Received: 8 February 2022 | Accepted: 15 June 2022

DOI: 10.1002/pan3.10383

PEOPLE AND NATURE | BRITISH ECOLOGICAL SOCIETY

REVIEW AND SYNTHESIS

The dark side of nature experience: Typology, dynamics and implications of negative sensory interactions with nature

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Funding information
Japan Society for the Promotion of Science, Grant/Award Number: 20H04375; Natural Environment Research Council, Grant/Award Number: NE/W004941/1; Research Institute for Humanity and Nature, Grant/Award Number: RIHN14200158

Handling Editor: Melissa Marselle

Abstract

1. The human health benefits of direct sensory interactions with nature (hereafter direct human–nature interactions) are increasingly recognised. However, these interactions can also have various negative health and well-being impacts on people, some of which may be severe. Compared to positive ones, there has been relatively little investigation of such negative direct human–nature interactions beyond the medical literature, and what has been done is widely scattered across disciplines.
2. Here, we provide an overview of the typology, characteristics and dynamics of negative direct sensory interactions with nature and suggest management implications and future research directions.
3. We highlight the breadth of forms that negative direct human–nature interactions occur, and evidence that the incidences of some have recently grown rapidly in many parts of the world.
4. Our review also suggests that more intense negative direct human–nature interactions can sometimes occur simultaneously or sequentially with more positive ones, and there may be trade-offs between the two.
5. Such serious implications highlight the importance of focusing research and public policy on improving the understanding of negative direct human–nature interactions, taking a more balanced view of the benefits and costs of nature experiences, and developing appropriate mitigation strategies.

KEYWORDS
ecosystem disservices, global change, human–wildlife conflict, personalised ecology, public health

1 | INTRODUCTION

Direct sensory interactions with nature (hereafter direct human–nature interactions) are an important part of many people's lives, and the health and well-being benefits that often result are increasingly recognised (Bratman et al., 2019; Hartig et al., 2014; Keniger et al., 2013). There is broad consensus that a regular 'dose' of nature contributes to improved physical, psychological and social well-being (Bratman et al., 2019; Cox, Hudson, et al., 2017; Shanahan et al., 2015) and, especially in higher income societies, policymakers and practitioners have made considerable efforts to design and implement strategies and programs aimed at increasing people's direct engagement with nature (Shanahan et al., 2019).

Alongside these benefits, direct human–nature interactions can also have various negative health and well-being impacts on people, some of which may be severe (e.g. being attacked by large mammals, being stung by venomous wasps; Barua et al., 2013; Gulati et al., 2021; Marselle et al., 2021; McPhee, 2014; Penteriani et al., 2016; Soulsbury & White, 2016). Compared to positive ones, there has been relatively little investigation of such negative direct human–nature interactions (see Box 1 for their definition) beyond the medical literature, and what has been done is widely scattered across disciplines and journals (Barua et al., 2013; Methorst et al., 2020; Soga & Gaston, 2022; Soulsbury & White, 2016). Indeed, while much attention has been paid to the health benefits derived from direct human–nature interactions (e.g. Bratman et al., 2019; Hartig et al., 2014; Keniger et al., 2013), their negative impacts have been little addressed in much recent discussion of such interactions (Marselle et al., 2021; Methorst et al., 2020). Moreover, since positive and negative direct human–nature interactions have traditionally been investigated by researchers from different disciplines and perspectives (the bulk of the consideration of positive interactions has occurred outside of the traditional medical domain, including from psychology, environment and public health perspectives), and therefore, how the two are linked remains poorly understood. The limited understanding of negative direct human–nature interactions in this broad context is problematic because (i) these interactions entail substantial economic and social costs (Gilbert et al., 2017; Gulati et al., 2021; Kasturiratne et al., 2017); (ii) in many parts of the world, there has been an increasing trend in some kinds of negative direct human–nature interactions (see Figure 1); (iii) it limits the attention paid to actions that reduce such interactions and improve human and animal welfare; and (iv) encouragement of positive direct human–nature interactions may fail to consider the potential simultaneous increase in the magnitude of the negative ones that people may experience.

Here, we provide an overview of the typology, characteristics and dynamics of negative direct human–nature interactions and suggest management implications and future research directions. Throughout, we take a global perspective, considering the wide range of negative direct human–nature interactions that can occur within different contexts, including both higher and lower income countries as well as urban and rural settings (see Table 1 for a list of examples). To date, beyond the medical literature, the negative impacts of nature on human health and well-being have been discussed mainly in the context of 'ecosystem disservices' or 'human–wildlife conflict' (Barua et al., 2013; Shackleton et al., 2016). However, while negative direct human–nature interactions are concerned with direct sensory interactions of people with nature (see Box 1), this is often not the case in these two contexts. Indeed, studies on ecosystem disservices and human–wildlife conflict have often focused on more generic economic or societal costs generated from nature that are not directly related to sensory interactions with it (e.g. crop weeds and pests, livestock damage, fire hazards; Barua et al., 2013; Shackleton et al., 2016). Also, as commonly in its definition human–wildlife conflict focuses mainly on interactions between humans and animals that have negative consequences for both parties (e.g. human injury or death caused by large carnivores), many negative direct human–nature interactions (especially those that result in

BOX 1 Definition of negative direct human–nature interactions

We consider negative direct human–nature interactions as 'a contact with nature by people through sensory systems that results in adverse health outcomes' (Soga & Gaston, 2020). Following the use in personalised ecology (Gaston et al., 2018; Soga & Gaston, 2020; Soga & Gaston, 2022), we define nature as 'all living organisms and ecosystems, excluding those that are not self-sustained'; we recognise that some prefer much broader definitions and that these may also include abiotic and cultivated/domesticated components (Ducarme & Couvet, 2020). We consider health as a state of complete physical, psychological and social well-being and not merely the absence of disease or infirmity (WHO, 1948). Negative consequences for human health are thus not simply the occurrence of physical injury or fatality but include the elicitation of negative emotions (e.g. fear, disgust, sadness). Under these definitions, there are a wide range of negative direct human–nature interactions, such as suffering from physical injury from bites, stings or attacks by animals, allergic or toxic reactions from contacting plants and physical injury during an accident occurred in natural environments (e.g. slip, fall), encountering a type of animal that causes psychological phobia, hearing sounds of animals that evokes fear and perceiving bad smells of animal carcasses or faeces left in natural environments (see Table 1). These sensory interactions could occur consciously or subconsciously, and will chiefly take place through tactile, visual, auditory and olfactory sensory channels (see Section 2 for a more detailed discussion). In principle, our definition of direct human–nature interactions could also include interactions through the sense of taste, although we will not discuss these further because for most people the associated health outcomes are normally derived from dead organisms, which therefore lie beyond our definition (for present purposes) of nature. Since the focus of this review is on 'sensory' interactions with nature, we will not discuss interactions with viruses or microorganisms (e.g. bacteria) or parasitism (e.g. roundworms), for which these are much less relevant. Obviously, these other interactions with nature are nonetheless vitally important for human health (Hay et al., 2004; Messina et al., 2019).

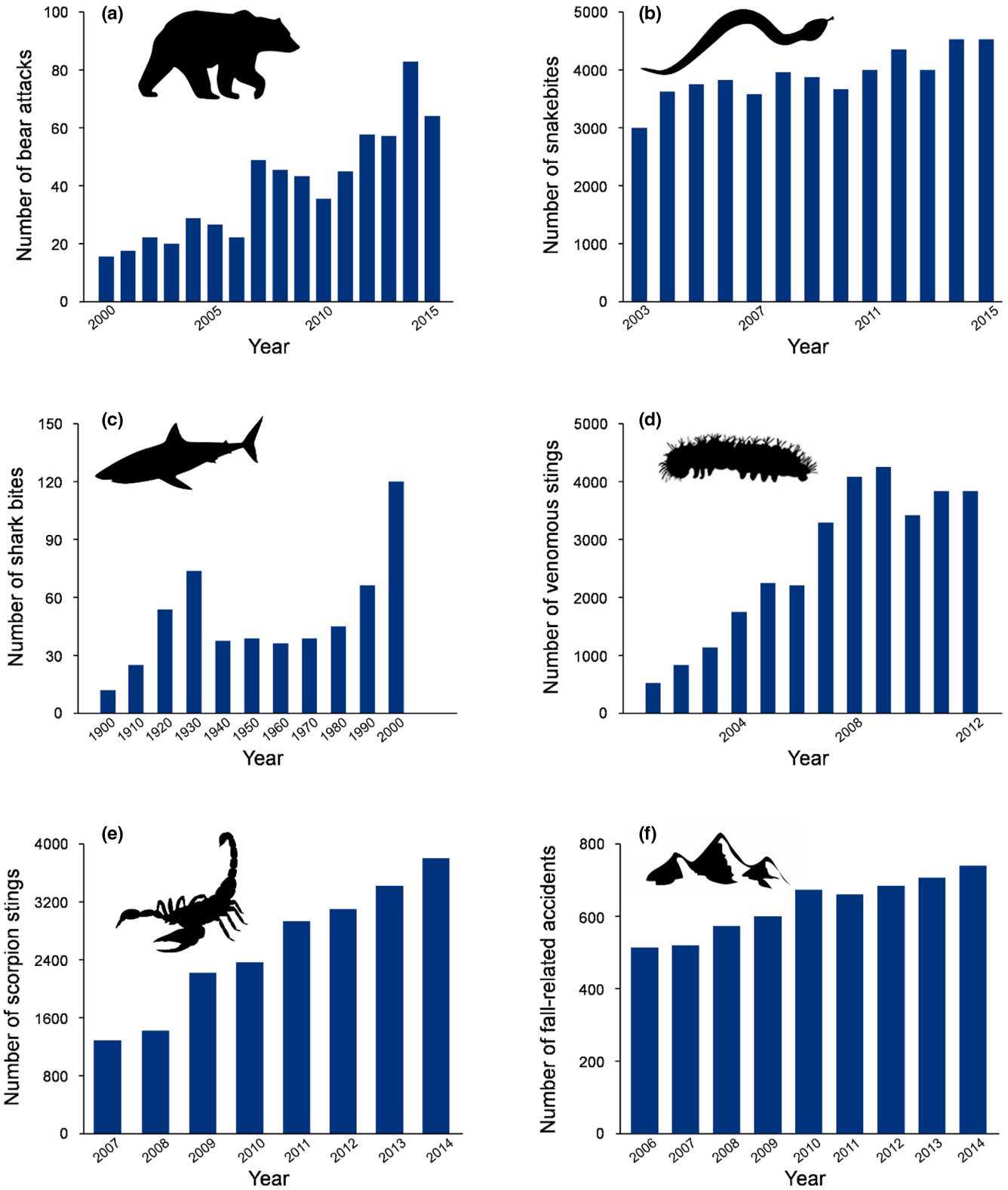

FIGURE 1 Global rise in negative direct human–nature interactions. Examples include: (a) the number of attacks by brown bears in developed countries has increased approximately fourfold over the last 16 years (Bombieri et al., 2019); (b) the number of snakebites in Mexico has increased approximately 1.5 times over the last 13 years (Chippaux, 2017); (c) the number of shark bites in Australia has increased approximately tenfold over the last 100 years (West, 2011); (d) the number of stings by venomous caterpillars in Brazil has increased approximately seven times over the last 12 years (Chippaux, 2015); (e) the number of scorpion stings in northeastern Brazil has increased approximately threefold over the last 8 years (Araújo et al., 2017); and (f) the number of deaths caused by fall-related accidents in the Austrian Alps has increased approximately 1.5 times over the last 9 years (Faulhaber et al., 2017). Note that the figures shown represent the total, rather than per capita, number of negative human–nature interactions.

TABLE 1 Examples of negative direct human–nature interactions according to the origin of nature and sensory pathways

Sensory pathway	Nature origin		
	Animals	Plants	Ecosystems
Tactile	• Suffering from physical trauma from bites, stings or attacks by animals • Suffering from allergic or toxic reactions from contacting animals • Killed by animals that have particularly strong physical impacts on the human body or those that are highly venomous	• Suffering from physical trauma from touching some parts of plants/trees such as thorns, prickles, spikes and sharp leaves • Suffering from allergic or toxic reactions from contacting plants • Being struck by a falling tree branch	• Suffering from physical injury during an accident occurred in natural environments (e.g. slip, fall or avalanche-related accidents)
Visual	• Encountering a type of animal that causes a phobic-like reaction such as fear and disgust • Seeing injured animals • Seeing animals harming or killing one another • Seeing animals harming or killing other people or livestock • Seeing other people harming or killing animals (e.g. killing bothersome insects) • Accidentally harming or killing animals (e.g. hitting deer with a car on a highway)	• Encountering a type of plant that causes a phobic-like reaction such as fear and disgust • Seeing damaged plants • Seeing plants harming or killing other people • Seeing other people harming or killing plants (e.g. cutting trees) • Accidentally harming or killing plants (e.g. trampling understorey vegetation)	• Visiting a highly dense and dark forest • Seeing damaged ecosystems • Seeing other people suffering from physical injury (e.g. falling a mountain) • Seeing other people destroying ecosystems (e.g. removing forests due to urban development)
Auditory	• Hearing sounds of animals that evokes a phobic-like reaction (e.g. the buzzing sound of bees, a bear's bark sound) • Suffering from noise nuisance caused by animals (e.g. crows, gulls, cicadas)		
Olfactory	• Perceiving bad smells of animals (e.g. stink bug, skunk) • Suffering from odour nuisance caused by animals	• Perceiving bad smells of plants (e.g. ginkgo tree, fish mint) • Suffering from odour nuisance caused by plants	• Perceiving bad smells of animal carcasses or faeces left in natural environments

psychological impacts on humans through non-tactile sensory channels; see Table 1) have been little considered in previous discussion of such conflict (Barua et al., 2013; Nyhus, 2016). Against this background, we think that this review will be useful to researchers, as well as policymakers, in facilitating a broad view and in-depth understanding of negative direct human–nature interactions and helping develop a more balanced view of the benefits and costs derived from direct interactions with nature. For this overview, we did not perform a formal systematic literature search because research on the topic of negative direct human–nature interactions is too fragmented and transdisciplinary for such an approach to be applied. The material we draw on was identified through a purposefully broad search (using a combination of Web of Science, Google Scholar and Google) of both peer-reviewed literature and other sources.

2 | FORM

As described in Table 1, negative direct human–nature interactions take diverse forms. They occur in a range of settings from highly urbanised to remote areas, from terrestrial to aquatic environments, and in both indoor and outdoor spaces. In this section, we outline some of the major types of negative direct human–nature interactions and discuss how they occur and the organisms and ecosystems responsible for them.

2.1 | Tactile interactions

Arguably, the most obvious form of negative direct human–nature interactions is tactile contact with animals that can harm humans. Numerous species from a broad range of taxonomic groups are known to be more or less a source of negative physical health outcomes such as physical injury (e.g. being attacked by large carnivores), allergic reactions (e.g. being bitten by mosquitoes) or toxic reactions (e.g. being stung by venomous wasps; see Table 2). Some of the well-reported groups of animals contributing to these interactions include annelids (e.g. leeches), arthropods (e.g. scorpions, spiders, ticks, crabs, moths [esp. caterpillars], ants, bees, hornets, centipedes), cnidarians (e.g. jellyfish, sea anemones), echinoderms (e.g. sea urchins, sea stars), molluscs (e.g. octopus, cone snails), fish (e.g. stingrays, sharks), reptiles (e.g. iguanas, snakes, turtles, alligators), birds (e.g. kites, crows, gulls) and mammals (e.g. cats, bears, monkeys; Bachleda, 2001; Burnett et al., 1996; Habermehl, 2012; Iverson & Skinner, 2006; Rowland & Eipper, 2019). The majority of these negative tactile interactions are caused by animals obtaining food resources or in the action of so doing (e.g. mosquito bites, tick bites, jellyfish stings), or protecting themselves, their territories or offspring from perceived threats from humans (e.g. large carnivore attacks, snakebites). Negative tactile interactions with animals in the worst case result in the death of humans, which is normally caused by animals that have particularly strong physical

impacts on the human body (e.g. large carnivores) or those that are highly venomous (e.g. snakes, spiders, wasps and jellyfish; Bachleda, 2001; Habermehl, 2012). While in many cases the incidence of negative tactile interactions resulting in death would not be high, there are exceptions; for example, it is estimated that snakebites result in approximately 100,000 deaths each year (WHO, 2021).

Plants can also often cause harm to humans through tactile contact, such as physical injury, chemical irritation and allergic reactions (Bachleda, 2001; Modi et al., 2009). For example, contact with plants with thorns, prickles, spikes or very sharp leaves (e.g. cactus, honey locust, thistle, palm, rose) is likely to result in some form of physical damage to the human body (e.g. cut or punctured skin). Likewise, in the case of trees, falling branches or trunks sometimes cause serious physical trauma or death (Brookes, 2007; Schmidlin, 2009). There are also many plant species that contain rash-inducing chemicals such as nettles, poison ivy and poison oak and dogwood (Bachleda, 2001; Modi et al., 2009). Despite such a potentially widespread occurrence of negative tactile interactions with plants, they have received remarkably little attention compared to those with animals. It thus seems important to develop further knowledge and understanding of the magnitude and spatial and temporal dynamics of negative tactile interactions with plants.

Negative tactile interactions with nature are not only caused by particular organisms, but also generated from ecosystems more generally. In terrestrial settings, for example, mountain-based activities such as hiking and mountaineering are associated with a risk of injury which may range from minor, to disabling, to even death (e.g. slip, fall or avalanche-related accidents; Faulhaber et al., 2017; Gatterer et al., 2019). A similar risk also exists with freshwater or marine environments (Bessereau et al., 2016; Peden et al., 2016). Indeed, in Japan alone, for example, there are estimated to be c. 3000 and 1500 accidents annually during mountain and maritime leisure activities, respectively (National Police Agency, 2022).

2.2 | Audio, olfactory and visual interactions

In discussions of direct human–nature interactions, most attention has so far been paid to tactile interactions with nature (Barua et al., 2013; Gulati et al., 2021; Marselle et al., 2021; Methorst et al., 2020). However, there are also many negative direct human–nature interactions that occur through non-tactile sensory channels (i.e. visual, auditory and olfactory), and these can occur at a much higher frequency and over a much wider range of conditions (see Section 3).

Encountering wild animals that are potentially harmful to humans, and environments that can harbour these organisms (e.g. dark forests), might be one of the common forms of non-tactile negative direct interactions with nature, especially in more developed societies, as it often provokes negative psychological reactions such as fear or disgust (Fukano & Soga, 2021; Polák et al., 2020; Rádlová et al., 2020; Soga & Gaston, 2022; Ulrich, 1993). This takes various forms, such as apiphobia (fear of bees), arachnophobia (fear of spiders), batrachophobia (fear of amphibians), botanophobia (fear of plants), dendrophobia (fear of trees), entomophobia (fear of insects), equinophobia (fear of horses), felinophobia (fear of cats), helminthophobia (fear of being infested with worms), herpetophobia (fear of reptiles), hylophobia (fear of forests), ichthyophobia (fear of fish), musophobia (fear of mice), ophidiophobia (fear of snakes), ornithophobia (fear of birds), selachophobia (fear of sharks) or zoophobia (fear of animals; Cromby et al., 2013; Phillips, 2007; Robertson, 2003; Table 2). These negative psychological reactions are considered to be both a genetic adaptation to harmful things and a learned behaviour from cultural sources related to individual and community survival (Fukano & Soga, 2021; Patuano, 2020), the degree of which can vary substantially among people (Soga et al., 2020; Fukano & Soga, 2021; see Section 3). Although the exact incidence of animal or plant phobia remains unclear, studies indicate that 3%–10% of people in the general population can have at least one particular animal specific phobia (e.g. Oosterink et al., 2009a, Oosterink et al., 2009b; Zsido, 2017; Zsido et al., 2018).

There are also cases in which, even if the organisms or ecosystems themselves do not evoke negative psychological reactions, certain behaviours or events may trigger such feelings. For example, people can experience uncomfortable emotions when they see animals harming or consuming one another (e.g. seeing predatory birds killing smaller birds or scavenging carcasses) or attacking livestock or other humans (Prokop et al., 2008; Treves, 2009). Similarly, when people see other people harming or killing animals or plants either intentionally or unintentionally (e.g. catching fish or insects, trampling understorey vegetation, removing natural vegetation due to urban development) or when they accidentally harm or kill organisms (e.g. hitting deer with a car), they might feel distressed, fearful or sad (c.f., Pagani et al., 2008). Of course, this can also be the case when people encounter organisms or environments that are damaged regardless of the cause (natural processes or anthropogenic impacts).

Many animals emit sound to communicate information such as mating potential and territory size, or in response to potential threats, which can sometimes result in unpleasant auditory experiences for humans. For example, some insect, frog, bird and mammal species (e.g. cicadas, pigeons, crows, gulls, foxes) can create loud or repetitive noises, especially when in groups and during the breeding season, which can lead to a severe noise nuisance, especially in urban areas (Gu et al., 2012; Kalnicky et al., 2019; Kung et al., 2015; Lyytimäki, 2014; Temby, 2004; Table 2). Of course, there is likely some variation in how the sound of animals is perceived among people, which is likely to be influenced by multiple personal, cultural and social factors (see Section 3).

Certain animals and plants (e.g. ginkgo tree, hawthorn, fish mint, lantana, skunk cabbage, stink bug, skunk, foxes) emit particular smells to defend themselves from their predators or to aid reproductive processes (Table 2; Jenkins, 2018; Kung et al., 2015; Nickel, 2022). Some of these smells can cause negative olfactory interactions of people with nature (albeit there is variation in how

TABLE 2 List of the organisms that are responsible for some of the major negative direct human–nature interactions. The list was generated by combining data from previous reports (see the main text). Filled circles represent the presence of documented cases. Note that the form of negative direct human–nature interactions likely varies across regions with different climatic, environmental and geological conditions, and thus the structure of the list may vary by region

	Groups of organisms																		
	Animals																	Plants	
	Vertebrates					Invertebrates													
Type of interaction	Mammals	Birds	Fish	Reptiles	Amphibians	Porifera	Cnidarians	Flatworms	Molluscs	Annelids	Nematodes	Arthropods (insects)	Arthropods (crustaceans)	Arthropods (centipedes)	Arthropods (millipedes)	Arthropods (arachnids)	Echinoderms	Trees	Herbs
Tactile																			
Suffering from physical trauma	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Suffering from allergic or toxic reactions	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Visual																			
Encountering a type of organism that evokes a phobia-like response	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Auditory																			
Suffering from noise nuisance	●	●	○	●	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○
Odour																			
Suffering from odour nuisance	●	●	○	●	●	○	○	○	●	○	○	●	○	○	●	●	○	●	●

the smell of organisms is perceived). Importantly, negative olfactory nature interactions sometimes cause severe consequences for human health. For example, *Umbellularia californica* (commonly known as the 'headache tree'), a tree indigenous to southwestern Oregon and Northern California, emits a scent from its leaves, inhalation of which has been reported to cause sinus irritation, sneezing, headache and even loss of consciousness (Nassini et al., 2012).

Negative olfactory interactions with nature can also be generated from ecosystems. For example, animal carcasses or faeces left in greenspace can often be a major source of odour nuisance in urban areas (e.g. faeces of raccoon dogs in domestic gardens).

3 | OCCURRENCE

The many forms of negative direct human–nature interactions can be classified along three key dimensions: *frequency*, *intensity* and *consistency* (Figure 2).

3.1 | Frequency

Within a given human population, some negative direct human–nature interactions occur frequently and others rarely (Figure 2). High-frequency interactions might include, for example, being bitten by a mosquito and suffering from noise nuisance caused by birds. Low-frequency interactions might include being stung by a stingray or falling down a mountain. Of course, the relative frequency of occurrence of negative direct human–nature interactions likely varies depending on the human population under consideration (Soga & Gaston, 2020). Nevertheless, in the main it is likely that the negative direct human–nature interactions that a person experiences in a space and during a certain period consist of many kinds of low-frequency interactions and a few kinds of high-frequency ones, although this assumption has not yet been formally tested.

As well as there being variation in the frequency with which negative direct human–nature interactions occur, there is also variation in how often an individual person experiences these interactions. This is because the opportunities that people have to experience negative direct interactions with nature are generally not uniformly distributed across the population but are biased heavily towards certain groups of people or sectors of society (Chaves et al., 2015; Dunham et al., 2010). For example, those working in the agriculture, forestry and fisheries sectors normally have greater opportunity to experience nature compared to other groups of people, and thus they often experience negative direct interactions with nature more frequently (Quandt et al., 2013). It is also known that, in more urbanised societies, those having regular nature experiences tend to be rare, and a high proportion of direct human–nature interactions are disproportionately experienced by a small proportion of the human population (Cox, Hudson, et al., 2017, Cox, Shanahan, et al., 2017; Soga et al., 2021). This implies that, at least in urbanised areas, most people have no or very low numbers of negative direct interactions with nature and a small proportion probably experience the majority of these interactions.

3.2 | Intensity

Intensity is the degree of negative health impacts that a person receives from direct nature interactions (Figure 2), which can be measured on dimensions such as the duration of symptoms, severity of pain or depth of fear felt. More intense interactions normally occur when a person is physically injured or suffers from long-term psychological sequelae such as post-traumatic stress disorder. On the other hand, less intense interactions do not require a person to be physically injured or psychologically harmed and might include such events as perceiving noise nuisance or bad smells or feeling fear while walking through a forest. While it remains unclear how the balance between more and less intense negative direct nature interactions varies between people, such variation can be associated with several personal factors. For example, those living in rural areas can experience more intense negative interactions more frequently because these environments often host wildlife species that can inflict serious harm on humans (e.g. venomous snakes, crocodiles; Bateman et al., 2021; Chaves et al., 2015; Chippaux, 2017; Dhanwatey et al., 2013; Dunham et al., 2010; Tchoffo et al., 2019).

3.3 | Consistency

Consistency is the degree to which direct nature interactions have the same level of negative impacts on human health and well-being independent of people's personal characteristics and the social and cultural context in which they live (Figure 2). More consistent interactions might include, for example, being attacked by large herbivores and being struck by a falling tree branch. Less consistent interactions might include encountering a type of organism that can evoke a psychological phobia and perceiving bad smells of plants. Indeed, it is known that the degree of such unfavourable perceptions towards organisms varies among people with different personal characteristics such as age, gender, education level and the degree of childhood exposure to nature (e.g. Belaire et al., 2015; Fukano & Soga, 2021; Kaltenborn et al., 2006) and with different social and cultural conditions (e.g. Özel et al., 2009; Prokop et al., 2010).

From a practical viewpoint, it seems vitally important to determine what types of negative direct human–nature interactions are less consistent and the key factors that determine such inconsistency. The knowledge gained from such an approach could have the potential to inform the development of policies and strategies to reduce the consequences of negative direct human–nature interactions. For example, it is suggested that those who have higher levels of natural history knowledge and exposure to nature are less likely to show biophobic reactions when encountering animals (e.g. Fukano & Soga, 2021; Soga et al., 2020). This implies that educational or

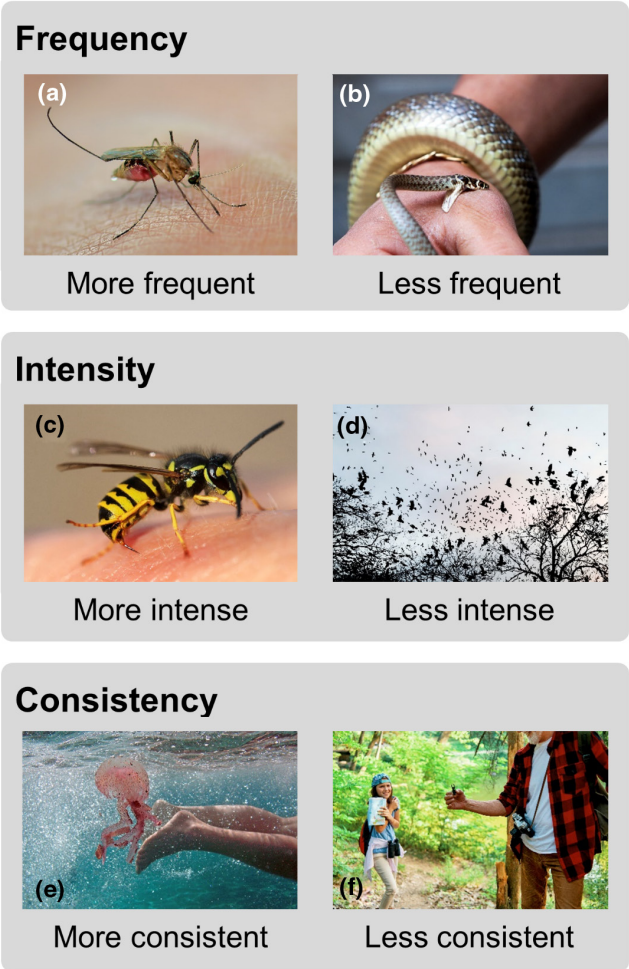

FIGURE 2 Examples of negative direct human–nature interactions across three dimensions to their typology (*frequency*, *intensity* and *consistency*). Examples include (a) being bitten by a mosquito, (b) being bitten by a snake, (c) being stung by a wasp, (d) perceiving noise nuisance caused by crows, (e) being stung by a jellyfish and (f) encountering a type of organism that can evoke a psychological phobia (e.g. insects). Note that the relative occurrence frequency of negative direct human–nature interactions likely varies across regions with different climatic, environmental and geological conditions, and thus the classification system in terms of frequency may vary by region. Images adapted from iStock.

recreational programs aimed at increasing people's knowledge about, and engagement with, nature can help reduce the number of people who have a greater degree of animal phobia.

3.4 | Inter-relations

The frequency, intensity and consistency of negative direct human–nature interactions are likely closely interrelated in several ways. For example, more intense negative direct nature interactions are likely to occur less frequently compared to less intense ones. Likewise, more intense negative direct nature interactions are more likely to be more consistent; they normally occur through the tactile sense. Determining the relationship between the three dimensions of negative direct human–nature interactions would be an important step in understanding the dynamics of these interactions and their consequences for human health and well-being.

4 | DYNAMICS

The occurrence of negative direct human–nature interactions varies at multiple spatial (from local to regional, and national to international) and temporal scales (from hourly to daily, seasonally and annually). This arises as a result of there being spatial and temporal variation in the opportunities that people have to experience negative direct interactions with nature. These opportunities are shaped by four different factors: (i) the abundance of nature potentially harmful to people, (ii) the behaviour of animals, (iii) the abundance of humans and (iv) the behaviour of humans (see Figure 3 for examples of each of the four factors). Of course, these four drivers do not shape the spatial and temporal dynamics of negative direct human–nature interactions independently, but rather are interrelated in multiple, albeit poorly understood, ways. For example, greater human population density is often associated with larger numbers of wild animals that cause potentially negative effects on humans (e.g. crows: Cox et al., 2018; mosquitoes: Leisnham et al., 2005; large mammals: Cox & Gaston, 2018) and alters their behaviour towards humans (e.g. becoming bolder towards humans: Galbreath et al., 2014; Kumar et al., 2019; becoming more likely to use human-induced resources: Cox & Gaston, 2018; Rose et al., 2020).

There are also likely several feedback loops by which occurrence of negative direct human–nature interactions can lead to further changes in these interactions. For example, the occurrence of attacks by large animals in ecotourism sites or in urban areas is often featured in and sensationalised by the media (see Hardiman et al., 2020 for the case of shark bites), which can lead to the extermination or removal of individuals of these organisms and/or a decrease in the number of visitors to the areas (due to both voluntary and regulated restrictions of the use of these areas; Farley et al., 2014). This, in turn, might reduce further incidence of these negative direct human–nature interactions, as it decreases the abundance of both humans and nature (i.e. negative feedback loops). Of course, there is the potential for a positive feedback loop to occur, as individuals of large carnivores that have attacked or killed humans can become bolder and thus more likely to do so again (Schell et al., 2021).

Over the last few decades, there has been a growing trend in some kinds of negative direct human–nature interactions such as snakebites (Chippaux, 2017), shark bites (Chapman & McPhee, 2016; McPhee, 2014), attacks by large carnivores (Bombieri et al., 2019; Penteriani et al., 2016), invertebrate interactions (Araújo et al., 2017; CDC, 2019; Chippaux, 2015) and fall-related accidents in mountains (see Figure 1). The so-called 'expansion of negative experience' (Soga & Gaston, 2022) is found in both developed and developing

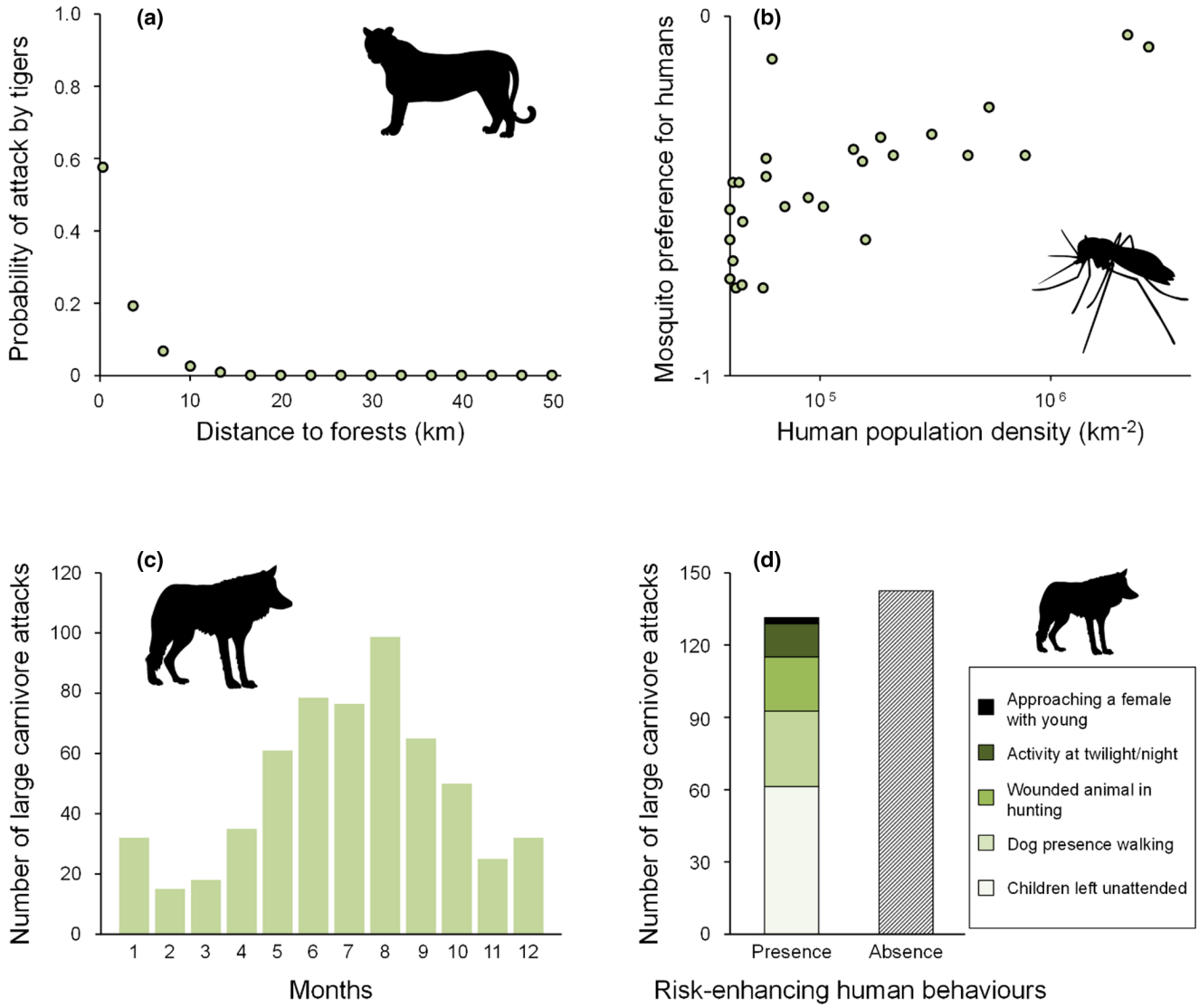

FIGURE 3 Evidence demonstrating the importance of the four drivers of negative direct human–nature interactions: (a) the abundance of nature potentially harmful to people, (b) the behaviour of animals towards people, (c) the abundance of humans, and (d) the behaviour of humans towards nature. Examples include that (a) tiger attacks on humans in the Chandrapur District of Central India occur mainly in and near forest that is the main habitat of tigers in this region (see Dhanwatey et al., 2013 for more details about how predicted occurrence was calculated), (b) mosquito preference for humans varies widely across Africa and increases significantly with human population density (see Rose et al., 2020 for more details about the preference scores), (c) large carnivore attacks on people in North America and Europe occur mainly from late spring to early autumn, because many people participate in outdoor recreational activities during this period (Penteriani et al., 2016), and (d) around half (47.6%) of the large carnivore attacks reported in North America and Europe were associated with certain human behaviours that may have contributed to the probability of suffering an attack (Penteriani et al., 2016).

countries and urban and rural areas (Figure 1). The expansion of negative experience is considered to be driven by several environmental and social factors, such as increases in human populations, increases in ecotourism activities, reductions in available natural habitat due to urban and agricultural developments, range expansion due to global climate change of some wildlife harmful to humans, increased international trade or the depopulation of rural areas, the growing familiarity of wild animals with people and inappropriate behaviour of people towards them (Chippaux, 2015; Enari, 2021; McPhee, 2014; Penteriani et al., 2016; Soga & Gaston, 2020; Vink et al., 2011).

5 | MITIGATION STRATEGIES

In principle, negative direct human–nature interactions can be mitigated by four major strategies (see Table 3). The first and perhaps most straightforward approach is to reduce inappropriate human behaviours that can lead to negative direct human–nature interactions (e.g. feeding and approaching wild animals, going for a nature walk without proper equipment or skills; Penteriani et al., 2016), which might be achieved by various educational and social marketing programmes aimed at increasing people's knowledge about nature

TABLE 3 Examples of mitigation strategies to reduce some major negative direct human–nature interactions. Note that this table does not necessarily represent all possible solutions

	Mitigation strategy			
Negative direct human–nature interaction	**Curbing unfavourable behaviours of animals**	**Suppressing people's use of nature**	**Reducing risk-enhancing human behaviours**	**Reducing the abundance of nature**
Being attacked by bears in national parks	• Reducing the intensity of artificial feeding or the exposure to anthropogenic food in national parks	• Restricting recreational activities in national parks	• Prohibiting walking an unleashed dog, engaging in outdoor activities at twilight/night and approaching bears (e.g. for the sake of taking photos)	• Killing large carnivores • Relocation of individual bears • Removing forests where bears inhabit
Being bitten by snakes in agricultural areas	• Developing electric fences along the edge of agricultural areas	• Restricting agricultural activities	• Prohibiting entering bushes and approaching snakes (e.g. for the sake of killing them) • Providing protective shoes and socks	• Killing snakes • Removing forests where snakes inhabit
Being stung by mosquitoes in urban parks	• Providing insect repellent	• Restricting recreational activities in urban parks	• Prohibiting entering bushes • Providing long-sleeve shirts and pants	• Killing mosquitoes • Removing temporary water pools where mosquitoes breed
Hitting deer with a car on a highway	• Developing fences along highways • Developing green bridges for deer to cross a highway	• Restricting traffic	• Developing speed regulation strategies • Prohibiting driving highway at night	• Killing deer • Removing forests deer inhabit
Encountering a type of organism that can evoke a psychological phobia in domestic gardens	• Providing insect repellent to prevent them from approaching humans	• Restricting activities in gardens		• Killing organisms that can evoke a psychological phobia • Removing vegetation that can harbour wild organisms
Suffering from a noise nuisance caused by birds at home	• Provide deterrents	• Closing a window		• Killing birds that cause a noise nuisance (e.g. crows) • Removing vegetation where birds inhabit • Driving away birds (e.g. using falconry, anti-bird spikes, bird netting and decoy kites)
Suffering from an odour nuisance caused by street trees at the office		• Closing a window		• Cutting trees that produce flowers with unpleasant smells

(Abrams et al., 2020). The second strategy is to curb the behaviours of animals that are potentially harmful to humans. For example, reducing the intensity of artificial feeding in national parks and the opportunities to obtain human-provided food in urban and suburban areas is likely to contribute to limiting levels of wildlife habituation to humans (Marley et al., 2017). The third strategy is to suppress people's use of nature (e.g. recreational or agricultural activities) during periods when or in places where there is a high risk of experiencing negative direct human–nature interactions (Linnell et al., 2005). The fourth, and often last resort, strategy is to reduce the abundance of nature potentially harmful to people, either through more or less selective direct population reduction (e.g. trapping, hunting), or through habitat reduction (e.g. vegetation clearance, removal of temporary water pools where mosquitoes breed).

Of course, the feasibility and effectiveness of the four strategies will depend strongly on the specific socioeconomic and cultural background of the regions concerned. For example, in many regions (especially those of particular importance for biodiversity conservation), it would not be desirable to undertake extermination of wild animals or clearing of vegetation (e.g. Colman et al., 2014). Likewise, these actions normally require significant financial resources, and thus they would often not be employed in areas where socioeconomically disadvantaged groups of people live (Bateman et al., 2021). Also, in areas where ecotourism is the major industry, suppressing people's use of nature (i.e. recreational activities) is not easily achievable for economic reasons. Furthermore, in urban areas where improving public safety and well-being is considered to be of predominant importance, people may be more inclined to accept

adopting strategies and policies aimed at reducing the abundance of nature potentially harmful to them (Bateman et al., 2021; Cahill et al., 2012). There is no 'one size fits all' solution to manage negative direct human–nature interactions and careful consideration is required when choosing among mitigation strategies.

Some of the above-mentioned approaches can decrease the intensity and frequency of positive direct human–nature interactions substantially, which may, in turn, reduce the health and well-being benefits that people can obtain from nature (Bratman et al., 2019; Hartig et al., 2014; Keniger et al., 2013). For example, preventing or restricting recreational activities in urban greenspace or national parks is likely to reduce people's opportunity and motivation to experience positive nature interactions in these environments (Bratman et al., 2019). Similarly, cutting trees that produce flowers with unpleasant smells is likely to decrease the positive impacts on people's health and well-being that interactions with these organisms can produce (e.g. psychological benefits of viewing trees through a window; Soga et al., 2021).

6 | FUTURE RESEARCH DIRECTIONS

There are several key areas in which research efforts could be focussed to improve the understanding of negative direct human–nature interactions (see Box 2 for a list of priority research questions). First, it is important to determine the scale, patterns and drivers of the recent documented increases in some kinds of negative direct human–nature interactions (Figure 1). It remains unclear how common and widespread such trends are across countries and regions with different socioeconomic, cultural and environmental contexts. Indeed, it is often pointed out that many negative direct human–nature interactions, especially more intense ones, have been under-reported because they are not witnessed, occur in poor countries, occur during illegal activities (e.g. poaching), or perhaps out of fear of bad press for popular vacation destinations (Koziarski et al., 2016; Ricci et al., 2016; Tchoffo et al., 2019). Hence, the existing evidence is probably just the tip of the iceberg and the actual number of negative direct human–nature interactions, and their associated costs to society, might be much higher.

BOX 2 Examples of key research questions for future research on negative direct human–nature interactions

1. What is the global economic cost of negative direct human–nature interactions?
2. What are the key drivers of the recent rise in some kinds of negative direct human–nature interactions?
3. How does the composition of negative direct human–nature interactions vary between people?
4. Are there any synergies or trade-offs between positive and negative direct human–nature interactions?
5. What are the differences between the animal and plant species that can have costs for human health and those that provide benefits?
6. What are the cumulative effects of experiencing negative direct human–nature interactions?
7. What role do negative direct human–nature interactions play in shaping people's attitudes and behaviour towards nature conservation?
8. How will conservation and restoration programmes influence the occurrence of negative direct human–nature interactions?

Second, it is crucial to understand how positive and negative direct human–nature interactions are related. Importantly, at least in more affluent societies, it is increasingly apparent that more intense negative direct human–nature interactions often occur together with more intense positive ones. For example, there is considerable evidence that the majority of large carnivore attacks in higher income countries occur when people engage with high-quality nature-based activities, including hiking and camping in wilderness areas (e.g. Bombieri et al., 2019; Chapman & McPhee, 2016; West, 2011). This implies the existence of a 'trade-off' between positive and negative direct human–nature interactions, raising significant challenges for policy-makers and practitioners as to how best to maximise the benefits of direct human–nature interactions while minimising their costs.

Third, it would seem valuable to understand how the ongoing loss of biodiversity, as well as associated conservation programs, can alter the occurrence of negative direct human–nature interactions. While it might be expected that decrease in species richness or abundance of wildlife decreases the amount of negative direct interactions with nature, this will not always be the case. For example, in the case of invasive alien species potentially harmful to humans (e.g. fire ants, snapping turtles, redback spider or spear thistle), the establishment of these organisms in an ecosystem can result in loss of many native species but it may increase negative direct human–nature interactions (Liu et al., 2021; Shackleton et al., 2017; Vink et al., 2011). Likewise, it might be possible that loss of some predator species due to anthropogenic activities can result in the increase in the abundance, and activity level, of wildlife that can cause negative health impacts for humans (Enari, 2021). In these cases, the amount of negative direct human–nature interactions per unit of biodiversity likely increases with decreasing biodiversity.

Lastly, from a conservation viewpoint, it would be important to determine how negative direct human–nature interactions affect people's attitudes and behaviours towards nature. It has often been argued that experiencing positive direct interactions with nature, especially at an early age, likely contributes to increased pro-environmental attitudes and behaviours (e.g. Cheng & Monroe, 2012; Soga & Gaston, 2016; Wells & Lekies, 2006) and thus increasing people's level of direct interactions with nature has a wide range of positive consequences for biodiversity conservation (i.e. the nature benefit hypothesis; Soga & Gaston, 2022). However, this might not be the case for negative interactions, especially for more intense ones, because this type of interaction can increase people's

unfavourable feelings towards wildlife (see Liu et al., 2011). An important direction for future research would be to determine the relative importance of and possibly interactive effects of positive and negative direct human–nature interactions in shaping people's pro-biodiversity attitudes and behaviours.

7 | CONCLUSIONS

With the ongoing growth of human populations and the associated increase in demand for natural resources, negative direct human–nature interactions are expected to escalate worldwide (Figure 1). Global climate change and urbanisation are also likely to accelerate this trend (Backe et al., 2021; Rose et al., 2020; Sonenshine, 2018; Zacarias & Loyola, 2019). It seems thus vitally important to develop a more comprehensive and detailed understanding of the nature and dynamics of negative direct human–nature interactions and enhance the ability to best manage them for improved human health and well-being. We argue that to advance this goal requires scientists to focus more attention on the negative personal, social and economic impacts resulting from direct human–nature interactions. This is, of course, not to say that nature experiences are bad and detrimental to humans. Rather, we argue that there needs to be a balanced view of the benefits and costs of direct human–nature interactions and a clear recognition of the inevitable trade-offs that potentially exist between the two. From a conservation view point, it will also be crucial to explore how negative direct human–nature interactions can be mitigated with a minimal impact on biodiversity, and how conservation and restoration programmes influence the occurrence of these interactions. Determining ways of maximising beneficial outcomes of direct human–nature interactions, while minimising negative consequences for both humans and nature, is a major challenge in the 'Anthropocene'.

AUTHORS' CONTRIBUTIONS

Both authors conceived the work, drafted the manuscript, edited and approved the final version.

ACKNOWLEDGEMENTS

We are grateful to D.T.C. Cox, S. Higgins, T. Kubo and two anonymous reviewers for comments on the manuscript. M.S. was supported by the Japan Society for the Promotion of Science (Project No. 20H04375) and the Research Institute for Humanity and Nature (RIHN: a constituent member of NIHU): Feasibility Project (Project No. RIHN14200158). K.J.G. was supported by the Natural Environment Research Council funded 'Renewing biodiversity through a people-in-nature approach (RENEW)' project (NE/W004941/1).

CONFLICT OF INTEREST

K.J.G. and M.S. are the Editor-in-Chief and an Associate Editor of *People and Nature*, respectively, but took no part in the peer review and decision-making processes for this paper.

DATA AVAILABILITY STATEMENT

No new data were generated or analysed in this study.

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How to cite this article: Soga, M., & Gaston, K. J. (2022). The dark side of nature experience: Typology, dynamics and implications of negative sensory interactions with nature. *People and Nature*, *00*, 1–15. https://doi.org/10.1002/pan3.10383