mechanisms, often leading to a reliance on heuristics and mental short-cuts for recall efficiency, and potentially biasing memories towards particularly memorable past conditions or 'baselines' (Tversky and Kahneman, 1973; Havari and Mazzonna, 2015). As discussed by Didham et al. (2020), the effectiveness of using past baselines to measure ecological change is dependent on the comprehensiveness of our historical knowledge of past conditions, leading to a phenomenon known as shifting baseline syndrome (Papworth et al., 2009; Jones et al., 2020). The ability to perceive long-term trends compounds the biases acting upon both current and past perceptions, as trend perception requires a comparison of environmental conditions between both time points, while also filtering out short-term noise (Daw et al., 2011). Data collection choices for LEK therefore require sensitivity to local socio-cultural and anthropological environments, with particular care needed when choosing population parameters of interest and framing questions (McKelvey et al., 2008).

The complementary use and comparison of LEK and biological datasets is increasingly recognised as a key solution to integrate knowledge systems, acknowledge local perceptions of ecological change, and measure and quantify the potential limitations, biases and inaccuracies of both datasets (Folke et al., 2010; Raymond et al., 2010; Penny et al., 2016; Albuquerque et al., 2021). Studies comparing social and biological data have been conducted in various contexts, such as: the population status of birds (Gilchrist et al., 2005), marine mammals and fishes (Huntington, 2000; Beaudreau and Levin, 2014) and terrestrial mammals (Anadón et al., 2009), using both abundance (Turvey et al., 2010) and trends (Rochet et al., 2008). Given the potential biases acting upon LEK-based data, understanding patterns in agreement between LEK and biological datasets presents an opportunity to account for potential inaccuracies in anecdotal datasets to ensure affective conservation outcomes. Especially when collecting LEK through interviews, biases and inaccuracies are likely to vary based on memories, therefore agreement is likely to vary based on which population parameters are collected (e.g., asking about current or past abundance, or long-term trends). However, mindful that no single approach to comparing local and scientific knowledge is optimal (Raymond et al., 2010), previous studies have warned against the validation of LEK against biological data (Tengö et al., 2017; Hill et al., 2020). As expressed by Torrents-Ticó et al. (2021), this can be avoided by recognising LEK and biological data as complimentary knowledge sources, with which convergences and divergences can be elucidated and discussed (Raymond et al., 2010; Torrents-Ticó et al., 2021). Albuquerque et al. (2021) highlight three key benefits of integrating local knowledge and biological datasets: the incorporation of human aspects into data-led strategies, recognition and promotion of the worth of LEK, and empowerment of local people to become directly involved in the future management of local natural resources (Huntington, 2000; Cross et al., 2017) and decision-making (Albuquerque et al., 2021).

The direct pairing or ‘matching’ of social and biological data involves the comparison of independent, long-term social and biological datasets (Huntington et al., 2004). As described by Huntington et al. (2004), data pairing enables investigation into the similarities and differences between social and biological datasets and the mechanisms driving differences in individual conclusions. In this study, we define a ‘paired dataset’ as social and biological data that has between statistically matched at the spatial and temporal scale. Previous studies have used multiple methods to integrate such data, including correlation and multivariate regression statistics (Anadón et al., 2009; Fernández-Llamazares et al., 2017), while Torrents-Ticó et al. (2021) used a holistic approach to describe areas of convergence and divergence between conclusions from each knowledge system in the context of carnivore populations in Kenya. However, previous studies have typically compared agreement between knowledge systems in only one region or country (Anadón et al., 2009; Penny et al., 2016; Fernández-Llamazares et al., 2017) and often have not explored the influence of individual-level factors (e.g., demographics and connectedness to nature) on variation in agreement (Torrents-Ticó et al., 2021).

We expand upon previous studies that use paired datasets, examining variation in agreement between large-scale online questionnaire datasets and independent long-term biological datasets in the UK and Finland. Focussing on seventeen bird species, with three species shared between both countries, we explore how agreement between social and biological data varies across species, key population parameters and countries, with additional investigation of the effect of participant demographics, experience, and interest in nature on this agreement. By identifying areas where LEK data show close congruence with independent biological data, and other areas where these two data types do not match, our findings provide guidance toward the choice of data collection methods and effective integration of LEK into species conservation research, practice, and policy.

Methods

Study hypotheses

This study investigates variation in agreement between perceptions and biological data for both relative abundance and trends across multiple species, and two countries. For both population parameters, we hypothesise that overall agreement will be higher in Finland than the UK. Many studies cite a ‘disconnection from nature’ in the UK, especially in younger generations (Kesebir and Kesebir, 2017; Chawla, 2020). By contrast, Finland has a rich cultural relationship with nature, through education and engagement with local nature (Hiltunen et al., 2020; Rantala and Puhakka, 2020). Due to fallibility of past memories and effects of multiple biases and heuristics on perceptions of the past (Tversky and Kahneman, 1974; Daw, 2010), we hypothesise agreement will be higher for current relative abundance than past abundance for all species in both countries. Finally, we hypothesise that participants with greater connectedness to nature and concern for species conservation are expected to have higher agreement with the biological data across all species.

Region and species selection

Biological data were available in the form of annual abundance indices and population trends for 10 bird species in both the UK and Finland (see Supplementary section S1 & 2 for UK and Finland questionnaires and S3 for more details on data collection). In the UK, annual population indices were calculated for 1966 to 2017 from the combined BTO-JNCC Common Bird Census (CBC) and Breeding Bird Surveys (BBS) datasets (Harris et al., 2018). Data were available for eleven contiguous counties in Southeast England: Berkshire, Buckinghamshire, Cambridgeshire, Essex, Greater London, Kent, Hampshire and Isle of Wight, Hertfordshire, East and West Sussex, and Surrey. Most of the species included in this study are present throughout these counties due to similar land use and climate (Dessai and Sims, 2010). In Finland, the annual monitoring of breeding birds dataset (Linnustonseuranta) provided biological data from 1984 to 2018 for southern and eastern provinces (co-ordinate limits 67°N latitude and 34°E longitude), including Uusimaa, Kymenlaakso, Päijänne, North and Southern Karelia, and Savonia. Southeast Finland was chosen due to high monitoring survey effort (LUOMUS Team, 2018) and similar habitat type and land use, meaning that target species ranges covered the study area (Valkama et al., 2011).

In both countries, species selection was restricted to species seen regularly in garden and urban areas, making it likely that participants would have personal experience of the species (Cox and Gaston, 2015). For the UK, we selected the following species: house sparrow (*Passer domesticus*), tree pipit (*Anthus trivialis*), common cuckoo (*Cuculus canorus*), Eurasian jay (*Garrulus glandarius*), barn swallow (*Hirundo rustica*), blue tit (*Cyanistes caeruleus*), Eurasian wren (*Troglodytes troglodytes*), sparrowhawk (*Accipiter nisus*), goldfinch (*Carduelis carduelis*) and collared dove (*Streptopelia decaocto*). For Finland, we selected the following species: wryneck (*Jynx torquilla*), starling (*Sturnus vulgaris*), barn swallow (*Hirundo rustica*), common cuckoo (*Cuculus canorus*), house sparrow (*Passer domesticus*), blackbird (*Turdus merula*), white wagtail (*Motacilla alba*), great tit (*Parus major*), willow warbler (*Phylloscopus trochilus*) and Eurasian robin (*Erithacus rubecula*). These selected species are generally distinctive and easily recognisable even to non-trained observers (Table S1). Ten bird species in each country were selected to encompass a wide range of abundances and trends, from abundant and increasing to rare and declining. These species also vary according to several co-variates such as genetic distinctiveness, charisma, mass, longevity and migration status. Species were ranked in order of abundance as number of pairs or territories in 2014 in Finland from the publicly available online Third Finnish Breeding Bird Atlas (Valkama et al., 2011a), and 2016 in the UK using the BTO BirdFacts website (Woodward et al., 2018). Species were also ranked by population trend (% annual change from 1970-2014 in Finland, 1966-2016 in the UK).

Data collection and preparation

Questionnaire data collection

The UK and Finland online questionnaires were designed, operated and distributed using the Qualtrics platform (version XM 2018). Full ethical approval was granted by Royal Holloway, University of London after piloting the English-language version with 12 participants from the 11th-13th July 2018. Translation of the UK survey into Finnish was conducted and proofread by native Finnish speakers. The UK survey was live from 16th July to 9th September 2018. The Finnish survey was live from 15th September to 9th December 2018 and repeated from 17th July to 2nd September 2019. A full overview of the sample sizes and demographic distribution of participants is given in Table 2.

Online questionnaires collected participant demographic data and location of residency at the time of the survey (present) and when they were 18 (past), as well as measures of experience and interest in birds and birdwatching. Participants were asked to select which species they recognised from photos; only the species selected as ‘recognised’ were included in the rest of the questionnaire. Participants were then asked about personal perceptions of species abundance as a relative rank (rank order from most to least abundant across all species recognised) and trends (each species categorised as increasing, static or declining) between the past and present. Finally, participants were asked to rank the species they had recognised in order of personal preference as a measure of perceived species charisma (rank dependent on number of species the participant recognised) and asked to give a score between 0 and 5 representing their perceptions of the need for local conservation support, in which species considered to be of highest priority gained a score of 5. For full details on questionnaire dispersal, question details, rationale and participant demographics, see Jones et al. (2020).

Biological data analysis

Analyses were conducted using R software version 3.6.2 (R Core Team, 2019). Biological data from both countries were collected and formatted for analysis using the R package rTRIM (version 3.5.3; Pannekoek & van Strien 2005). rTRIM fits trends and annual population indices using log-linear Poisson-models and handles missing data through imputation. Over-dispersion and temporal autocorrelation are accounted for using a quasi-Poisson approach and generalized estimation equations, respectively (Pannekoek and van Strien, 2005).

In the UK, annual biological data were available at the county-level across the study. Biological and social data were matched temporally and spatially per participant at the annual and county-scale; biological data were subset to include only the local county and year range from the year the participant was 18 years old to 2017. In Finland, biological data were available at the regional scale (i.e., Southeast Finland and non-Southeast Finland), and so biological data were not matched spatially but were matched temporally from the year the participant was 18 years old to the year of the survey. This differing approach may negatively affect agreement in Finland as spatial comparisons are coarser. In both countries, temporal matching of data meant the participant sample was limited by the earliest available biological data. Data were available from 1966 in the UK and from 1984 in Finland, giving a maximum participant age of 70 and 52, respectively.

Pairing of social and biological data

Analyses were conducted separately for relative abundance and trends, as the responses variables were of different data types and distributions (see Table 1). The response variables were calculated as a measure of agreement between individual perceptions of biological change and the biological data, therefore an absolute value was taken giving a response variable with range 0 (no agreement) to 1 (total agreement). A response variable was calculated separately for current and past relative abundance and for long-term trends, with analyses conducted per species and per participant. For current and past abundance, the response variable was calculated as the difference between perceived and biological ranks, normalised according to the total number of species that each participant had selected as 'seen' at that time point on a scale from 0 to +1, per participant, in which 0 represents complete agreement (Table 1). Trend agreement was calculated as the difference between perceived and biological trends, creating a scale of agreement scores (0 = 'total agreement', 1 = 'adjacent values', 2 = 'no agreement').

Table 1: Methods used to pair and analyse biological and social data for the population parameters (current abundance rank agreement, past abundance rank agreement and trend agreement score) used as response variables for mixed effect modelling (see Table S3 for model rationale).

Response variable	**Time period**	**Biological data**	**Questionnaire data**	**Comparison method (per species)**
Relative abundance agreement	**Current abundance rank agreement**	Ranked current abundance calculated per species, for all species recognised by each participant	Perceived ranked abundance of all recognised species from questionnaire divided by number of species seen per participant in the year of the survey	$Current\ rank\ agreement = \mathrm{abs}(\frac{Species\ perceived\ rank_{current} - Species\ bio\ rank_{curre}}{Overall\ N\ seen_{current}}$ Data are continuous between range = 0–1, 0 = full agreement. Agreement value calculated per species.
	Abundance rank agreement at age 18 (past)	Ranked abundance calculated per species for the year each participant was 18 years old (past), for all species recognised by each participant	Perceived ranked abundance of all recognised species from questionnaire divided by number of species seen per participant at age 18 (past)	$Past\ rank\ agreement = \mathrm{abs}(\frac{Species\ Perceived\ rank_{Past} - Species\ Bio\ rank_{Past}}{Overall\ N\ seen_{past}})$ Data are continuous between range = 0–1, 0 = full agreement. Agreement value calculated per species.
Trend agreement score (from age 18 to current)		Each species classified as increasing (positive trend, SE not including 0), decreasing (negative trend. SE not including 0) or static trend (falling between positive and negative SE) per county	Species classified as increasing trend	$\text{Trend agreement score} = \text{abs(Perceived Trend} - \text{Biological Trend)}$ TAS = Trend agreement score. Response data are ordinal, where range = 0, 1 or 2; 0 = full agreement and 2 = opposite perceptions. Agreement value calculated per species.
			Species classified as static trend	
			Species classified as declining trend	

Statistical analyses

Welch's two sample t-tests were used to explore significant differences between the UK and Finland for all continuous demographic predictors.

Two mixed-effect models were conducted to investigate variation in agreement between participant perceptions and the biological data per species; one model for perceptions of ranked abundance and one for trends due to differences in formatting of response variables (see Table 1). Participant samples from the UK and Finland were combined to investigate variation in agreement between countries, between species, and between current and past time periods for abundance (see Table 2 for predictor rationale). Interactions between country and species were included in both models, and the abundance model also included an interaction between time period and species. 'Participant ID' was a random effect and predictors were unstandardised to allow direct examination of the relationships between each predictor and the response variable (Harrison et al., 2018). For abundance agreement, a Cox proportional hazards left-censored mixed regression model was used from the 'survival' package (Pettitt, 1986; Therneau et al., 2021). For trend agreement, a cumulative link ordinal logistic regression mixed model (CLMM) was used from the 'clmm' function in the 'ordinal' package (Christensen, 2019).

Table 2. List of predictor variables included in the mixed effect models, used to investigate the effect of species, country and time period (abundance) on variation in participant perceptual agreement with the biological data.

Model type	Predictor	Data format	Rationale for predictor
Mixed effect models	Species	**Categorical –** 10 non-control species	Testing for species-level differences in agreement
	Country	**Categorical -** UK/Finland	Testing for country-level differences in agreement
	Time period (relative abundance)	**Abundance time period –** Current/Past	Testing for differences in agreement between abundance time periods

The residuals of each mixed-effect model were checked for heteroscedasticity and the appropriate variance structure was selected using the *nlme* package (Pinheiro et al., 2020). Due to a high number of levels (17 species across both countries), the 'species' predictor was re-coded using deviation coding for all models using the 'contr.sum' function to allow comparison of estimates across all species (R Core Team, 2019). Deviation (or 'Sum' coding) coding compares all levels of a factor to the grand mean of that factor, as opposed to R's default treatment contrasts in which one level of a factor is used as the comparator for all other levels. Under this coding, the grand mean is the mean of means of the dependent variable at each level of the categorical variable. All predictors were checked for collinearity (see supplementary materials, Section S4). For abundance and trends, smaller or negative coefficients indicate higher agreement between social and biological data, and *vice versa* for larger positive coefficients (Table S5). For trends, results are interpreted as comparative odds ratios between ordinal levels of agreement (Table S6 & S7).

Participant-level variation in agreement

The participant intercepts of the random effects from each mixed model were extracted and combined to serve as a measure of mean participant-level variation in agreement across all species for abundance and trends. In this case, larger coefficients indicate higher agreement between social and biological data, and *vice versa* for smaller or negative coefficients. The effect on participant agreement of demographic variables (age and gender) and interest in nature (frequency of experience in nature, connectedness to nature (CTN) score, and proportion of lifetime with birding experience) was explored using generalised linear models (GLMs). To limit exploratory analyses and prevent model overfitting, model explanatory variables were selected based on *a priori* investigation of the original literature (see Table S4), and collinearity was checked using the same methods as described above (Burnham and Anderson, 2002). Model estimates indicate the probability of observing agreement between participant perceptions of a species and the biological datasets. As a value of zero in the response variable indicates complete agreement between the datasets, lower model estimates for a predictor indicate higher agreement, while higher model estimates indicate lower agreement.

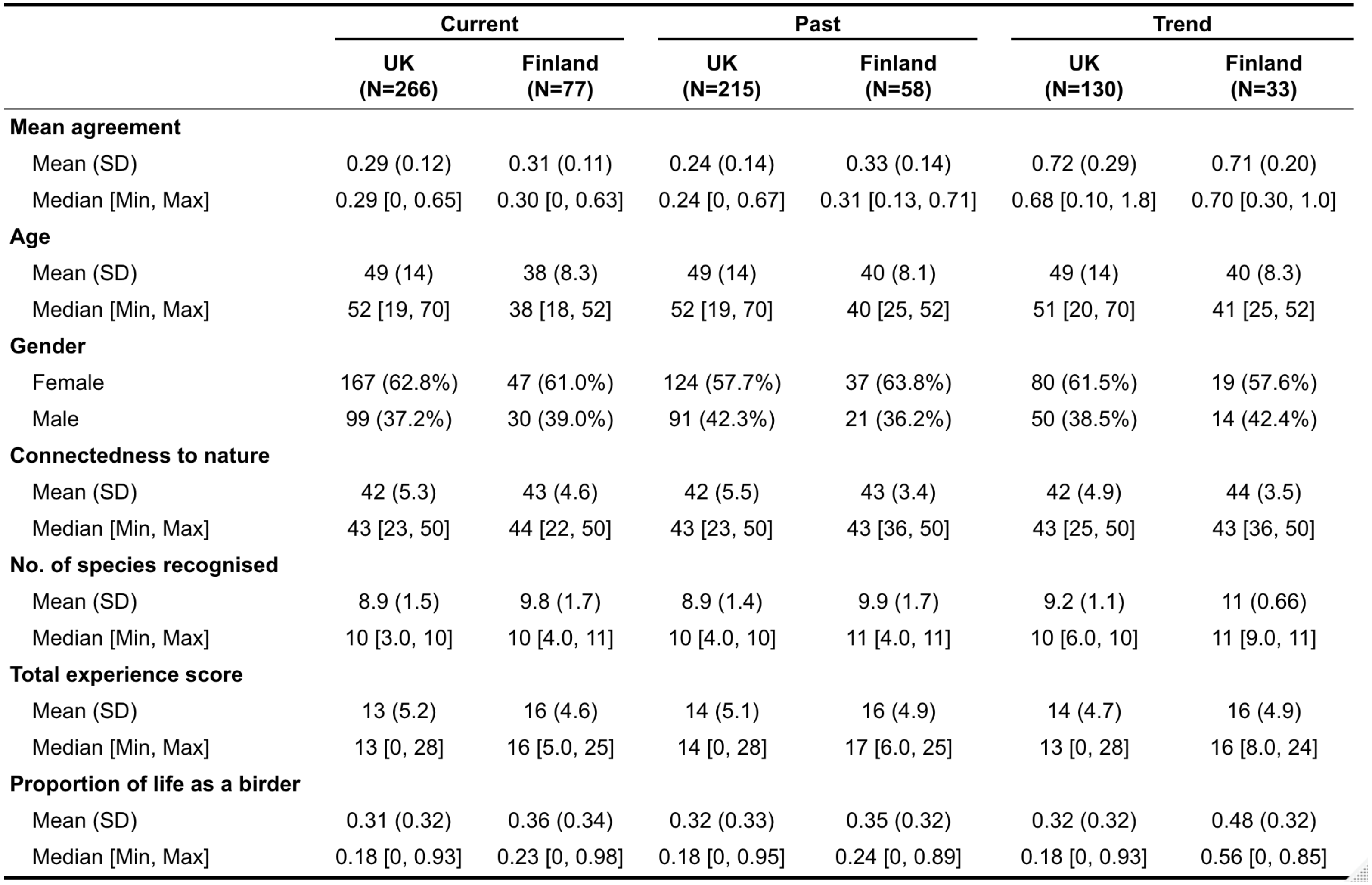
An information theoretic model selection and averaging approach was used to explore the relative importance of the explanatory variables on agreement (Burnham and Anderson, 2002). Candidate models were selected from the global model using the ‘dredge’ function in the MuMIn package (Bartoń, 2019) and ranked according to AICc values. Models with a ΔAICc value of <2 were retained as a ‘confidence set’ of models, for which Akaike Weights were calculated and model averaging was performed to calculate a combined multi-model inference (Harrison et al., 2018). Model averaging was used to reduce model selection uncertainty (Grueber et al., 2011). Selected model confidence sets and model estimates including standard errors, 95% confidence intervals and p-values are given in the supplementary information (Tables S8 & S9) and averaged model estimates and p-values are given in Table 3.

Results

Participant information

Sample sizes and participant demographic and geographic distributions are given in Table 3. For both abundance and trends, mean participant age was significantly higher in the UK than in Finland (Abundance: t = 9.57, df = 227, p<0.001; Trend: t = 4.24, df = 85, p<0.001), while the Finland sample had significantly higher mean number of species recognised (Abundance: t = -3.73, df = 126, p<0.001; Trend: t = -9.47, df = 83, p<0.001) and higher experience of nature scores (Abundance: t = -4.73, df = 152.52, p<0.001; Trend: t = -2.81, df = 48, p<0.001 - Table 3). For connectedness to nature (CTN) scores and proportion of lifetime as a birder, no significant difference was found between countries for both abundance and trends (CTN: Abundance: t = -1.35, df = 434, p=0.17; Trend: t = -0.40, df = 77, p-value = 0.69; Proportion of lifetime as a birder: Abundance: t = -0.74, df = 138, p=0.46; Trend: t = -0.90, df = 74.98, p-value = 0.37). Summary statistics for paired data agreement across all species can be found in Table S2 and frequency of trend agreement scores per species can be found in Table S3.

Table 3: Summary statistics and sample size for the samples used in the mixed-effect modelling analysis in the UK and Finland at the time of the survey (current), at age 18 (past), and in both time periods (long-term trends). Mean, median, range and standard deviations (SD) are shown for each response variable (current and past abundance agreement, and trend agreement), as well as demographics, connectedness to nature (CTN) score and number of species recognised. N = number of participants.



	Current		**Past**		**Trend**	
	UK (N=266)	**Finland (N=77)**	**UK (N=215)**	**Finland (N=58)**	**UK (N=130)**	**Finland (N=33)**
Mean agreement						
Mean (SD)	0.29 (0.12)	0.31 (0.11)	0.24 (0.14)	0.33 (0.14)	0.72 (0.29)	0.71 (0.20)
Median [Min, Max]	0.29 [0, 0.65]	0.30 [0, 0.63]	0.24 [0, 0.67]	0.31 [0.13, 0.71]	0.68 [0.10, 1.8]	0.70 [0.30, 1.0]
Age						
Mean (SD)	49 (14)	38 (8.3)	49 (14)	40 (8.1)	49 (14)	40 (8.3)
Median [Min, Max]	52 [19, 70]	38 [18, 52]	52 [19, 70]	40 [25, 52]	51 [20, 70]	41 [25, 52]
Gender						
Female	167 (62.8%)	47 (61.0%)	124 (57.7%)	37 (63.8%)	80 (61.5%)	19 (57.6%)
Male	99 (37.2%)	30 (39.0%)	91 (42.3%)	21 (36.2%)	50 (38.5%)	14 (42.4%)
Connectedness to nature						
Mean (SD)	42 (5.3)	43 (4.6)	42 (5.5)	43 (3.4)	42 (4.9)	44 (3.5)
Median [Min, Max]	43 [23, 50]	44 [22, 50]	43 [23, 50]	43 [36, 50]	43 [25, 50]	43 [36, 50]
No. of species recognised						
Mean (SD)	8.9 (1.5)	9.8 (1.7)	8.9 (1.4)	9.9 (1.7)	9.2 (1.1)	11 (0.66)
Median [Min, Max]	10 [3.0, 10]	10 [4.0, 11]	10 [4.0, 10]	11 [4.0, 11]	10 [6.0, 10]	11 [9.0, 11]
Total experience score						
Mean (SD)	13 (5.2)	16 (4.6)	14 (5.1)	16 (4.9)	14 (4.7)	16 (4.9)
Median [Min, Max]	13 [0, 28]	16 [5.0, 25]	14 [0, 28]	17 [6.0, 25]	13 [0, 28]	16 [8.0, 24]
Proportion of life as a birder						
Mean (SD)	0.31 (0.32)	0.36 (0.34)	0.32 (0.33)	0.35 (0.32)	0.32 (0.32)	0.48 (0.32)
Median [Min, Max]	0.18 [0, 0.93]	0.23 [0, 0.98]	0.18 [0, 0.95]	0.24 [0, 0.89]	0.18 [0, 0.93]	0.56 [0, 0.85]

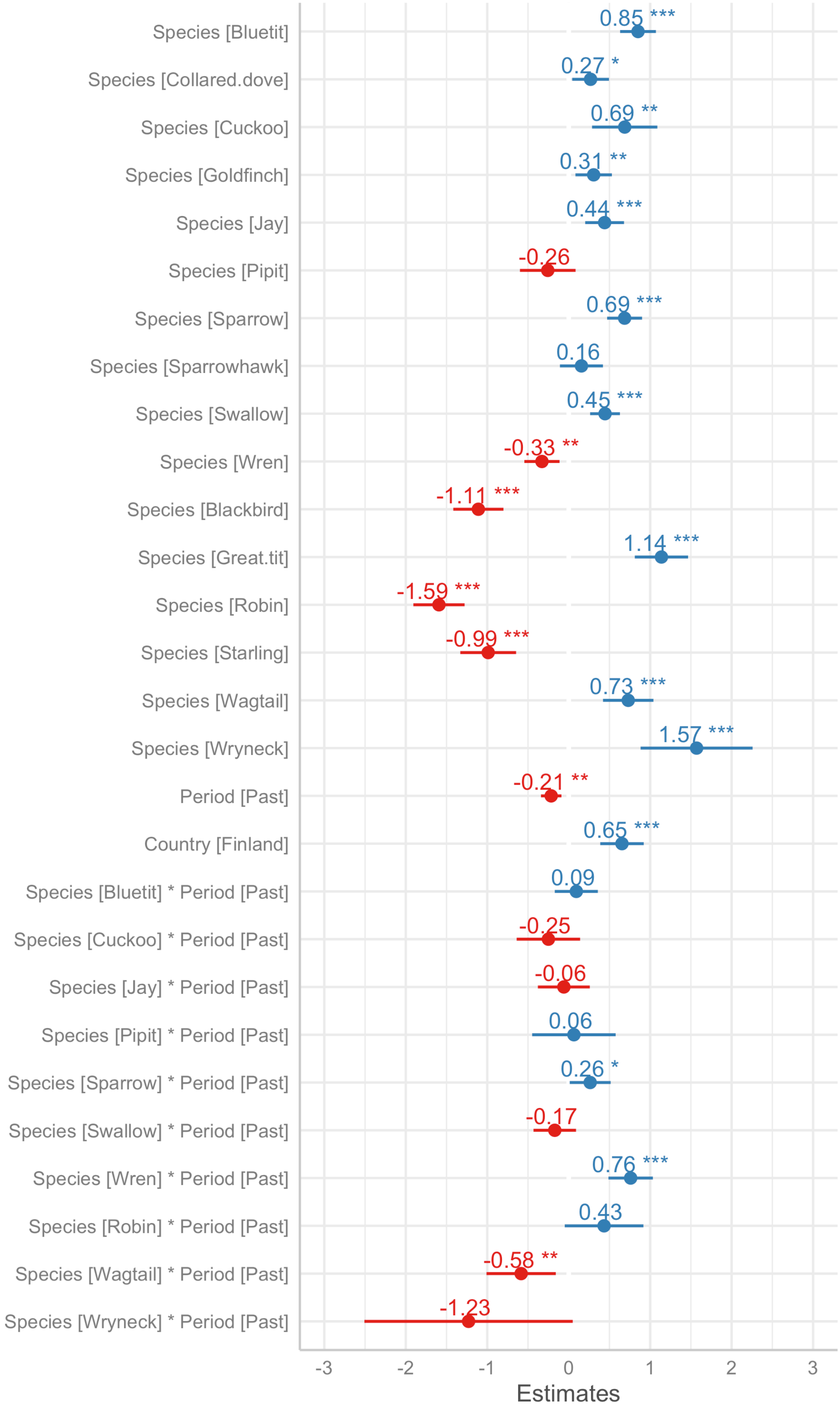
Investigating variation in agreement between species, country and time period

Comparing relative ranked abundance agreement across time periods

Across both countries, current abundance disagreement was higher than past abundance disagreement, indicated by a significant effect of time period (Period [Past]: -0.22 ± 0.07, $p<0.01$ – Figure 2). For 14 of the 17 species in both countries, current abundance agreement was significantly different from the grand mean, therefore these species deviated significantly from the overall mean across all species. Of these 14 species, ten species (UK: blue tit, collared dove, goldfinch, jay; Finland: great tit, white wagtail, wryneck; both countries: cuckoo, house sparrow, swallow) indicated significant disagreement from the grand mean, while four species (UK: wren; Finland: blackbird, robin, starling) showed significantly higher agreement than the grand mean.

Past relative abundance agreement was significantly different from the grand mean for only six species. Four species (UK: wren; Finland: blackbird, robin; both countries: house sparrow) indicated significant disagreement from the grand mean, while two species (Finland: great tit, white wagtail) showed agreement that was significantly higher than the grand mean.

Figure 1. Model estimates of the effect of species, time period and country on predicted abundance agreement coefficients. On the x-axis, smaller values equal higher agreement and higher values indicate lower agreement. Error bars represent 95% confidence intervals. Red estimates indicate a value < 1 and blue estimates indicate values > 1. For full abundance regression results see Tables S5.



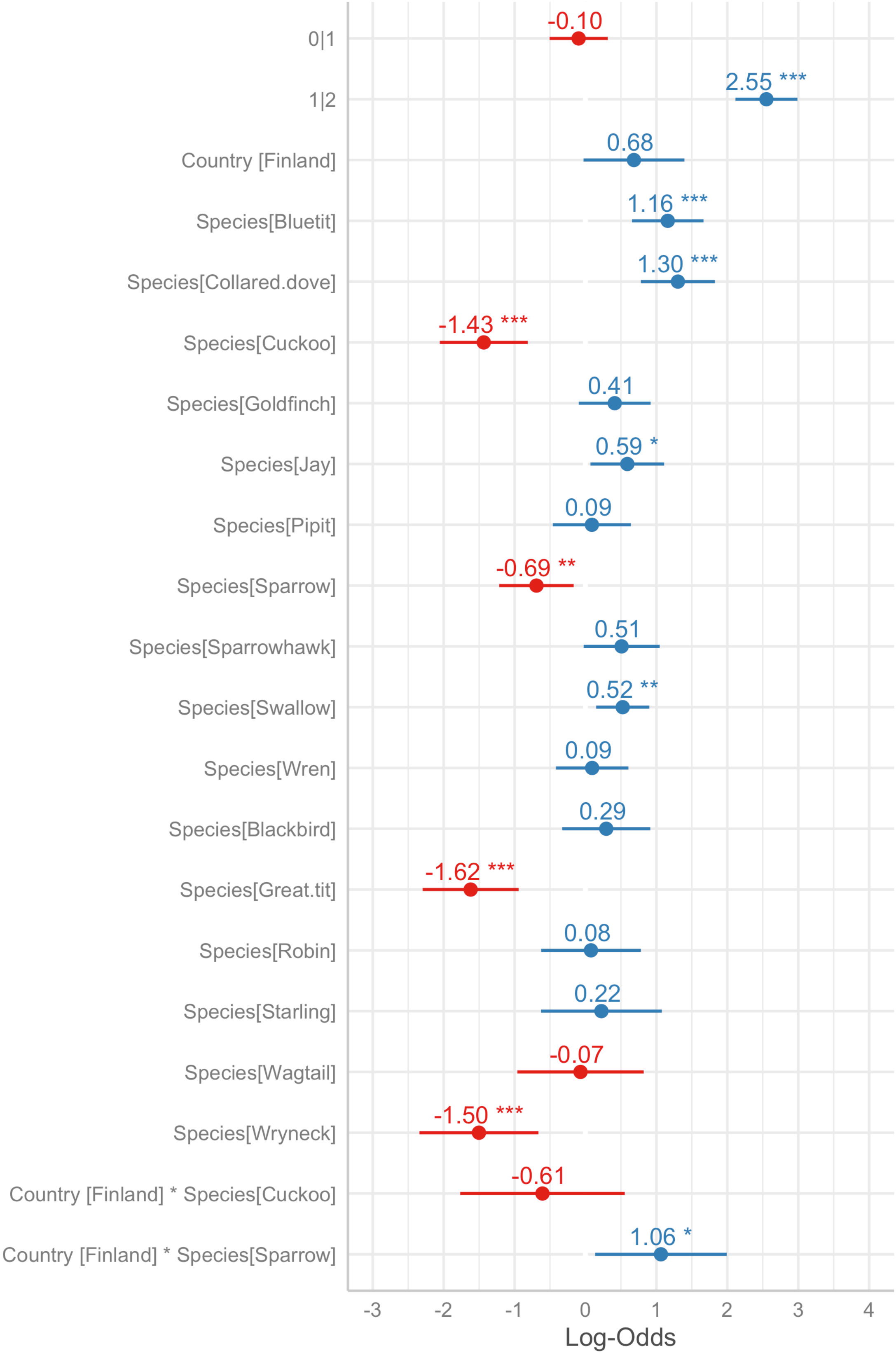
Species-level variation in trend agreement

Across all species in both countries, participants were significantly more likely to perceive trends that were adjacent values rather than total disagreement (odds ratio =12.82, CI = 8.28-19.86, $p < 0.001$, n =231; Figure 2, Tables S6 & S7). However, no significant difference was found between the probability of participants' perceiving species trends that were adjacent values or full agreement (odds ratio = 0.82, CI = 0.60-1.37, p = 0.64, n =231).

For nine of the 16 species (16 due to the k-1 contrasts due to deviation coding), trend agreement was not significantly different from the grand mean (Table S6). For three species (Finland: great tit, wryneck; both countries: house sparrow), participants were significantly more likely to perceive trends that indicated greater agreement with the biological data (great tit: odds ratio=0.20, CI=0.10-0.39, $p<0.001$; wryneck: odds ratio=0.22, CI=0.10-0.52, $p<0.001$; house sparrow: odds ratio=0.50, CI=0.30-0.85, p=0.01). These results are reflected in Table S3, in which the majority for participants select the same trend option as the biological trend (stable trend) for these species.

Contrastingly, for four species (UK: blue tit, collared dove, jay; both countries: swallow), participants were significantly more likely to perceive trends that indicated lower agreement with the biological data (blue tit: odds ratio=3.32, CI=1.93-5.29, $p<0.001$; collared dove: odds ratio=3.68, CI=2.18-6.20, $p<0.001$; jay: odds ratio=1.80, CI=1.07-3.03, $p<0.05$; swallow: odds ratio=1.69, CI=1.16-2.46, $p<0.01$). Again, these results are reflected in Table S3. For example, for barn swallow in the UK, participants tend to select more optimistic trends (stable) compared to the biological trend (decline).

Figure 2. Model estimates of the effect of species and country on trend agreement between biological data and participant perceptions. On the x-axis, smaller values equal higher agreement and higher values indicate lower agreement. Underlined species were included in both the UK and Finland questionnaires. Error bars represent 95% confidence intervals. For full CLMM results see Tables S6 & S7.



International variation in agreement using shared species

Variation in agreement between countries was investigated using the three species that are shared between both countries' questionnaires (house sparrow, swallow, and cuckoo). For abundance, country had a significant effect, with greater abundance disagreement in Finland than the UK across these species (Country [Finland]: 0.654 ± 0.147, $p<0.001$; Table S5). House sparrow was the only species to show a significant difference in abundance agreement between countries, with higher agreement in Finland (-1.816 ± 0.201, $p<0.001$).

By contrast, no significant difference in trend agreement was found between the UK and Finland (odds ratio = 1.98, CI = 0.97-4.03, $p = 0.06$, $n =231$). However, a significant effect of country was found for house sparrow, for which participants in Finland were 290% more likely to show lower agreement with the biological data (odds ratio = 2.90, CI=1.14-7.33, $p <0.05$, $n =231$). This is reflected in Table S3, in which the majority for participants are shown to have perceived a stable local population trend, while the biological data indicates a negative trend.

Which demographic traits drive variation in individual agreement?

Participant-level variation in agreement

Model averaging results (Table 4) indicate that no socio-demographic predictors significantly predicted participant agreement with the biological data for trends, but mean participant agreement with the biological data for abundance (current and past) varies according to several demographic, experience and knowledge-based characteristics for both population parameters. For abundance, mean agreement of male participants was found be 6.1% higher than female participants (0.06 ± 0.03, $p<0.05$, $n=436$), and mean agreement tended to be 4.0% higher for participants who recognised a greater number of species from photographs (0.04 ± 0.01, $p<0.001$, $n=436$). Participants that reported a greater number of years of birding experience as a proportion of their lifetime were also found to show 12.7% higher agreement with the biological data for abundance (0.12 ± 0.04, $p<0.01$, $n=436$). However, no significant effect of country was found at the participant-level (Table 4).

Table 4. Model averaged estimates and confidence intervals (CI) for generalised linear models (GLM) investigating the effects of participant traits on individual agreement with the biological data for species abundance and trends. Estimates are calculated for variables in the confidence set of top models (ΔAICc <2). For full results and variable names see Tables S8 & S9. Variables where *p* < .05 are **bold.**

	Abundance						**Trends**					
		Exp.	*Std.*	*CI*				*Exp.*	*Std.*	*CI*		
Predictors	*Estimates*	*Coefs*	*error*	2.5%	97.5%	*p.value*	*Estimates*	*Coefs*	*error*	2.5%	97.5%	*p.value*
(Intercept)	**-0.447**	**0.640**	**0.083**	**-0.609**	**-0.284**	**<0.001**	0.006	1.006	0.064	-0.119	0.131	0.926
Country [Finland]	-0.045	0.956	0.030	-0.104	0.014	0.134						
Gender [Male]	**0.060**	**1.061**	**0.025**	**0.010**	**0.109**	**0.019**	-0.054	0.947	0.031	-0.116	0.007	0.085
Number of species recognised	**0.039**	**1.040**	**0.009**	**0.023**	**0.056**	**<0.001**						
Proportion of life as a birder	**0.120**	**1.127**	**0.040**	**0.041**	**0.199**	**0.003**						
Experience score	-0.002	0.998	0.002	-0.007	0.002	0.348	0.004	1.004	0.003	-0.002	0.009	0.210
CTN	0.001	1.001	0.002	-0.003	0.006	0.582	-0.001	0.999	0.003	-0.007	0.005	0.786
Mean conservation attention score	0.027	1.028	0.063	-0.097	0.151	0.666						
Age							-0.001	0.999	0.001	-0.003	0.001	0.512
Observations	***436***						***231***					

Discussion

The comparison of biological datasets and LEK enables exploration of the areas of agreement and disagreement between datasets, to better inform our understanding of the information-content of conservation-relevant datasets and improve the effectiveness of conservation management decisions. We paired social and biological datasets at temporal and spatial scales to investigate differences in the level of congruence between personal perceptions and biological survey data of population change for multiple bird species in the UK and Finland. Our results indicate that greater variation in agreement is more likely for species abundance, than for long-term trends. Within abundance, current abundance showed greater disagreement between data sources than past agreement, and overall agreement was found to be greater in the UK than in Finland. Furthermore, multiple demographic, experience and knowledge-based variables explained variation participant agreement with the biological data for species abundance. However, none of the socio-demographic variables included in this study explained variation in trend agreement and no significant difference in agreement was found between countries, but overall, participant perceptions of trends were unlikely to completely disagree with biological trends (Figure 2). Our results therefore highlight that perceptions of species trends may be a more reliable measure of species status than abundance, illustrating the power and value of paired data studies for identifying patterns in agreement between social and biological datasets.

These results suggest that agreement between local people's perceptions and independent biological survey data is lower for current species abundance (at the time of the survey) than for perceptions of past abundance (at age 18) across a range of bird species in the UK and Finland. Therefore, when comparing abundance agreement between time points, our results suggest that agreement between data sources is greater for current abundance compared to past abundance (Figure 1). However, contrary to our original hypotheses, we found no consistency in agreement across time periods any of the species included in this study, as none of the species had significantly greater or lower agreement in both time points, despite differences in species characteristics that are known to influence public interest and knowledge of bird species (Schuetz and Johnston, 2019). For wren, blackbird and robin, current abundance agreement was significantly higher than the grand mean and lower for past abundance agreement, while for great tit and white wagtail the opposite pattern was observed (Table S5). These results suggest that the impact of perception and memory of abundance varies significantly between species for both time periods, but no clear or consistent pattern can be found to explain agreement within each time period. For species where participant agreement with the biological data was higher in the present than the past, this may indicate evidence of shifting baseline syndrome (Pauly, 1995; Jones et al., 2020), as participant experience had a significant positive effect on overall abundance agreement (Table 4).

Regarding trend agreement, our results suggest that participants were significantly more likely to perceive trends that were adjacent values to those derived from biological data, rather than showing total disagreement with the biological data (Figure 2, Tables S6 & S7). However, no significant difference was found between the probability of participants' perceiving trends that were adjacent values or full agreement. These results (and Figure 2) suggest that in general this sample had a high level of agreement with the biological data for long-term trends across all species, potentially indicating effective memory and perception of species trends. As noted by Huntington et al. (2004), one of the greatest challenges in assessing environmental change is the ability to distinguish true ecological trends from external 'noise', as trends are interpreted from multiple sequential observations of abundance (see also Didham et al., 2020). Yet, in the case of this study, participants may be more able to perceive trends simply due to the simplicity of the question itself. As indicated in Table 1 (see also Supplementary S1 & 2 for full questionnaires), participants were given only three trend options (increasing, stable and declining), therefore participants were likely to give an accurate 'best guess', especially when compared to abundance, in which participants were asked to rank all species they recognised from images. However, like our results for patterns of abundance, these results do not suggest a consistent pattern in trend agreement between datasets across the species in this study.

When comparing levels of agreement between the two countries investigated in our study, abundance agreement was significantly higher in Finland than in the UK across all species (Table S5). These results could be due to differences in the characteristics of each set of species that affect recognisability and memory, such as species charisma, evolutionary and visual distinctiveness (Schuetz and Johnston, 2019), as well as personal differences in interests and abilities to identify ecological change. Our results indicate that when conducting interviews using LEK to assess species abundance, participant gender, ability to recognise species from images (knowledge), and years of specific nature-based experience should be considered as sources of potential disparity with biological datasets (Table 4). For trend agreement however, none of the socio-demographic predictors significantly predicted participant agreement with the biological data. These results indicate that future studies should give greater attention to the socio-demographic characteristics of participants for LEK-based studies assessing species abundance, but less so regarding species long-term population trends. However, for both population parameters, no significant effect of participant age, connectedness to nature score, frequency of experience of nature or perceptions of required species conservation attention was found, suggesting that these variables may not influence participant perceptions of abundance or long-term ecological change. Regarding age, our results agree with a recent study investigating the influence of age on agreement between LEK and scientific knowledge, in which no age-related differences in the level of consistency between datasets were detected (Morales-Reyes et al., 2019). However, the lack of effect of connectedness to nature and participant experience (Table 4) contrasts with our original hypotheses and the wider literature, which suggest that the extinction of experience may impact ability to recognise ecological change (Pyle, 1993; Soga and Gaston, 2016; Gaston and Soga, 2020).

However, when focussing on the three species in our questionnaires that were shared between both countries, house sparrow was the only species to indicate a significant difference in agreement between countries for abundance (Table S5), and no significant differences in agreement scores were found between countries for long-term species trends (Tables S6 & S7). No consistent patterns in agreement were therefore found across these shared species for either of these key population parameters. These results contrast with a recent study comparing abundance agreement between communities, in which no significant differences in the detected number of livestock carcasses by scavengers were found between communities in northern and southern Spain (Morales-Reyes et al., 2019). To our knowledge, no previous study has compared agreement between LEK and biological datasets between countries. Conversely, these results indicate that our conclusions regarding trend agreement may be generalisable to other conservation-relevant systems with comparable demographic characteristics and species distributions. However, it is worth noting that the lack of significant difference between countries could be the result of differences in biological data availability, limiting spatial and temporal resolution of the Finland sample compared to the UK (Valkama et al., 2011b; LUOMUS Team, 2018). Limited temporal range of the Finland sample may result in range restriction, which has been shown to reduce the power of statistical analyses (Dunbar, 1991; Hunter et al., 2006). However, the effect of 'false baselines' should not impact the validity of the conclusions of this study, as the temporal range of the biological data and participants' knowledge was limited to the same temporal range (Didham et al. 2020).

The limited significance of socio-demographic factors in influencing agreement for both abundance and trends in our study may be the result of non-random sampling and bias towards participants with an existing interest in nature, as denoted by high CTN scores across all samples (mean score = 42–44 out of 50 across all samples; Table 3). Generally high trend agreement might also suggest bias in this sample, as non-random sampling in both countries may have favoured participants with high knowledge and interest in bird species populations. While such bias may limit generalisability of these findings, our results are likely to be representative of many LEK studies, which often focus on local experts (Davis and Wagner, 2003; Silvano and Valbo-Jørgensen, 2008). While this study provides a first step in investigating agreement between population parameters, countries and species, future studies with greater resources should aim to use nationally representative sampling methods, such as crowdsourcing (e.g., Fink et al., 2014). This study is also restricted to two developed countries and to mostly non-threatened bird species due to the limited availability of long-term, standardised biological datasets against which to compare perceptions of ecological change, for which few datasets are available for global biodiversity hotspots (Magurran et al., 2010). Finally, as highlighted by Albuquerque et al., (2021), while LEK and biological datasets often do not converge, this does not give grounds to criticise or ignore either data source (Albuquerque et al., 2021). These data present alternative lenses through which to observe ecological change, and both are valid and valuable for assessing and understanding long-term ecological change. The direct comparison of these data types has therefore been criticised by both natural and social scientists (Gilchrist and Mallory, 2007), with studies observing marginalisation of both data types in different situations (Brook and Mclachlan, 2005; Tibby et al., 2007).

We provide a cautionary tale for the use of different data sources to assess species abundance and long-term trends in some scenarios, highlighting the extent to which outcomes can be sensitive to data collection methods, temporal range, and survey design due to question framing, participant memory and unequal recall of past experiences. Through this study, we aimed to inform future studies as to areas where LEK and biological datasets are likely to agree or disagree. Using perceptions of locally occurring bird species as an effective study model, our results suggest that future conservation studies which aim to identify species status may benefit from the comparison of local knowledge and scientific knowledge to elucidate areas of agreement or disagreement (see also Torrents-Ticó et al., 2021). However, in many conservation scenarios resources prevent the collection of multiple datasets. To conclude, in conservation-priority systems where baseline ecological survey data are unavailable for species of concern, our study indicates that local perceptions of species abundance are likely to differ from biological datasets, between species, countries and according to participant demographics. Conversely, agreement between perceptions and biological datasets is less likely to vary between countries, or between participants of varying socio-demographic traits for long-term trends.

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Conflict of interest

The authors declare no conflict of interests.

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7. Is there evidence of shifting baseline syndrome in environmental managers? An assessment using perceptions of bird population targets in UK nature reserves

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Is there evidence of shifting baseline syndrome in environmental managers? An assessment using perceptions of bird population targets in UK nature reserves

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ABSTRACT

Shifting baseline syndrome (SBS) describes changing perceptions of biological conditions due to a loss of historical knowledge. Perceptions of 'normal' environmental conditions are continually updated, leading to underestimation of the true magnitude of long-term ecological change and potential setting of unambitious management targets. There has been speculation as to the presence and impacts of SBS within conservation management since Daniel Pauly's seminal paper in 1995, which outlined the potential effects of SBS on target-setting in fisheries management. Previous case studies have suggested that SBS may not occur in management, despite empirical evidence of SBS in other systems. In this study, 44 professionals and volunteers involved in bird species management, monitoring and target-setting across England were interviewed. Interviews asked for personal perceptions of current, maximum and target abundance, long-term trends, and perceived conservation priority for six bird species. Using paired tests, this study found no significant effect of experience on perceptions of current, maximum or target abundance of all species, despite differences in national abundance and trends, and differences in participant experience. Further power analysis indicated that even if SBS was statistically detectible with a larger sample, the practical implications of the syndrome would be minimal due to small effect sizes. Finally, the effect of experience on individual perceptions of species conservation priority varied between species, with generational amnesia in the form of 'lifting baselines' suggested for only one of the six species. This study suggests that shifting baseline syndrome may not be as significant a threat in conservation management as first thought.

1. Introduction

Evidence-based decision-making is increasingly recognised as standard practice for conservation management, championing the use of robust scientific data on which to base effective research and action (Sutherland et al., 2004; Christie et al., 2020; Downey et al., 2021). Such approaches seek to close the 'research-implementation gap' between conservation science and real-world management (Knight et al., 2008; Dubois et al., 2020). The rise of open-access publishing and free-to-use data repositories enables access to global research but has also led to the expectation for conservation professionals to utilise and learn from cutting-edge research from around the world (Fuller et al., 2014; Sutherland and Wordley, 2017). Furthermore, increasingly dynamic conservation management, policy and decision-making is required to keep pace with unprecedented rates of ecological change and unpredictable new threats (Steffen et al., 2015; Canessa et al., 2020). For on-the-ground conservation managers, these challenges are compounded by the translation of high-level international research and policy into locally relevant targets and decisions (Pullin et al., 2004), and a relative shortage of research and funding in some of the world's most biodiverse regions (Wilson et al., 2016). Conservation researchers, managers and practitioners are therefore under increasing pressure to drive positive change, despite additional time and resource pressures acting upon them. However, studies investigating the importance of evidence in decision-making often overlook the underlying cognitive and psychological processes that drive current conservation decisions, and their influence on the direction and effectiveness of future initiatives (Kørnøv and Thissen, 2000; Clayton et al., 2013; Osbaldiston, 2013;

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Papworth, 2017).

In psychology, multiple theories have been described to explain the decision-making process, based on the reasoning, beliefs, values and experience of the decision-maker (Evans, 2008). In conservation, it is theorised that younger or less experienced decision-makers are more likely to make slower, evidence-based decisions, while older and more experienced decision-makers are more commonly associated with fast-paced decisions, often based on personal experience and intuition (Papworth, 2017). Although evidence-based decisions are thought to be less influenced by personal opinion and emotion, professional time pressures alongside limited resources and inaccessible information (via barriers to both accessing and assimilating information) can lead conservation managers to rely more heavily on personal, experience-based knowledge for decision-making (Walsh et al., 2015). In conservation this issue has been termed 'evidence complacency', leading to criticism of current management systems and the level of pressure on decision-makers and practitioners, due to the potential introduction of inefficient practices and a 'post-truth' ethic (Sutherland and Wordley, 2017). However, others argue that the inherent complexity and non-linearity of decision-making makes evidence complacency unavoidable, and overlooks the implicit, unquantifiable knowledge of experienced decision-makers (Fazey et al., 2006; Evans et al., 2017).

Decision-making is made more complex through the influence of cognitive and social biases, such as shifting baseline syndrome (hereafter SBS). SBS is a socio-psychological phenomenon, previously shown to significantly impact perceptions of both current and past ecological conditions and the perceived need for future conservation interventions (Jones et al., 2020). SBS describes the discrepancy between an individual's perceived environmental baseline used to measure change, and the true environmental 'starting point' (Pauly, 1995). It is thought to arise from a loss of historical ecological knowledge due to a lack of intergenerational communication, extinction of experience, and distortion of personal memories (Miller, 2005; Soga and Gaston, 2018). The loss of knowledge regarding past conditions results in a persistent downgrading of perceived 'normal' environmental conditions over time, rendering people unable to perceive the true extent of ecological change (Fernández-Llamazares et al., 2015). SBS can occur via two mechanisms: generational amnesia, which occurs when the baseline for 'normal' ecological conditions shifts with each successive generation; and personal amnesia, in which individuals forget their past experiences and accept current conditions as the new normal (Papworth et al., 2009).

The conceptual foundations of SBS lie in the field of conservation management. In 1995, Daniel Pauly first defined SBS in the context of fisheries science and possible impacts on "targets for [environmental] rehabilitation measures" (Pauly, 1995). Pauly realised that scientists often tended to compare current conditions to those experienced at the beginning of their career, rather than to a systematic biological baseline. Since Pauly's highly influential paper (2471 citations – Google Scholar, June 2021), evidence for the phenomenon has been reported in a range of ecological contexts across both marine (e.g. Ainsworth et al., 2008; Daw et al., 2011; Plumeridge and Roberts, 2017) and terrestrial ecosystems (Papworth et al., 2009; Jones et al., 2020), and has been the subject of many commentaries on the possible impacts of SBS in biological conservation and restoration (e.g. Wu et al., 2011; Soga and Gaston, 2018). According to Papworth et al. (2009), in order to investigate evidence of SBS, perceptions-based data must be statistically compared to biological data on the same temporal scale in order to confirm age- or experience-related differences in perceptions of biological change. The conditions to confirm SBS are that all participants have experienced biological change during the study period and have a similar perception of current biological conditions (Papworth et al., 2009). A lack of long-term biological data against which to directly compare perceptions of biological change is the most common barrier preventing empirical examination of SBS (see Thurstan et al., 2016; Guerrero-Gatica et al., 2019).

However, although over 25 years have passed since Pauly's formative paper was published (Pauly, 1995), there is still a lack of evidence for the existence of SBS within conservation management. Furthermore, no study has yet investigated evidence regarding the potential effects of SBS on the effectiveness and ambitiousness of conservation decisions. Plumeridge and Roberts (2017) are one of few studies to investigate evidence of SBS in a management scenario, focussing on manager perceptions of the Dogger Bank region of the North Sea. This study interprets a lack of change in recorded perceptions of ecological conditions as evidence of SBS, leading to unambitious modern-day conservation management targets and underestimation of the extent of long-term biological change. However, these findings are suggestive of change blindness rather than SBS (as described by Papworth et al., 2009), due to the lack of age- or experience-related differences in perceptions of change. Under change blindness, people do not notice change occurring and believe current conditions to match those of the past (Simons and Rensink, 2005; Plumeridge and Roberts, 2017), as opposed to SBS, in which change is forgotten over time (Papworth et al., 2009).

By contrast, Muldrow et al. (2020) explored evidence for SBS in the context of coral reef conservation in Florida, interviewing 54 local experts regarding perceptions of current and past coral cover. Experience was quantified as the number of hours dived on the reef; as previously recommended by Papworth et al. (2009), diving provides a "discrete event that can only be 'on' or 'off' and there is no leakage into everyday life". The study found no evidence for SBS among the sample, as both age and experience had no significant effect on perceived baselines, and only 17% reported the use of personal perceptions over secondary data sources for decision-making. Similarly, while not focussing explicitly on SBS, Cook et al. (2014) systematically investigated the accuracy of conservation practitioners' judgements in line with the criteria of Papworth et al. (2009). This study compared the accuracy of practitioners' knowledge of vegetation condition within the areas of their management constituency against a condition assessment tool. Interestingly, in this case little evidence of SBS was indicated, as approximately 60% of practitioners were found to have an accurate current perception of vegetation condition, despite most only using personal experiences to inform their judgments. The remaining 40% tended to be conservative in their estimates of condition, and no significant effect of practitioner experience, level of education, or gender was found (Cook et al., 2014). Previous studies of SBS in conservation management have thus found little or no evidence to suggest the existence or effects of SBS, and none have yet investigated the potential effects of SBS on target-setting.

The lack of evidence of SBS in previous studies of management contexts is therefore in contrast to Pauly's original paper (Pauly, 1995). We hypothesise that conservation managers, for whom monitoring ecological change is a key part of their job, are likely to be acutely aware of ecological change (Cox and Gaston, 2016). Due to their career choice, it is unlikely that differences in perceptions of change between conservation professionals are due to lack of interest or exposure (as is often cited regarding 'the extinction of experience'; Miller, 2005; Gaston and Soga, 2020), but if found, differences could be due to variability in experience leading to generational amnesia, or memory loss with increasing age leading to personal amnesia (Papworth et al., 2009). Alongside experience, connection to nature (CTN) and interest in nature inherently influence people's perceptiveness of changes in the natural world (Soga and Gaston, 2016; Chawla, 2020). Perceptions of change are also likely to depend on the rate and magnitude of change, and the 'prominence' of multiple components of biodiversity (e.g., rare and rapidly declining species may be more frequently monitored and discussed). Fig. 1 shows a pair of theoretical 'assessment matrices' representing the probability of SBS occurring and the potential risks posed by SBS in a given scenario. Scenarios involving very rare species (therefore, unlikely to be experienced) or species with rapidly changing status, and involving people with low connectedness to or interest in nature, are at highest 'risk' of SBS. Conversely, situations involving stable ecological conditions or species populations, and people who are highly connected

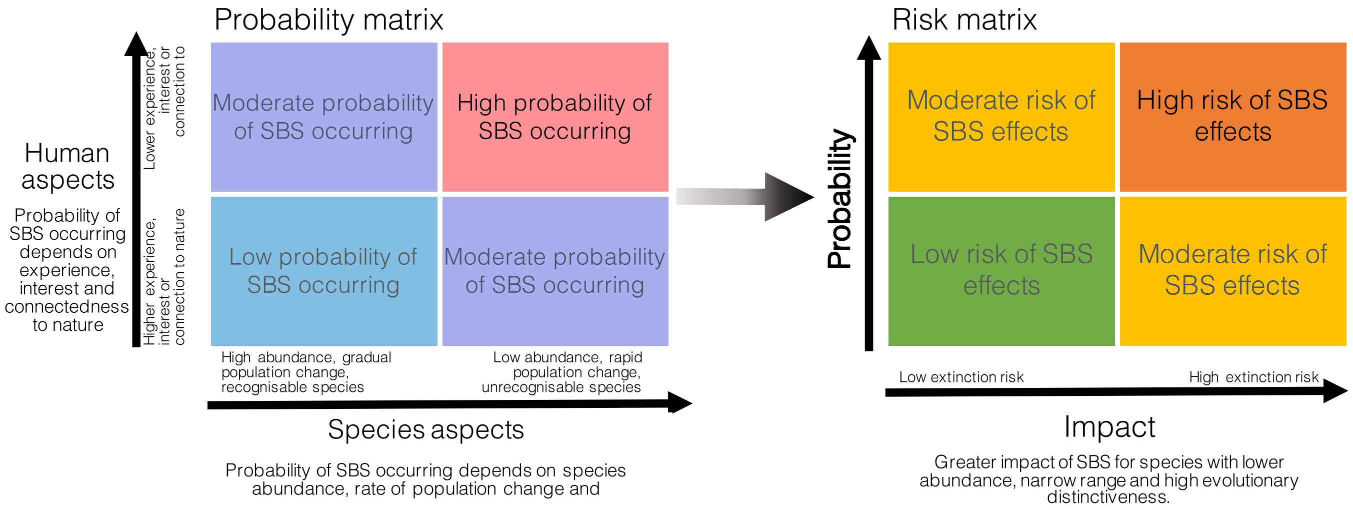

Fig. 1. Two theoretical assessment matrices indicating the potential risk of the effects of SBS occurring in a given situation. The probability matrix (left) outlines human and species-level factors that influence the likelihood that SBS may occur, which provides one axis of the SBS risk matrix (right). The other axis of the risk matrix, impact, represents the severity of potential environmental impact of SBS; for example, SBS may have greater impacts on very rare species or threatened habitats.

to and interested in nature, are at low risk of SBS. Limited risk may explain the lack of previous evidence of SBS in conservation managers. However, due to variation in experience, CTN and species population change, managers may still be at risk of SBS.

This study aims to investigate evidence of SBS in the field of conservation management and provides the first examination into the impact of the syndrome on conservation target-setting and decision-making. We interviewed 44 conservation professionals and volunteers involved in bird species management and monitoring across England, from a range of organisations, collecting participants' perceptions of current and maximum possible species abundance and long-term species trends within their local reserve (Cook et al., 2014; Plumeridge and Roberts, 2017; Muldrow et al., 2020). Two 'paired' participants were interviewed from each reserve and were asked a series of questions about the site or reserve they currently worked on most frequently (focal reserve). Personal perceptions of current, maximum and target abundance, long-term population trends and relative conservation priority were collected for six species in each interviewee's focal reserve, as well as demographic and experience-related information.

Through this study we aim to investigate whether evidence for SBS exists in conservation management, and if so, whether it holds the power to impair the effectiveness of conservation targets. Our findings thus provide important practical guidance into whether methods to combat SBS in conservation management are required.

2. Methods

2.1. Study hypotheses

Under SBS, all individuals should have a similar perception of current population abundances; however, their perceptions of maximum population abundances are likely to be based on past experiences and knowledge, which form an individual's personal baselines (Papworth et al., 2009). Our first hypothesis states that there will be no significant difference in the perceptions of current abundance between paired individuals. However, we expect to find a significant difference between perceptions of maximum abundance within each pair. This would suggest SBS in the form of generational amnesia. If a significant difference between perceptions of maximum abundance is found, we hypothesise that the effect of past experience on these differences will depend on the historical population trend of the species. Under generational amnesia, we would expect more experienced participants to perceive greater maximum abundance than less experienced participants for declining species, as they have prior knowledge of historical abundance levels and population trends. Conversely, for increasing species, we expect more experienced participants to perceive lower maximum abundance compared to less experienced participants. We also explore paired differences in perceptions of species trends and examine whether greater differences in experience between paired individuals coincide with greater differences in perceptions of all measures of species abundance and trends.

The impacts of SBS on conservation decision-making are investigated using perceptions of species abundance targets and ranked species conservation priority on participants' focal reserves. We hypothesise that more experienced conservation participants in this study would be significantly more likely to set more optimistic targets (higher abundance) and attribute greater priority to species that are declining nationally, compared to less experienced participants. We hypothesise the opposite trend for increasing species, as more experienced participants are likely to perceive lower, less optimistic target abundances and lower priority, reflecting a lower baseline species abundance.

2.2. Species and area selection

We selected six bird species, either currently or historically found in inland environments across much of England: three with populations that have been consistently declining during recent decades (skylark *Alauda arvensis*, marsh tit *Poecile palustris*, nightingale *Luscinia megarhynchos*), and three that have been consistently increasing (blackcap *Sylvia atricapilla*, nuthatch *Sitta europaea*, buzzard *Buteo buteo*), according to the British Trust of Ornithology's (BTO) Common Bird Survey (CBC) and Breeding Bird Survey (BBS) data for England (see Table 1). Within each set of three, species varied by relative abundance from abundant to rare (Woodward et al., 2018). A focus on inland species (as opposed to coastal or wetland birds) reduced potential variability between species and sites.

Interviews were completed with employees and volunteers of nature and bird reserves throughout England. Selected reserves were run by any

Table 1

Biological long-term population data used to inform selection of the six bird species included in this study. Species are separated by trend and listed according to national abundance. Long-term trend is the percent change in the number of CBC/BBS plots in which the species was identified in England. Data gathered from BTO BirdTrends (Woodward et al., 2018) and BTO BirdFacts (Robinson, 2005) in England.

Group	Species name	Scientific name	UK red list status	Abundance (in 2009)	Long-term trend (% change)
Declining	Skylark	*Alauda arvensis*	Red	1.5 million territories	−63% (1967–2016)
	Marsh tit	*Poecile palustris*	Red	~41,000 pairs	−76% (1967–2018)
	Nightingale	*Luscinia megarhynchos*	Red	~5500 territorial males (2012)	−93% (1967–2016)
Increasing	Blackcap	*Sylvia atricapilla*	Green	1.2 million territories	+288% (1967–2016)
	Nuthatch	*Sitta europaea*	Green	220,000 territories	+257% (1967–2016
	Buzzard	*Buteo buteo*	Green	~70,000 pairs	+844% (1967–2016)

conservation or wildlife management organisation, charity or governmental organisation. Conducting a national-level study ensured a large potential sample size, but required the selection of bird species that are currently or were historically (within living memory) found across the study area.

2.3. *Participant sampling strategy*

Ethical approval was granted by the ethical committees of the Zoological Society of London and Royal Holloway, University of London (see ethics statement). The survey was piloted with three colleagues in March 2020. Data collection interviews were conducted from March 23rd to December 15th, 2020, with a hiatus from April to July and in November due to participant furloughing and lack of availability during the first and second Covid-19 pandemic lockdown periods in the UK. Due to a limited sample pool, participants were contacted opportunistically via email; some participants were also subsequently introduced via chain referral (Huntington, 2000). Eligible participants were any person whose role directly and regularly contributed to the data collection, surveying and management of local bird species populations, and/or in making management decisions as local experts or facilitating the decision-making process (Davis and Wagner, 2003). This includes but is not limited to: site managers, reserve wardens (including seasonal, assistant, and volunteer wardens), volunteers and ecologists. Participants under the age of 18 were not accepted. Relevant job roles were dependent on reserve management authority (e.g., RSPB or Wildlife Trusts). If possible, we requested to interview the youngest and oldest people working at any given reserve as a pair of interviews; however, in many cases any available staff were invited for interview.

In order to approximate potential sample size, the number of inland reserves (including local and national nature reserves, Sites of Special Scientific Interest, and Special Areas of Conservation) with permanent staff was estimated at ~300 inland/non-wetland reserves using Natural England's Designated Sites Search tool (Natural England, 2021). Many UK reserves have multiple staff (e.g., RSPB reserves), but smaller reserves are often staffed by regional teams who manage multiple reserves. We therefore estimated total sample frame as approximately 250 pairs.

2.4. *Interview outline*

Interviews were split into three sections (Supplementary S1 for questionnaire transcript and Table S1 for question rationale). Section one of the questionnaire collected participant demographic data, local conservation experience (current role, employer, years of experience in current role, years of conservation experience, years since first visit to the reserve that the interview focussed on) and birding interest and experience (proportion of time spent at the reserve/bird watching). Section two asked participants three questions for each of the six species: their perceptions of the maximum possible abundance on the reserve if all management was tailored toward that species, the current abundance on the reserve, and a desirable target abundance which balanced management for other desirable species and processes on the reserve. The final section asked participants for their perceptions of long-term trends on the reserve for each species, from their first experience of the reserve to the time of the interview (from the following categories: 'increased', 'no change', 'decreased', 'not present,' and 'don't know'), and to rank species in order of conservation priority (1 = highest, 6 = lowest), considering the answers given in the previous section and on long-term trends. Having completed this final section, participants were then given the opportunity to change their earlier answers regarding perceived abundance; however, none of the participants chose to change their answers.

Interviews were conducted either by phone or video call, using semi-structured interview techniques. As face-to-face interview techniques can provide lower non-response rates (Heerwegh and Loosveldt, 2008) and highly representative results (Szolnoki and Hoffmann, 2013), video calls were preferred over phone calls wherever possible. When participants consented, interviews were recorded to allow future reference to anecdotes and details mentioned during the interview. Interview results, data and key notes about perceived reasons for species population change were written on pre-printed interview sheets (see supplementary S1) and transcribed into a spreadsheet after each interview. All participants confirmed that they recognised all of the species by name at the start of the interview and confirmed that they were based on conservation sites or reserves in England.

2.5. *Data analysis and statistics*

A total of 45 participants were interviewed, with 44 participants completing the full questionnaire. Participants were paired according to their focal reserve and categorised into 'high' or 'low' groups according to each measure of experience (age, years in current role, years on reserve, years of conservation experience, years since first memory of reserve). A single participant was sampled for six of the reserves, so these unpaired participants were not included in any subsequent analyses. Three participants were interviewed for two reserves, so the oldest and youngest were paired and the third participant was excluded. The final paired sample size comprised of 36 individuals, or 18 pairs (Table 2).

Statistical analyses were conducted using R software version 3.6.2 (R Core Team, 2019). To explore the relationship between age and experience for each pair, we counted the number of pairs in which age and each measure of experience were congruent (i.e., the oldest member of the pair was also the most experienced). For years of experience on reserve, years of experience on reserve in conservation, and years since first visit to the reserve, the older participant had fewer years of experience than the younger participant in two pairs, while for experience in role, the oldest participant had fewer years of experience in three pairs. Therefore, for all measures of experience, age and experience were not statistically substitutable. However, Pearson correlations indicated a strong correlation ($r > 0.75$, $p < 0.05$) between age, years in conservation, and years since baseline (Table S2). We therefore chose to run all subsequent analyses for number of years since each participant's first visit to the reserve (chosen to represent total time each participant had experience of the focal reserve); all subsequent references to 'experience' refer to this metric.

Table 2
Overview of participant demographics for all participants that completed the questionnaire (n = 44) and the paired sample used in subsequent paired data analysis (n = 36), separated into high and low experience groups.

	Full Dataset	Paired Dataset	
	Full (N = 44)	High (N = 18)	Low (N = 18)
Age			
Mean (SD)	44 (14)	52 (11)	36 (12)
Median [Min, Max]	42 [23,73]	54 [31, 71]	33 [23, 73]
Gender			
Female	9 (20.5%)	2 (11.1%)	4 (22.2%)
Male	35 (79.5%)	16 (88.9%)	14 (77.8%)
Job Role			
Area manager	3 (6.8%)	3 (16.7%)	0 (0%)
Assistant warden	4 (9.1%)	0 (0%)	4 (22.2%)
Ecologist	5 (11.4%)	1 (5.6%)	0 (0%)
Senior site manager	2 (4.5%)	1 (5.6%)	1 (5.6%)
Site manager	8 (18.2%)	4 (22.2%)	3 (16.7%)
Volunteer	7 (15.9%)	5 (27.8%)	2 (11.1%)
Warden	15 (34.1%)	4 (22.2%)	8 (44.4%)
Years in current role			
Mean (SD)	8.0 (9.6)	13 (13)	5.1 (4.9)
Median [Min, Max]	5.0 [0.33, 45]	9.0 [0.75, 45]	3.5 [0.33, 18]
Years on current reserve			
Mean (SD)	11 (11)	18 (14)	6.1 (5.6)
Median [Min, Max]	5.8 [0.50, 47]	16 (1.0, 47]	4.5 [0.50, 18)
Years since first visit (baseline)			
Mean (SD)	16 (13)	26 (14)	7.4 (5.4)
Median [Min, Max]	11 [1.0, 47]	28 [3.0, 47]	6.0 (1.0, 18]
Years in conservation			
Mean (SD)	19 (13)	29 (13)	11 (8.2)
Median [Min, Max]	17 (0.75, 49]	30 [0.75, 49]	10 [2.0, 36]
Prop.of time on reserve			
Mean (SD)	0.61 (0.27)	0.63 (0.33)	0.64 (0.22)
Median [Min, Max]	0.60 [0.10, 1.0]	0.75 [0.10, 1.0]	0.60 [0.30, 1.0]
Missing	1 (2.3%)	1 (5.6%)	0 (0%)
Frequency bird watching			
Daily	36 (81.8%)	14 (77.8%)	16 (88.9%)
More than once a week	8 (18.2%)	4 (22.2%)	2 (11.1%)

2.5.1. *Perceptions of abundance and long-term trends*

Prior to statistical analysis, pairs where both participants stated that the species in question was not present on the reserve currently and was unlikely to ever occur on the reserve (and therefore gave zero values for maximum, current and target abundance) were removed from subsequent paired analysis of abundance. Subsequent sample sizes for each species are given in Table S3. A two-way ANOVA was used to explore the significance of the relationship between experience, professional role and gender.

Differences in perceived current, maximum and target abundance were calculated within each pair by subtracting the perceived value provided by the more experienced participant from the value perceived by the less experienced member of each pair. A mean paired difference was then calculated across all pairs, for each measure of abundance. Similarly, differences in perceptions of species trends were calculated per pair as a measure of pairwise agreement. Paired agreement of perceptions of species trends were reported as three categories: 'total agreement' (both reported the same trend), 'adjacent trends' (one participant of a pair reported no change and the other reported increasing or decreasing), and 'no agreement' (one participant of a pair reported an increase and the other reported a decrease).

Significant differences in the perceptions of each measure of abundance (maximum possible population size, current population size, target population size) were tested between paired experience groups for each of the six species. The assumption of normally distributed difference scores between paired groups was first examined per species using Q-Q plots of the residuals and the Shapiro-Wilk normality test from the 'rstatix' package (Kassambara, 2020), adjusted using the Bonferroni correction for multiple comparisons. Paired t-tests were then used for normally distributed data and paired two-sample Wilcoxon tests were used for non-normal data. The null hypothesis for all tests predicted no significant difference in the paired means (in the case of t-tests) or medians (for Wilcoxon tests) between more and less experienced participants.

Linear models were used to investigate the relationship between paired differences in years of experience and perceptions of maximum, current and target abundance for each species. Similarly, the relationship between paired differences in experience and differences in levels of agreement of perceived trends was investigated using an ordinal logistic regression using the 'MASS' package (Ripley et al., 2021).

2.5.2. *Generational differences in target-setting*

The impact of years of experience and personal perceptions of local trends on perceived ranked species conservation priority was investigated at the individual-level, using cumulative link ordinal logistic regression mixed models (CLMMs) from the 'clmm' function in the 'ordinal' package (Christensen, 2019). A mixed model approach was used to group participants by reserve as a random effect to account for perceptual similarities within pairs. Trend factor levels with fewer than three participants were dropped to prevent rank deficiency, and perceived species priority ranks were binned into three groups (1|2 = 'high', 3|4 = 'medium', 5|6 = 'low') to ensure a sufficient sample size per priority level. The proportional odds assumption was met for all species except buzzard and marsh tit, and so the results for these species were not included in the following analyses.

2.5.3. *Power analysis*

Power analyses were used to exclude the effect of small sample sizes on the insignificance of the paired test results for all species and estimate the necessary sample size required to find a significant mean difference between paired groups for perceptions of maximum, current and target abundance for each species. For species with a normally distributed response variable, Cohen's *d* effect size was calculated using the 'pwr.t.test' function from the 'pwr' package (Champely et al., 2018) at the 80% statistical power threshold, which commonly benchmarks a 'high' effect size (Cohen, 1992; Miciak et al., 2016). Power was simulated at sample sizes ranging from 0 to 250 pairs (representing the approximate maximum sample frame), at intervals of 25 pairs for each species for each measure of abundance using the 'wp.t' function from the 'WebPower' package (Zhang et al., 2018), producing predictive power curves. High sample sizes indicate high levels of variability between pairs and *vice versa*. For species with a non-normally distributed response, study power was computed using Monte Carlo simulations at the same range of sample sizes using the 'sim.ssize.wilcox.test' function from the 'MKpower' package (Kohl, 2020).

3. Results

3.1. *Demographics and experience*

An overview of the sample size and the demographic characteristics, experience and interest in bird watching of participants in the full and paired samples is given in Table 2.

A mean difference in years of experience of 18.8 ± 8.8 years (range = 46 years) was found between the high and low experience groups (mean per group: high = 26.2 ± 14.3 years, low = 7.4 ± 5.5 years). We found a significant relationship between experience and gender (F (1, 26) = 6.78, $p < 0.05$), but not between experience and role (F (6, 26) = 1.75, p = 0.15) or the interaction of role and gender (F (2, 26) = 0.66, p = 0.52), indicating that male participants tended to have more years of experience but did not necessarily hold higher positions within reserve pairs. All participants stated that they watched birds at least once a week, indicating a high level of interest in and exposure to birds.

3.2. *Investigating evidence for SBS*

Paired tests found no evidence for significant differences in perceptions of current abundance between experience groups for any of the six species (Table 3). This result indicates that both members of each pair had a similar perception of current conditions, in line with the criteria required to provide evidence of generational amnesia. However, we also found no significant experience-related difference in paired perceptions of maximum abundance for all species, despite paired differences in number of years of experience (Table 3). These results are substantiated by Fig. 2, in which differences in perceptions of maximum and current abundance between pairs are very low for all six species, relative to mean perceived maximum and current abundance for each species, across all participants of each experience group (see Table S3). Furthermore, there was no significant effect of paired differences in years of experience and paired perceptions of current or maximum abundance for any species (Table S4).

No significant effect of paired differences in experience on the level of paired agreement of perception trends was found for any species (Table S5). However, buzzard showed the highest frequency of ‘total agreement’ between pairs (12 of 18 pairs), and skylark showed the highest frequency of ‘no agreement’ between pairs (2 of 15 pairs) (see Figure S2 for full results).

3.3. *Generational differences in target-setting*

No significant differences were found in perceptions of target abundance between experience groups, for any species (Table 3 and Fig. 2), meaning that experience has no significant effect on perceptions of desired target abundance for species with either increasing or declining national population trends. Furthermore, paired differences in years of experience did not significantly explain variation in paired perceptions of target abundance for any species (Table S4).

Of the three species experiencing national decline, nightingale was perceived as ‘high’ priority by the highest number of participants across all species (21 of 35), followed by marsh tit (Table S6). However, neither experience, trend, nor an interaction between experience and trend significantly predicted perceived species rank for skylark or nightingale. Perceived species priority levels are given in Table S6, and full results for all species are given in Table S7 & S8. The majority of participants perceived the nationally increasing species as ‘medium’ priority (blackcap = 16 of 35, nuthatch = 19 of 35, buzzard = 22 of 35), while skylark, blackcap and nuthatch were perceived as ‘low’ priority by the highest number of participants across all species (11 of 35). Neither experience nor perceived trend significantly predicted perceived rank for blackcap. For nuthatch, the odds of awarding a higher priority level increased by 38.7% for each year of increasing participant experience between each level of perceived conservation priority, independent of perceived trend (odds ratio = 0.613, p = <0.01, n = 29). Perceived trend also had a significant effect for nuthatch (Fig. 3), as participants who perceived a stable population trend were 76.1% more likely to award a higher priority than those who perceived an increasing population trend (odds ratio = 0.239, p < 0.01, n = 29). However, a significant interaction effect of experience and trend indicated that for every year of increasing experience, participants were 1.9% less likely to give nuthatch a higher priority when an increasing trend was perceived rather than a static trend (odds ratio = 0.981, p < 0.01, n = 29).

3.4. *Effect of sample size on study conclusions*

Mean sample sizes required to find a significant mean difference between higher and lower experience groups at the 80% threshold varied between species and abundance measures, with the greatest overall range seen for current abundance (Table 4). Given an approximate maximum sample size of 250 reserves in our study area, our results suggest that a significant difference between groups for all measures of abundance is only statistically possible for buzzard (Table 4). Across all species and if sampling all 250 reserves, a significant difference would

Table 3
Mean paired differences in perceptions of species abundance for: maximum, current and target abundance, comparing high and low experience groups per reserve, and paired test results testing for a significant difference between pairs for each measure of perceived abundance. Abundance refers to number of bird pairs. Increasing species are shaded white, and decreasing species are shaded grey.

Measure of abundance	Species	Mean difference in perceived abundance within each pair	Test	d.f.	t-value	V-value	P-value
Maximum abundance	Skylark	+10.80	Wilcoxon	14	▨	56	0.85
	Marsh tit	-5.24	T-test	16	-0.85	▨	0.42
	Nightingale	-3.21	T-test	13	-0.74	▨	0.47
	Blackcap	-6.44	Wilcoxon	17	▨	68	0.70
	Nuthatch	-7.94	T-test	16	-0.42	▨	0.68
	Buzzard	-1.61	T-test	17	-1.10	▨	0.29
Current abundance	Skylark	-13.93	Wilcoxon	14	▨	67	0.71
	Marsh tit	0.00	T-test	16	0	▨	1.00
	Nightingale	0.07	T-test	13	0.06	▨	0.95
	Blackcap	-9.56	Wilcoxon	17		34	0.08
	Nuthatch	-4.19	T-test	16	-1.29	▨	0.22
	Buzzard	-0.78	T-test	17	-1.10	▨	0.29
Target abundance	Skylark	-4.93	Wilcoxon	14	▨	58.5	0.73
	Marsh tit	-2.00	T-test	16	-0.74	▨	0.47
	Nightingale	3.86	T-test	13	0.81	▨	0.43
	Blackcap	-7.19	Wilcoxon	17	▨	45.5	0.25
	Nuthatch	-4.50	T-test	16	-0.73	▨	0.48
	Buzzard	-0.67	T-test	17	-0.83	▨	0.42

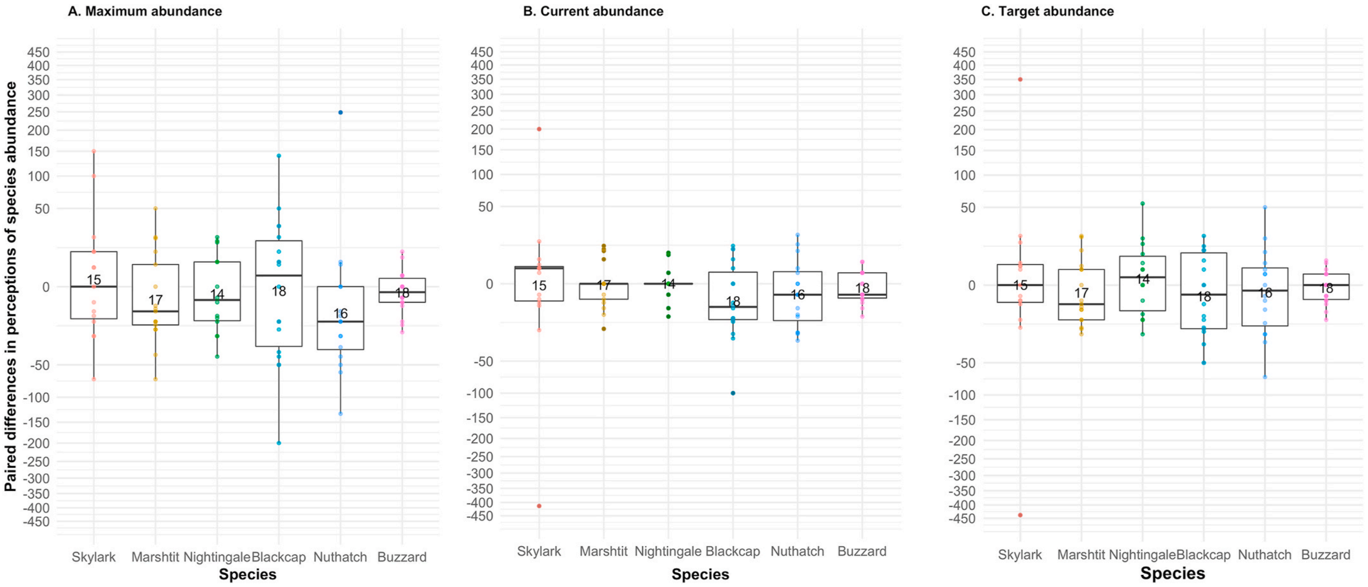

Fig. 2. Paired box and whisker plots comparing paired differences in perceived abundance between paired high and low experience groups for each species (high group – low group = differences). Box and whisker plots show the median, IQR and outliers (>2 standard deviations outside mean) of the perceived differences between paired perceptions for all pairs for: A, Maximum abundance; B, Current abundance; and C, Target abundance. Abundance refers to number of bird pairs. Sample sizes (number of pairs) are shown at the mean of each boxplot.

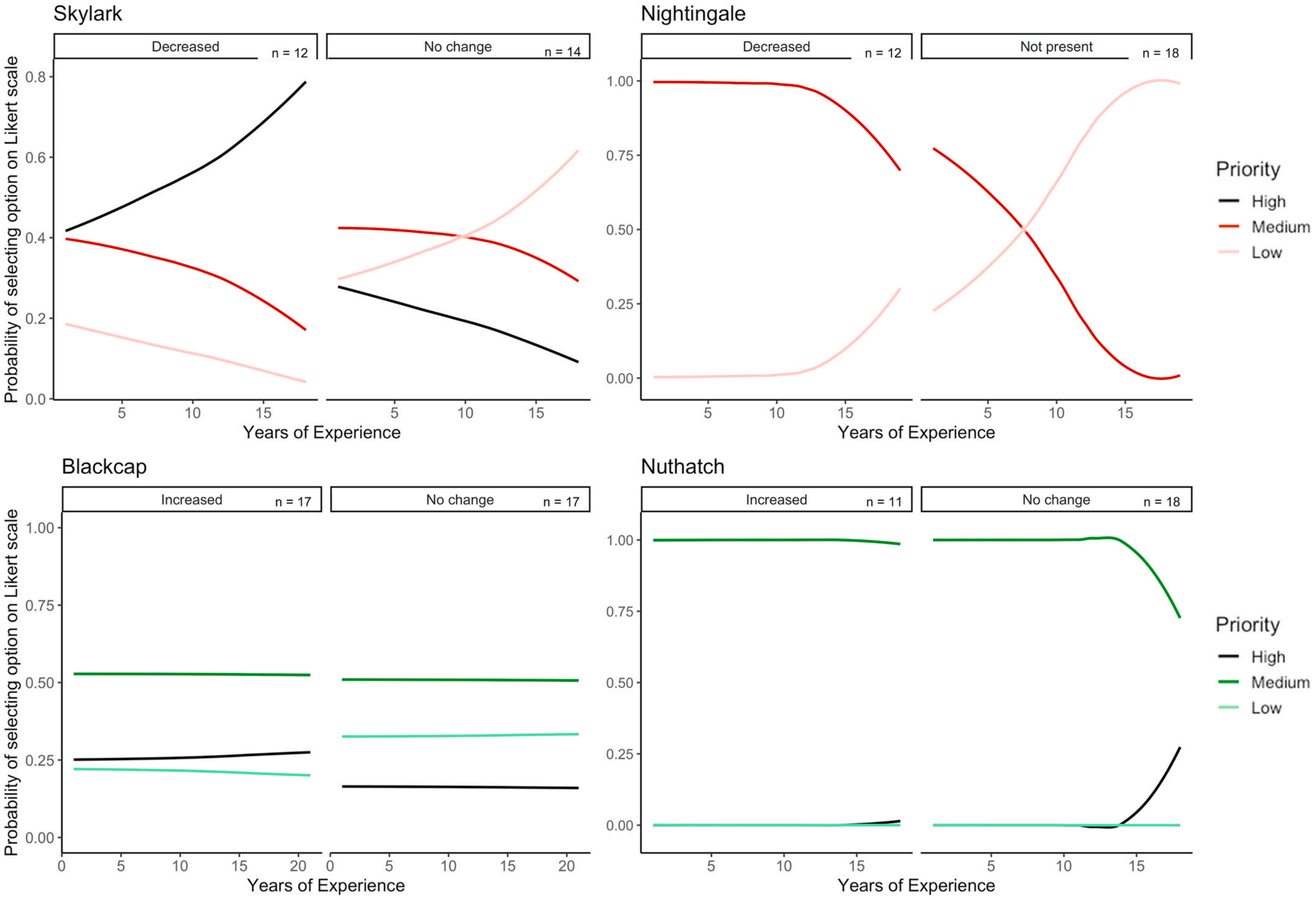

Fig. 3. Interaction effects of participant experience and perceived species trends on perceptions of conservation priority at the participant's focal reserve, represented by conservation priority. Significant results are found only for nuthatch, with a significant effect of experience, trend, and the interaction of experience and trend. For full CLMM results see Tables S7 & S8.

Table 4
Required sample size (pairs) to find a significant mean difference between higher and lower experience groups using paired t-tests at power = 0.80, and associated effect sizes. A value could not be estimated for current abundance of marsh tit, as Cohen's *d* effect size was equal to zero.

Abundance measure	Sample size (pairs) required for power = 0.8					
	Skylark	Marsh tit	Nightingale	Blackcap	Nuthatch	Buzzard
	Wilcoxon	T-test	T-test	Wilcoxon	T-test	T-test
Maximum	225	185	204	850	728	119
Current	775	N/A	26,227	55	77	119
Target	9600	244	175	65	239	206

be least likely to be detected in maximum abundance, and most likely to be detected in target abundance. Power analyses indicate that 250 would be a sufficient sample size to detect differences in target abundance for all species except skylark. Full power curves and predicted power at abundance intervals can be found in supplementary Figure S2 and Table S9.

4. Discussion

In 1995, Daniel Pauly coined shifting baseline syndrome in the context of conservation managers and academics working within fisheries ecology, citing the possible impacts that SBS may have on perceptions of fisheries conservation targets (Pauly, 1995). In this study, we explore evidence to support or contest Pauly's original hypothesis in the context of bird species population management on reserves across England, focussing on six species with varying relative national abundance and trends. Our results do not support Pauly's original hypothesis, as we find little evidence to suggest that SBS is occurring in this case study. Pairing participants according to higher and lower experience, we found no significant differences in paired perceptions of either current and maximum possible species abundance on local reserves. Most importantly, we are the first to investigate the possible effect of SBS on target-setting within conservation management. We found some individual variation in perceptions of species conservation priority when comparing between species, driven by amount of participant experience and perceptions of species trends since their first visit to the reserve, indicating possible evidence for generational amnesia for one species. However, when individuals were asked to set target abundances if conservation was directed for a single species, we find no significant effect of experience on paired perceptions of target abundance for any of the six species included in our study. Our results suggest that SBS may not be a significant issue in conservation management, but generational differences in target-setting may occur when individuals must choose between species.

According to the definitions outlined by Papworth et al. (2009), the first two criteria required to indicate evidence of SBS are demonstrated in this sample. First, all participants have been exposed to, and have experience of, biological change, as evidenced by the documented abundance changes across all species (Table 1) and high participant interest and exposure to nature (Table 2). Second, despite differences in experience of biological change within each pair (measured as number of years since each participant's first visit to the reserve) we found no significant differences between paired perceptions of current abundance for all species (Papworth et al., 2009). However, the lack of experience-related differences between paired perceptions of maximum abundance demonstrates that years of experience, and therefore differences in personal baselines and experiences of long-term population change, have no significant effect on perceptions of maximum possible species abundance (Table 3). Furthermore, mean differences in paired perceptions of current and maximum abundance between experience groups were not only statistically insignificant (Table 3), but also very low compared to the mean perceived abundance for each species (Table S3). Finally, no significant effect of paired differences in experience was found for any species, either for differences in perceived maximum and current abundance (Table S4), or for the level of paired agreement of perceived long-term trends (Table S5). This suggests that experience has little effect on perceptions of species population change, despite differences in experience of past population change. These findings therefore suggest that there is no detectible effect of SBS in this sample.

Evidence of the effects of SBS on target-setting was explored using experience-related differences in paired perceptions of target species abundance, again finding no significant difference between perceptions of experience groups (Table 3 and Table S4). At the individual-level, ordinal logistic regression analysis tested the effects of experience and perceptions of species trends on perceived conservation priority (Fig. 3 and Tables S7 & 8) and found significant effects for nuthatch, but not for three other species. We found more experienced participants tended to attribute higher priority for this nationally increasing species (Fig. 3). Although contrary to our original hypotheses, this result may be attributed to greater number of years of experience of population change and, as the nuthatch is a rapidly increasing species across the UK, a lower 'baseline' population size in more experienced participants. According to the BTO, national nuthatch populations have increased by nearly 70% since 1966, with some declines in Cornwall, Kent and Wales (Woodward et al., 2018). Therefore, compared to less experienced participants, those with greater experience may be more cautious in their future target-setting, given knowledge of much smaller populations in the past. As generational amnesia is a key mechanism driving SBS (Papworth et al., 2009; Jones et al., 2020), characterised as age- or experience-related differences in perceptions of change, these generational differences in targets may also be indicative of generational amnesia in the form of 'lifting baselines', as more experienced participants may be basing decisions on past experiences of historical declines, despite recent increases in national nuthatch abundance (BTO, 2010; Roman et al., 2015). However, experience-related differences may also be reflective of generational differences in the factors driving personal perceptions of change outside personal experiences, such as education curricula and alternative knowledge sources such as social media (Soga and Gaston, 2018).

Focussing on participant perceptions of species abundance and trends, our results are in agreement with previous studies of conservation managers (e.g., Cook et al., 2014; Muldrow et al., 2020), as we find little evidence to suggest that SBS occurs in this sample. However, our study goes beyond the scope of previous research by investigating the impacts of SBS on conservation target-setting, indicating that generational differences in experience and knowledge may influence perceptions of species conservation priority for increasing species, but with no evidence for an effect for declining species. As SBS is likely to have more significant negative effects for declining species (see Fig. 1), these results suggest that SBS is not a significant conservation concern in this case study. Furthermore, especially when combined with the findings of previous studies of SBS in conservation management, our results support the theory that conservation experts are at low risk of SBS (Fig. 1), especially when compared to previous evidence of the effects of SBS in other stakeholder groups (e.g., Papworth et al., 2009; Turvey et al., 2010; Jones et al., 2020).

Finally, power analyses showed that based on the data collected in this study, even if the estimated maximum sample frame of 250 pairs of conservation managers on UK reserves were sampled, it would not be possible to detect a statistically significant difference in perceptions of abundance or targets for half of the species studied here (Table 4). Even if SBS was statistically detectible in this larger possible sample, the practical effects and implications of SBS would be minimal, as the differences in perceived abundance are low for all species, across all measures of abundance (Table 3). The minimal effects of SBS are signified by low predicted effect sizes (Table S9) which translate into high predicted sample sizes required to find a significant statistical effect. These results are likely due to high agreement between pairs, despite differences in years of experience, which may be driven by many factors, including communication, access to datasets and written records, and/or connectedness to nature (Zelenski and Nisbet, 2014; Soga and Gaston, 2018).

Our results, and those of previous studies (e.g., Cook et al., 2014; Muldrow et al., 2020) may be explained by multiple factors that enable the retention of knowledge through generations. Effective training and the co-development of species targets by more and less experienced members of the reserve management team may lead to the homogenisation of perceptions on the reserve as a result of communication and knowledge-sharing, despite variation in age or experience (Fazey et al., 2006). In addition, open communication about the past and open access to local and national historical data on species population change may enable participants of any age to gain knowledge of past ecological conditions and shift the temporal 'position' of their baselines to encompass historical ecological change. At the national scale, long-term biological datasets such as the BTO CBC/BBS, as well as bird guides and books (e.g., Cocker and Mabey, 2005; Macdonald, 2019), provide a rich, open-access history of bird species population change, while volunteer-led citizen-science datasets held by experienced individuals can also provide access to in-depth local knowledge (e.g., Treswell Wood, 2021). However, relevant local ecological knowledge is often not recorded, as stated by one participant: "Things that we think we will remember are never recorded", risking effects of SBS in future due to loss of knowledge through memory loss or distortion (Barthel et al., 2010). Additionally, three participants in this sample cited a lack of funding and paid positions as current and future barriers to communication and knowledge-sharing between generations in the sector, as unpaid internships may disincentivise young people from joining the profession (Fournier et al., 2019).

Some limitations in this study should be addressed in future research. This case study is constrained to England and focuses only on birds, primarily to maximise sample size, as bird conservation is represented by some of largest conservation charities in the UK (e.g., the RSPB and BTO), and to minimise travel time and costs for interviews. To ensure the generalisability of conclusions, future studies should seek to expand this research to other areas of conservation, including fisheries, to verify our findings in relation to Pauly's original hypothesis (Pauly, 1995). Face-to-face interviews were prevented by the global Covid-19 pandemic, which alongside persistent time pressure on conservation managers (e.g., Canessa et al., 2020) may have prevented measurement of the full extent of managers' implicit experiential knowledge (Fazey et al., 2006). Our questionnaire was also designed to minimise the time-cost for time-pressured interviewees, meaning that questions were constrained to 'closed' formats. Although notes were taken during interviews, the full extent of implicit knowledge was therefore not assessed due to a lack of more 'open' questions such as free listing (Newing, 2010). Furthermore, we found that more experienced participants were more likely to feel uncomfortable when asked to hypothetically estimate the maximum possible abundance of a species on the reserve, if all management was tailored towards that species. This may have introduced bias into their answers towards what they thought was acceptable, rather than their true perceptions (Grimm, 2010). By basing decisions more on experience, more experienced managers may also be more unwilling to consider a hypothetical scenario compared to less experienced managers, who could be more likely to utilise abstract thinking based on learned knowledge to estimate possible future scenarios (Evans, 2008).

Future studies should consider the use of participatory group methods, in addition to individual interviews, to encourage open discussion between experience groups and observe differences in opinion about current and past ecological conditions (Newing, 2010). Further research should also explore variation in the presence of SBS across all areas of environmental management (e.g., policy, academia and ecological consultancy) and across a variety of taxonomic groups, countries, cultures and management sectors (Soga and Gaston, 2018). Factors other than the duration of personal experience (e.g., type of personal experiences, preferences and values towards individual species, and local resources) may also drive conservation priorities and decision-making, and future exploration of such factors and how they influence personal perceptions of conservation prioritisation may reveal predictors of conservation effectiveness or success (Cook et al., 2014). More broadly, while the use of past baselines is useful in many circumstances, including to set targets for ecological restoration and species conservation, in the face of novel ecological conditions future studies may need to shift focus away from the effects of experience on predicted, towards the use of alternative baselines. For example, Hirsch (2020) identified the need for anticipatory practices and targets using a case study of the Columbia River Basin, especially in the face of accelerating land-use and climate change. The study highlights the importance of baselines for future target-setting but recognises the need for adaptive predictions of future change based on emerging ecological threats (Hirsch, 2020).

Growing evidence suggests that SBS is less of a threat to conservation management than previously hypothesised (Pauly, 1995; Cook et al., 2014; Thurow et al., 2019). Using a case study within bird species conservation management in England, we found no significant experience-related differences in paired perceptions of current and target abundance, indicating little evidence to suggest that SBS is occurring in this sample. Differences in perceived conservation priorities when selecting between species highlight the influence of multiple factors when choosing conservation targets. By empirically testing the influence of factors such as communication of past knowledge and experiences, connection to nature and access to historical data on preventing the occurrence of SBS, we might hope to map out potential methods to combat the negative effects of SBS on conservation in other areas (see Jones et al., 2020). In the face of accelerating ecological change, conservation managers and practitioners face an increasingly difficult task when attempting to assess and conserve the state of current ecosystems. However, this study suggests that SBS may not be as significant a threat in conservation management as first thought.

Data availability statement

All anonymised social data are available from Royal Holloway Figshare Digital Repository are available from Royal Holloway Digital Repository (https://figshare.com/s/c58a76407509d5267fe0; Jones et al., 2021). Please contact corresponding authors for more information. Please contact the corresponding author for more information.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.113308.

Author contributions

L.P.J., S.K.P. and S.T.T. conceived the project idea, developed methods and discussed results; L.P.J. collected questionnaire data and performed analyses. All authors contributed to and authorized the final manuscript.

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8. Discussion

In 1995, the term ‘shifting baseline syndrome’ (SBS) was coined to describe a tendency to forget personal experiences of the past, leading people to view the world through a short-sighted lens (Pauly, 1995). Other early studies also predicted that SBS would have negative consequences on conservation research (Kahn and Friedman, 1995; Pauly, 1995), however, little empirical evidence of the existence or consequences of SBS exists in the current literature (Soga and Gaston, 2018; Guerrero-Gatica et al., 2019). This thesis presents new evidence for the existence of SBS within conservation and provides novel understanding of the implications of the syndrome for conservation science, management, and policy. The work presented in this thesis also highlights the importance of local ecological knowledge (LEK) and personal experience-based perceptions of ecological change, not only in investigating the impacts of SBS, but as a key knowledge source for conservation (Aswani et al., 2018), especially in the absence of long-term biological datasets and in rapidly shifting biological systems (Redpath et al., 2013).

Background

Almost all ecosystems exist in a state of constant shift and change. Human impacts on the natural environment are growing in magnitude, threatening species, landscapes and ecosystems at ever-increasing rates (Steffen et al., 2015). Over the past few decades, humankind have witnessed 75% declines in total flying insect biomass in protected areas (Hallmann et al., 2017), global wildlife populations have decreased by 50% (Dirzo et al., 2014), while land use and climate change, invasive species and diseases, pollution and species overexploitation already threaten 25% of all mammal species and 13% of all bird species (Tilman et al., 2017; Almond et al., 2020). However, such global figures are hard for most individuals to grasp, often leading to us to underestimate the true extent of ecological change and view the world in a local context based solely on our own experience (Soga and Gaston, 2018).

As evidenced by this thesis (Chapter 3), gradual ecological change can go unnoticed as new conditions are readily accepted as the normal state of play over multiple generations (Jones et al., 2020). By forgetting the past, people have little context on which to judge long-term change, potentially biasing perceptions of current ecological conditions and future possible targets (Pauly, 1995). Under current rates of ecological degradation, the long-term potential impacts of SBS present an ever-growing challenge, as people continue to accept increasingly degraded visions of ecological conditions as a new normality (Tilman et al., 2017; Soga and Gaston, 2018).

Furthermore, in terms of ecological management, SBS has been thought to hold the power to bias perceptions of past baselines and negatively impact the ambitiousness of future conservation planning and restoration targets as the magnitude of the differences between current and past ecological conditions is underestimated (Pauly, 1995; McClenachan et al., 2012). Yet, very little empirical evidence of the impact of SBS on target-setting exists (Chapter 1), despite extensive discussion in the literature (e.g., Cook et al., 2014; Muldrow et al., 2020).

Contributions

An important contribution made by this thesis has been to review contemporary knowledge of SBS in the context of LEK and previous ‘paired data’ studies, including evidence for the existence of the syndrome, previous methods to investigate evidence of SBS, its potential causes, implications and proposed methods to combat the possible negative effects of SBS on conservation ecology (Chapter 1). The bringing together of concepts from ecology, psychology and social science enabled the consideration of the interconnection of multiple concepts, such as memory effects (Rost, 2018), connectedness to nature (Kahn and Friedman, 1995), the extinction of experience and evidence for SBS (Soga and Gaston, 2018), with the aim to identify key gaps in the current interdisciplinary literature. In this review, two key limitations of the SBS literature are identified: a lack of empirical evidence of the existence of SBS by statistically comparing social and biological datasets, and a lack of evidence of the potential effects of SBS, both on public perceptions of the need for conservation and on conservation decision-making and target-setting within conservation management.

First, while the SBS literature is growing, the majority of studies do not investigate empirical evidence for the syndrome following the widely accepted criteria defined by Papworth et al. in 2009 (Papworth et al., 2009; Guerrero-Gatica et al., 2019). By contrast, most studies only cite SBS as a ‘possible’ mechanism behind age-related or generational differences in perceptions of ecological change (e.g., Saenz-Arroyo et al., 2005; Ainsworth et al., 2008), without directly comparing social and biological datasets on similar temporal and spatial scales. As discussed in Chapter 1, these studies may serve to artificially bolster the profile of the syndrome, as relatively little empirical evidence exists to support the proposed impacts of SBS that such studies frequently cite. Furthermore, most SBS studies focus on marine ecology (e.g., Ainsworth et al., 2008; Pinnegar and Engelhard, 2008; McClenachan, 2009; Thurstan et al., 2016), with comparatively little investigation into evidence for the effects of SBS in terrestrial contexts (Guerrero-Gatica et al., 2019).

This thesis provides one of only five published studies to investigate empirical evidence of SBS in the field of conservation (Guerrero-Gatica et al., 2019), and furthers development towards a methodological framework for future studies to follow and build upon (Chapter 3). Empirical evidence of SBS was investigated in the context of garden bird species population change in the UK. Spatial and temporal pairing of social and biological datasets created a measure of paired agreement. Empirical evidence of generational amnesia was found, as younger, less experienced people were less aware of historical ecological conditions and at greater risk of indicating evidence of SBS (Jones et al., 2020). Furthermore, the majority of the current SBS literature focuses only on 'generational amnesia', which is only one of the two possible mechanisms thought to drive evidence of SBS. Despite becoming a widely accepted theory (Soga and Gaston, 2018), prior to this thesis only one study had investigated evidence of 'personal amnesia' (Papworth et al., 2009). In Chapter 3, evidence of personal amnesia was only found in 2% of the study sample, therefore although this study fills an important gap in SBS research, my findings suggest that personal amnesia should be considered an individual-scale rather than a population-scale issue (Jones et al., 2020).

Following the methodological framework outlined in Chapter 3, this thesis also provides the first study to investigate international differences in empirical evidence of SBS, in the UK and Finland (Chapter 4). The availability of long-term biological datasets in these countries presented a unique opportunity to compare international evidence on the incidence of SBS using similar garden species, with three species shared between both datasets (Chapter 4). As countries with distinct cultural differences and attitudes towards nature (see Chapter 2), comparison of agreement between social and biological datasets in the UK and Finland enabled investigation into the possible mechanisms driving incidence of SBS, beyond those included in Chapter 3. Correlation of participant age and magnitude of biological change over time indicated a similar negative trend in both countries, with younger participants experiencing less change over time than older participants (Chapter 4, Figure 1). However, the limited temporal range of biological data in Finland, compared to that available in the UK, resulted in a restriction in the age range of participants in this study. When comparing results to those found in Chapter 3, significant differences could be found between analyses using the restricted UK dataset (spanning 52 years) and the unrestricted UK dataset (spanning 72 years), as no significant age-related differences in abundance agreement were found using the restricted UK dataset, suggesting evidence of a statistical phenomenon known as range restriction (Dunbar, 1991; Bobko, 2001; Hunter et al., 2006). These results therefore suggest that future studies should be cautious when studying evidence for SBS over a limited temporal range. Evidence of the potential implications of range restriction on future conservation studies was explored further using model comparison and power analysis on the UK and Finland samples (Chapter 4). Range restriction represents a major issue that is relatively under-studied in the conservation social science literature, yet this thesis highlights the potential negative effects of range restriction on statistical conclusions and power. The value of LEK as a key data source in conservation is again highlighted by this phenomenon, as living memory, as well as other alternative historical data sources can provide in-depth, long-term datasets on ecological change (Turvey et al., 2015; Thurow et al., 2019), which may help to limit the effects of range restriction.

Where long-term biological datasets do not exist and are perhaps impractical or even impossible to collect, LEK is increasingly valued as a primary data source for investigating species abundance and trends, and evaluating species conservation status (Nash et al., 2016; Turvey et al., 2015). However, especially for rare, elusive and data-poor species, relatively little is known as to the best and most effective course of action with which to collect LEK. Furthermore, several potential biases and heuristics, (including SBS) are likely to influence personal perceptions of current and past species status (Turvey et al., 2010). In Chapter 6, patterns in agreement between data sources were investigated, using perceptions of bird species abundance and trends in the UK and Finland as an effective case study. This thesis provides early evidence of areas of agreement and disagreement between data sources, highlighting agreement was likely to vary between time period, species, countries and participants for species abundance. By contrast, my results indicated that trend agreement was likely to vary between species but not between countries or according to participant traits, indicating that for poorly known species, research on long-term trends may be a more reliable measure of species status than abundance.

Evidence for SBS within conservation management remains a topic of discussion in many SBS publications (e.g., Campbell et al., 2009; Plumeridge and Roberts, 2017; Soga and

Gaston, 2018), since Daniel Pauly first described the issue in the context of fisheries management (Pauly, 1995). Pauly suggested that knowledge of baseline ecological information is lost between generations, leading to the gradual accommodation of degraded conditions and less ambitious conservation targets. However, only a small pool of studies has investigated evidence of SBS in conservation and fisheries managers, each finding little evidence for SBS (Cook et al., 2014; Plumeridge and Roberts, 2017; Muldrow et al., 2020). This thesis provides further evidence to contest Pauly's original hypotheses, finding no significant experience-related differences in conservation professional's perceptions of bird species abundance or long-term trends in England (Chapter 7). Further power analysis discounted the effects of limited sample size on study conclusions, as for all species, SBS would not be statistically detectible even if the maximum estimated sample frame were sampled (Chapter 7, Table 4). These results, combined with empirical evidence of SBS in members of the public (Chapter 3) support the theoretical risk matrix presented in Chapter 7. This thesis suggests that experience, and therefore often age, is the principal predictor for increased risk of SBS occurring in conservation, however further research should test the applicability of this risk matrix in a wider variety of case studies, as is discussed later in this chapter.

The second key limitation in the SBS literature tackled by this thesis is the lack of empirical evidence of the effects of SBS on perceptions of conservation priority (Soga and Gaston, 2018). Despite extensive discussion of the suspected negative impacts of SBS on conservation awareness and support, both in marine (Pinnegar and Engelhard, 2008; Campbell et al., 2009) and terrestrial contexts (Kai et al., 2014; Herman-Mercer et al., 2016), this study presents the first evidence of a negative impact of SBS on perceptions of conservation priority for declining species (Jones et al., 2020). In Chapter 3, my findings suggest that younger people were less likely to perceive a greater need for conservation action for species in decline, in contrast the global media portrayal of younger people as pro-environmental advocates (Gardner et al., 2020). These results confirm that SBS hypotheses that SBS negatively impacts public support for conservation initiatives, especially for declining species, as described by the SBS risk matrix in Chapter 7. Furthermore, our conclusions potentially extent to wider landscape-scale projects such as rewilding, as anecdotally discussed in the 2018 book 'Wilding' regarding Knepp Estate, in which older local people were more likely to support the return of wild landscapes than younger generations (Tree, 2018).

Limited evidence for the impacts of SBS on the ambitiousness of conservation target-setting and decision-making has remained a significant gap in the SBS literature since Pauly's seminal essay (Pauly, 1995; Guerrero-Gatica et al., 2019). Due to the gradual accommodation of degraded conditions, it was hypothesised that the use of inappropriate reference points for evaluation would lead to the setting of less ambitious targets (Pauly, 1995). As previously mentioned, the lack of evidence of SBS within the conservation managers surveyed in Chapter 7, agrees with previous studies in this area (e.g., Cook et al., 2014; Muldrow et al., 2020). Furthermore, these findings provide additional evidence to suggest that SBS may not be as significant a threat to conservation decision-making as first thought, as the impacts of generational amnesia was suggested for only one of the six species in the form of 'lifting baselines' (Roman et al., 2015), rather than indicating negative impacts of SBS seen in Chapter 3. While further research is needed to confirm these conclusions across a range of conservation disciplines, my results suggest that future SBS research should focus on public perceptions of ecological change to minimise potentially negative impacts of SBS for conservation (Chapter 3).

Limitations and future work

Although over 25 years have passed since the publication of Pauly's paper on SBS (Pauly, 1995), little empirical evidence for the syndrome exists and research into the causes, implications and combat methods to reduce the potential impacts of SBS is still at an early stage (Soga and Gaston, 2018). The following section discusses directions for future work that build upon the findings in this thesis.

The most significant barrier to gathering empirical evidence of SBS and its impacts on conservation that should be addressed is the lack of robust, standardised and long-term biological datasets against which to compare perceptions of ecological change (Soga and Gaston, 2018). While the importance of long-term monitoring datasets in ecology is well-recognised, there are still relatively few studies that span multiple generations, and even fewer that collect data within current biodiversity hotspots of ecological change, where the impacts of SBS are likely to be most significant (Magurran et al., 2010). Furthermore, as encountered during this thesis, many of the long-term biological datasets are not fully open-access or are unavailable to many potential users, including academics (Chapter 2). When accessible, potential bias and error are still a possible issue in long-term datasets, often due to spatial or temporal variability and non-standardised sampling techniques (Boakes et al., 2010; Turvey et al., 2015).

To avoid issues with biological data access and availability, a potential future option for SBS research is the use of alternative long-term data collection methods and sources in place of biological datasets, against which to compare social perceptions of change. Possible alternative data sources include historical photographs (e.g., Chen et al., 2011), paleo-ecological datasets (e.g., Chambers et al., 2013) and historical or museum archives (Turvey et al., 2015; Manzano et al., 2020) to construct robust long-term descriptions of past ecological change. In recent meta-analysis of SBS research, Guerrero-Gatica et al., (2019) defined empirical SBS investigations as "scientific articles that showed both biological and social measurements" of the species or ecosystem studied, thus excluding any study using alternative data sources to measure biological change (Guerrero-Gatica et al., 2019). Many novel data sources have already been utilised to suggest evidence of SBS (e.g., McClenachan, (2009) used historical photographic records in the Florida Keys, USA - see Chapter 1, Figure 2), however, only one study has compared perceptions of change to non-scientific data to provide empirical evidence of SBS. In the absence of comprehensive local data sources, Fernandez-Llamazares et al. (2015) conducted a systematic review of the literature on local ecological change to ascertain historical baselines of the Tsimane community of Bolivia, which were then compared to local perceptions of current and past ecological conditions. The study found evidence of generational amnesia, which they attributed to gradual decreases in the intergenerational sharing of LEK in the community (Fernández-Llamazares et al., 2015).

If using these alternative data sources to investigate empirical evidence of SBS, researchers would need to consider the potential inherent biases (Chapter 6), as well as those found in people's perceptions of ecological change (Papworth et al., 2009; Daw, 2010). However, such studies would still provide critical evidence to map out the potential scenarios in which SBS might take place. The longevity of alternative historical datasets may also enable the investigation of SBS over longer timescales and multiple generations, which may serve to prevent the effects of issues such as range restriction (Chapter 5). For example, Plumeridge and Roberts (2017) suggested evidence of the impacts of SBS using historical perceptions of ecological change in the Dogger Bank within the North Sea, UK. The studies presented in this thesis (exemplified by Chapter 4 in which no evidence of SBS was found using samples with restricted age range) may be limited by the temporal scale over which SBS was investigated.

Building on the risk matrix presented in Chapter 7, future studies should seek to create a generalisable measurement of SBS 'risk', as a combined measurement of potential likelihood of a detectible level of SBS occurring and to identify the potential magnitude of SBS effects within a range of conservation-relevant scenarios. A measurement of SBS risk may help to drive a greater evidence-base of SBS by bridging gaps in the current SBS record, where biological data might be scarce or restricted (Chapter 5) and could provide a standardised system to compare evidence of SBS more easily between countries or communities (Chapter 4). Furthermore, a recent study suggested that the effects of SBS may be more significant at a critical rate of ecological change in which change is difficult to recognise, as "the urgency of a problem…is not yet obvious", especially if biological evidence of ecological change is unclear (van der Bolt et al., 2021). This critical rate of change may vary globally, in conjunction with generational timespans of local communities. A risk matrix may therefore provide key indicators regarding the likelihood of SBS effects having a negative effect on conservation. Additionally, mapping the incidence of SBS to certain areas, communities or age groups may confirm the key risk factors and aid in predicting evidence of SBS. Furthermore, the characteristics of those not impacted by SBS would help to chart a course to combat the negative impacts of SBS and illuminate the most effective preventative measures needed to counteract potential negative effects of SBS, such as increasing experience of local nature and promoting intergenerational conversations about ecological change (Soga and Gaston, 2018). A risk framework may also be transferable to other fields in which SBS may occur as both negative changes (e.g., climate change, crime rates) and positive changes (e.g., progressions in public health and quality of life) may go unnoticed between generations.

More widely, my findings and the risk matrix (Chapter 7) suggest that SBS may present an important issue in any industry or academic field which deals with change over time, indicating the need to widen SBS research into other fields. While this thesis focusses on conservation, age- or experience-related differences in knowledge of the past may significantly impact perceptions of geological, business, political, and industrial risk, to name a few. Diane Vaughan's 'normalisation of deviance' theory explains a habitual acceptance of deviance from the rules and a lack of considerations of risk (Vaughan, 1998). Similarly, Herbert A. Simon's theory of 'bounded rationality' states that each individual's ability to make rational decisions is primarily limited by the available contextual information (Simon, 1997). A common precursor to both theories states that a lack of knowledge, experience or awareness may inhibit a full and accurate perception of the current system conditions, preventing rational decision-making. For example, in the field of environmental disaster risk, Atreya et al., (2013) found evidence of knowledge loss in perceptions of risk of local flooding events in Georgia, USA. Experience-related differences in perceptions of flooding risk were investigated in the context of house price fluctuations following severe flood events, finding that perceptions of flood risk normalised after a four-to-nine-year period as house prices returned to pre-flood levels faster than expected by inflation (Atreya et al., 2013). Similarly, 'organisational knowledge loss' is described as the loss of valuable skills and knowledge as more experienced employees leave employment (Lucie and Hana, 2011), leading to the loss of skills that may be vital to the ongoing success of many companies and skilled industries (Strack et al., 2008).

The risk matrix presented in Chapter 7 may provide a template for identifying and predicting the risk of SBS in many neighbouring fields and help to combat the negative impacts of SBS (Chapter 3). For example, Jennex (2014) formulated a methodological framework for assessing and preventing knowledge loss due to retirement by quantifying risk of knowledge loss and prioritising the conservation of knowledge based on the potential importance of memories and the likelihood of retirement (Jennex, 2014).

Wider significance

Given the hypothesised causes of SBS (Chapter 1), evidence for the existence of SBS and its negative impacts on conservation and restoration is likely to increase. According to Soga & Gaston (2018), lack of access to historical datasets and disconnection from nature are the key causes of SBS. The review cites 'the extinction of experience' as a key factor, as reduced interest and interactions with nature form a positive feedback loop driving unfamiliarity with changes in the natural environment (Soga and Gaston, 2018).

While evidence of SBS is currently focussed within the Global North (e.g., Papworth et al., 2009; Herman-Mercer et al., 2016; Plumeridge and Roberts, 2017; Jones et al., 2020) where long-term biological datasets are more available (Magurran et al., 2010), current initiatives to increase connectedness to- and awareness of nature (Bragg et al., 2013; Harvey et al., 2020), may lead evidence of SBS to plateau in many Western and developed countries. However, the effects of SBS may become more pronounced in many urbanising areas, as local communities may be increasingly unable to communicate the extent of change that occurs within a single generation. In the face of rapid urbanisation, younger generations may be increasingly unable to experience nature first-hand as rural-urban migration leads to increased physical and cultural ‘distances’ between older and younger generations (Pilgrim et al., 2008). Reduced intergenerational communication is therefore likely to lead to the loss of traditional ecological knowledge and languages with each generation and dominance of centralised education systems (Aswani et al., 2018).

Furthermore, with ongoing ecological degradation, SBS is increasingly recognised as a major current and potential future barrier to conservation success on a global scale (Soga and Gaston, 2018). Academic records indicate sharp rises in the number of citations of SBS studies in the last two decades, with a 41% increase in citations from 2017 to 2020 (Figure 1 – Web of Science, 2021). The issue has filtered through to non-academic mediums, such as environmental advocacy groups (Campbell et al., 2009), popular science books (Tree, 2018), and recently captured the interest of news outlets around the world (Greenreport.it, 2020; Popmech, 2020).

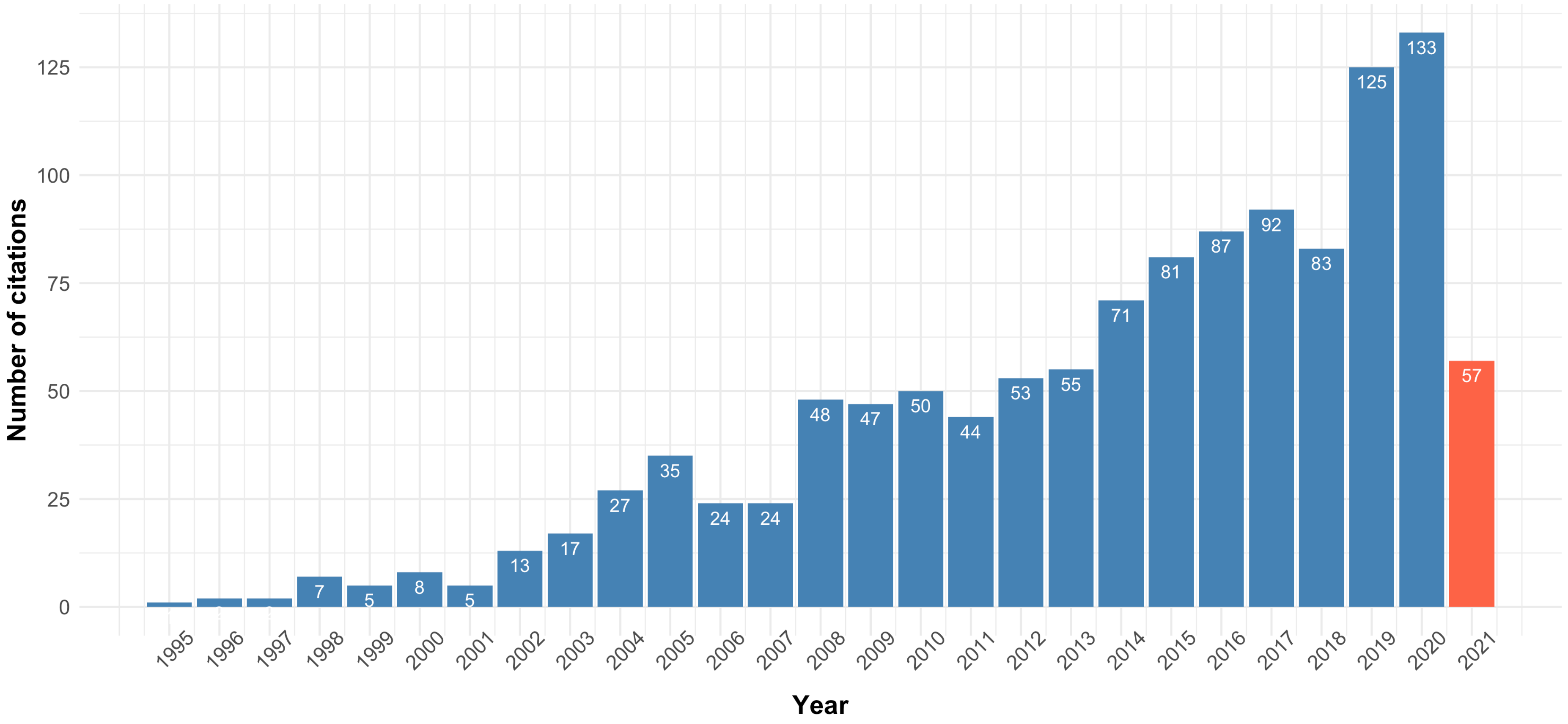

Figure 1. Total number of times that Daniel Pauly’s original paper on SBS has been cited per year since its publication in 1995, as a proxy for trends in citations of ‘shifting baseline syndrome’ over time. Citations in 2021 (red) are lower as this includes only the first 7 months of 2021. Data source: indexed items within Web of Science Core Collection. Accessed: 09/07/21.

Conclusions

This thesis significantly contributes to the current SBS literature, both confirming and refuting multiple hypotheses regarding the impacts of SBS on multiple areas of conservation research and practice. I provide empirical evidence of both generational and personal amnesia and the first evidence that SBS can negatively impact perceptions of conservation priority for species in decline (Jones et al., 2020). Significantly, this thesis adds to the limited number of studies investigating the potential impacts of SBS on conservation target-setting, concluding that SBS may not be as significant a threat in conservation management as first thought. Although this study focusses on evidence of SBS in two Western countries, the results have broader implications, both within the field of conservation and beyond. More broadly, the work presented here demonstrates the importance of local knowledge, experience, and perceptions to understand local perspectives of ecological change. Future studies should seek to recognise, chart, and quantify the effects of biases such as SBS on research conclusions when utilising LEK as a key knowledge source in conservation research. SBS research is critical for fully understanding perceptions of ecological change and will therefore be a cornerstone for future global policy on sustainable action and green recovery (Almond et al., 2020; United Nations, 2020). Through communication and understanding of the extent to which our own actions are degrading the natural environment, we can hope to tackle the impacts of SBS in the future.

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