

# Personalised ecology and detection functions

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## Abstract

1. Direct interactions with nature are important for people's health, well-being and support for pro-nature policies. There is an urgent need better to understand the structure and dynamics of these interactions, and how they differ among individual people, human populations and the communities to which they belong.
2. The determinants of these interactions have two components. First are the factors that influence whether someone undertakes actions that may lead to interactions with nature (e.g. looking through a window, going for a walk, travelling to the countryside). These factors have attracted significant attention. Second are the factors that influence what nature interactions are obtained when someone is present in a situation in which these could occur. These have received little explicit attention.
3. One way of formalizing understanding, and identifying gaps in knowledge, of the second group of factors is to consider human–nature interactions in terms of detection functions. Rather than using such functions for the estimation of species abundances, the purpose for which they were originally developed, they can be reorganized as descriptors of influences on people's nature interactions.
4. This paper considers how the different variables contained within detection functions influence human–nature interactions, and in particular how the number of nature interactions a person has in a given place and time is shaped both by clearly ‘nature’-associated variables, such as the number of organisms present, and also by variables that are strongly influenced by characteristics of the observer, such as how they use or explore an area and their personal nature detection abilities.
5. Many issues explored in the context of human–nature interactions are then seen to concern these component variables of detection functions, and approaches to improving the frequency of interactions seen, in effect, to be targeted at affecting change in different ones of these variables.

## KEYWORDS

behaviour, detectability, extinction of experience, human–nature interactions, observers, sampling

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## 1 | INTRODUCTION

Each of us has a 'personalised ecology', a set of direct interactions with nature that is unique in its composition and varies through time on multiple scales (daily, weekly, annually; Gaston et al., 2018). There is an urgent need for a much improved understanding of the composition of these nature interactions, and how and why they differ between people and through their life course (Soga & Gaston, 2020). This stems foremost from widespread recognition and growing empirical evidence of the human health and well-being benefits of such interactions (Hartig, Mitchell, de Vries, & Frumkin, 2014; Keniger, Gaston, Irvine, & Fuller, 2013; Russell et al., 2013), and the potential of using nature-based interventions to address a variety of medical conditions, especially ones associated with mental health (although much still needs to be understood in these regards; Shanahan et al., 2019). It is further stimulated by concern over the incidence and scale of the 'extinction of experience': the progressive loss of direct human–nature interactions that is occurring between successive generations across much of the world (Miller, 2005; Pyle, 1993; Soga & Gaston, 2016). This has consequences not only for human health and well-being but also for people's understanding of the current state of the natural environment (shifting baseline syndrome; Soga & Gaston, 2018), their emotional affinity for and attitudes towards nature and, critically, the levels of support for pro-nature policies and management actions (Evans, Otto, & Kaiser, 2018; Mackay & Schmitt, 2019; Prévot, Clayton, & Mathevet, 2018; Whitburn, Linklater, & Abrahamse, 2019).

A major challenge to achieving an improved understanding of personalised ecology has been the lack of any agreed theoretical framework within which present knowledge can be placed and significant gaps identified, and which can be used to guide the management of human–nature interactions. The determinants of these interactions have two major components. First are the factors that influence whether and what actions someone undertakes that may lead to interactions with nature (e.g. looking through a window, going for a walk, travelling to the countryside). These have attracted significant attention (e.g. Boyd, White, Bell, & Burt, 2018; Hand et al., 2018; Hornigold, Lake, & Dolman, 2016; Lin, Fuller, Bush, Gaston, & Shanahan, 2014; Richardson, Cormack, McRobert, & Underhill, 2016). Second are the factors that influence what nature interactions are obtained when someone is already present in a situation in which these could occur. These have received little explicit attention. Indeed, studies have understandably often documented the, much easier to measure, potential interactions available to a person living in or visiting an area (e.g. which species are present and in what numbers), rather than those interactions that necessarily actually occur (e.g. Cox et al., 2018; Dallimer et al., 2012; Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007; Turner, Nakamura, & Dinetti, 2004; Wood et al., 2018). Here I argue that the essence of a framework to understand the factors that influence what nature interactions are obtained lies in formal ecological and wildlife research methods for determining the occurrence and abundance of species. These centre on detection functions.

## 2 | DETECTION FUNCTIONS

In the context of biodiversity measurement and monitoring schemes, a detection function describes the relationship between the probability that a person observes or hears (or possibly senses in some other way) an individual of another species and the number of individuals of the species that are present (the approach can also be extended to inanimate detection devices). Such functions have been widely employed particularly to understand, and to correct, the biases in biodiversity surveys and monitoring schemes (Buckland, Rexstad, Marques, & Oedekoven, 2015; Pollock et al., 2002). Indeed, schemes are often formalized around an understanding of such functions, for example so that use can be made of distance sampling techniques (which account for variation in detection with distance from an observer, while often controlling also for other factors). As such, detection functions have contributed importantly to a dominant theme in the history of the study of ecology, namely a growing ability accurately to estimate the actual occurrences and abundances of species (Gaston et al., 2018).

Almost no attention has been paid to what detection functions tell us about human–nature interactions themselves, although in capturing the relationship between what nature is present and that which people detect, they undoubtedly embody much of the information that is needed. Indeed, one might argue that detection functions are a key descriptor of the basal unit of all direct human–nature interactions (ignoring those with microbes etc.), the individual detection event (if detections do not occur, then there are no interactions, nor any of the benefits or costs that may follow).

Let us imagine an individual person within a specific area over a given time period. Their nature interactions will be some function of the numbers of individuals of the different species, such as birds, which occur within that area and time frame. Reorganizing a general estimator for abundance of a single species (Pollock et al., 2004) gives:

$$C = N \times P, \quad (1)$$

where  $C$  is the number of organisms detected by an observer (or potentially multiple observers),  $N$  is the actual number of organisms in the population (population size) and  $P$  is the probability of detecting a typical individual. Although in the context of estimating abundances the term 'observer' refers to someone actively seeking detections of other organisms, in the context of human–nature interactions detections will frequently be obtained more passively (e.g. while undertaking other activities). Indeed, detections need not even be, and in the vast majority of cases doubtless are not, conscious events. They may be subconscious or unrealized (many people encounter organisms under circumstances and at distances that are well within their sensory abilities to detect them, but they remain oblivious); the relative importance of conscious, subconscious and unrealized interactions with nature remains little understood, and should be a key topic of future research. For consistency I will continue to refer to observers, but do so in this broader sense.

$P$  can be decomposed into various causes of non-detection such that

$$P = p_a \times p_v \times p_d, \quad (2)$$

where  $p_a$  is the proportion of area sampled by an observer,  $p_v$  is the probability of an individual organism being available to be detected by an observer and  $p_d$  is the probability of detection by the observer given that an individual organism is available to be detected.

In the context of estimating abundances various methodological constraints are required to ensure that  $C$  is the number of different individuals encountered, such as trying to avoid counting the same individual more than once, and where multiple observers are involved ensuring that their counts are conducted independently or are targeted at different components of a population (e.g. on different sides of a transect). As will be discussed further, these constraints are not especially relevant in the context of human–nature interactions, and so to avoid confusion I will express this estimator in terms of  $I$ , the number of realized human–nature interactions for a given observer, where

$$I = N \times p_a \times p_v \times p_d. \quad (3)$$

In this paper I will explore how each of these variables influences  $I$ . That is, how the number of nature interactions a person has in a given place and time is shaped both by clearly ‘nature’ factors, such as the number of organisms present ( $N$ ), but also by factors that are strongly influenced by characteristics of the observer, such as how they use or explore an area (i.e.  $p_a$ ,  $p_v$ ) and their sensory capabilities and expertise (i.e.  $p_d$ ). Understanding these relationships is important both from a fundamental perspective, and also because it has implications for how human–nature interactions can best be increased to address human health and well-being issues and redress the extinction of experience.

Throughout this article I focus on the number of human–nature interactions in which a person engages, but these interactions may, of course, differ greatly in the form and quality of their contribution to human–nature *experiences*. Although the terms ‘interaction’ and ‘experience’ are often used interchangeably, here I differentiate the two (see also Gaston & Soga, 2020). Direct human–nature interactions (sometimes also termed ‘nature exposure’ or ‘nature dose’) are the literal occurrences of sensory (usually visual or acoustic, but olfaction may also be important) links between a person and an element of nature. Interactions are a necessary prerequisite for experiences, but experiences are more than just interactions. Experiences are defined situations in which a person is engaged with an interaction on an emotional, physical, spiritual or intellectual level (Clayton et al., 2017). These experiences might be positive, including, for example, various improvements in physical (e.g. reduced incidence of high blood pressure), psychological (e.g. reduced stress) and social well-being (e.g. increased social interactions with other people). They might be neutral in these regards. Or they might also be negative, including, in terms of physical (e.g. injury through being stung or bitten), psychological (e.g. expression of various phobias, observing

animals in some kind of distress) and social well-being (e.g. limiting who will participate in particular outdoor activities). Among those experiences that are positive, some may be profoundly more so than others, and likewise for those that are negative experiences. Key determinants of how human–nature interactions translate into nature experiences are varied. For any given person they may include their emotional state, attitudinal state (e.g. level of nature connectedness), and short and long-term history of previous nature interactions and experiences (and thus the novelty of any new nature interaction). The relative importance of these determinants is not well-understood. Both nature interactions and nature experiences will change through a person's life span, and will differ greatly geographically, and with culture and socioeconomics.

### 3 | POPULATION SIZE ( $N$ )

In the context of estimating abundances,  $N$  is usually the actual population size of a particular species in an area. In the context of interest in human–nature interactions themselves the focus can be much broader and more diverse, ranging from links with greenness or greenspace, through links with vegetation, and links with broad taxonomic groups (such as trees, butterflies or birds), to links with individuals of other species. These broader conceptualizations may often be more appropriate, because most people are quite limited in their desire or abilities to distinguish among species (or perhaps individuals) even for more readily distinguished groups (see below). This said, it is useful to focus on human–nature interactions with single species, particularly because this is the level at which much variation in detection functions occurs, even when observers are not particularly conscious of such differences. So,

$$I_T = I_1 + I_2 + I_3 + \dots I_s, \quad (4)$$

where  $I_T$  is the total number of human–nature interactions in a given place and time frame, with  $I_T$  contributed by multiple species  $s$ . In practice, of course,  $I_T$  is likely to comprise contributions from species from a wide diversity of different higher taxa, and the different  $I_s$  may not be entirely independent (if, for example, focussing attention on species from some taxa reduces or increases the likelihood of interacting with others; e.g. focussing on flowers can increase the likelihood of observing bees).

$N_s$  is a key contributor to  $I_s$  and, although far from the sole determinant, is likely to play a major influence on the contribution of different species to human–nature interactions (particularly within a taxonomic group). Indeed, all of the other factors in Equation (3) essentially reduce the proportion of  $N$  that contributes to human–nature interactions (although with high levels of multiple interactions with the same individual organisms  $p_d$  could in principle exceed a value of 1; see below). When estimating abundances,  $C$  will often be a small proportion of  $N$ , even with aware and experienced observers. Known (e.g. through use of playback simulations) or estimated densities of species (e.g. using intensive sampling or distance sampling)

are, for example, commonly a factor of two or more times larger than the number of individuals actually detected by such observers over short periods at sampling points or when walking transects, and not infrequently very much greater (Alldredge, Simons, & Pollock, 2007; Diefenbach, Brauning, & Mattice, 2003; Earnst & Heltzel, 2005). It will similarly be the case that  $I$  will typically be a small proportion of  $N$ .

Where habitat areas are genuine habitat patches (as opposed to ones delimited purely for the purposes of a study), for a given species  $N$  may increase at a faster rate than does the size of an area (density increases with area; Connor, Courtney, & Yoder, 2000), the so-called patch individuals–area relationship (Gaston & Matter, 2002). This means that, all else being equal, human–nature interactions will increase in larger areas because of a higher density of organisms to interact with.

Some socio-economic groups of people may, at least locally, have more immediate access to areas in which the total number of species, their summed abundance and the abundance of particular key species are higher or lower. In cities and towns the so-called ‘luxury effect’ is one in which the number of species and their abundance is greater in the areas where wealthier groups live and which they use, either because they can better afford to live in and use such areas and/or because they are better able to maintain biodiversity at, or restore it to, higher levels in those areas (Hope et al., 2003; Irvine et al., 2010; Leong, Dunn, & Trautwein, 2018; but see Chamberlain, Henry, Reynolds, Caprio, & Amar, 2019); wealthier groups are also more likely to enhance their personalised ecology through eco-tourism. The so-called ‘poverty effect’, which has more seldom been documented, is the converse, in which in cities and towns the number of species and their abundance is greater than in the areas where poorer groups live and which they use (Shaw, Chamberlain, & Evans, 2008). This can occur when becoming wealthier is associated with moving to less biodiverse environments, such as from more rural to more urban locations under circumstances where rural landscapes have more wildlife (which may not be the case where these are under intensive agriculture).

One determinant of the extinction of experience, the progressive decline in people’s nature interactions, is a general decline in  $N$  as wildlife populations have fallen in many localities, and hence regionally and globally (Hallmann et al., 2017; Inger et al., 2015; van Strien, Van Swaay, van Strien-van Liempt, Poot, & WallisDevries, 2019; WWF, 2018). Such declines may also commonly occur through the increasing urbanization of people’s lives, although in suburban and moderately urbanized environments wildlife populations can have higher densities than those in agricultural areas (Tratalos et al., 2007).

#### 4 | PROPORTION OF AREA SAMPLED ( $p_a$ )

People in effect ‘sample’ areas for human–nature interactions in multiple ways. Some areas are encountered as an incidental part of other activities (e.g. en route to work) and some are visited more purposefully (e.g. through walks in the countryside or travel to eco-tourism destinations). Some are ‘sampled’ dynamically (e.g. walking

through an urban greenspace, driving through a national park), and others in a static fashion (e.g. viewing them from a building window). Some are visited regularly, some sporadically and some on just a single occasion.

In estimating species abundances the proportion of an area that is sampled,  $p_a$ , is critical because only a small (sometimes very small) proportion of the area over which this estimation is required is usually actually sampled by observers. For most people the proportion of any area visited that they actually frequent and which they therefore in effect sample for nature interactions will commonly be yet smaller (they are typically not actively trying to reduce the area that is unexplored). That proportion is likely also to be a declining function of the sizes of those areas (i.e. smaller for larger areas), at least once they get beyond some low threshold size.

Arguably just as significant as the proportion of area sampled, is the implicit assumption in determining species abundances that study areas are probabilistically (e.g. systematically or randomly) sampled is likely to be severely violated by the ways in which people use areas for other purposes and accrue nature interactions. Some violation almost certainly occurs in estimating species abundances with, for example, observers tending often to move along roads (possibly using a vehicle) and footpaths, and to go around the edges of fields and lakes rather than across them. However, in the context of human–nature interactions, movements are likely to be more highly biased to some parts of areas, and commonly those that are more accessible (e.g. nearest to roads, car parks, access paths and other facilities). For example, Irvine et al. (2010) found that people using public greenspaces in Sheffield, UK stated that the presence of more natural and complex, and biodiversity-rich, habitats were among the reasons for their visits, but that these were not the parts of these greenspaces that they tended directly to use, preferring instead those with proportionally greater impervious surface and turf. Likewise, Gaston et al. (2018) documented how occurrence records of the magpie *Pica pica* as recorded by members of the general public are highly spatially biased, occurring much more frequently along major transport links and in towns and cities (the areas in which people disproportionately occur), compared with the distribution across Britain determined by a formally spatially structured sampling program.

It seems reasonable to modify Equation (3) to read

$$I = N \times p_a \times p_b \times p_v \times p_d, \quad (5)$$

where  $p_b$  is the proportional lack of bias of spatial sampling with respect to the distribution of individuals of a species.

Of course, nature interactions may be obtained by a person while they are physically static in an area rather than moving through it, such as when they have views from a window; in urban environments views from a window may be the most frequent source of human–nature interactions (Cox, Hudson, Shanahan, Fuller, & Gaston, 2017). The proportion of the area that is then in effect being sampled for human–nature interactions will vary depending on sight lines and acoustics and will likely be highly biased in its habitat composition.

## 5 | PROBABILITY OF BEING AVAILABLE ( $p_v$ )

$P_v$  is the probability that an individual organism that is present in an area is available to be detected by the observer. In extremis, for example, an individual that is below-ground (e.g. in a burrow) is not available for observation above-ground, and one that is underwater is not available for observation at the surface. Perhaps more commonly for many observers, an individual organism that is not calling or singing is not available to be heard, and an individual that calls or sings frequently is more available to be heard than one that does not.

For plants, the probability of mature individuals (although often not other life stages) being available to be detected tends to be very high. For many animal species the probability of individuals being available to be detected will often be quite low, particularly because a high proportion of species have life stages during which they are concealed (e.g. within the bodies of other species [plant or animal], in soil).

On average, the probability of many species being available for detection is lower for the general public compared with expert observers. This is particularly so because availability for detection can depend on time of day (Bart & Herrick, 1984; Bas, Devictor, Moussus, & Jiguet, 2008) and for many people the times when they might have nature interactions are when these probabilities are disproportionately low. That is, people tend to be more active outdoors towards the middle of the day, and not at night when most mammals are active (Bennie, Duffy, Inger, & Gaston, 2014) or around sunrise when many birds are most vocal and active (Bart & Herrick, 1984); some species are becoming more nocturnal in response to daytime human activity (Gaynor, Hohnowski, Carter, & Brashares, 2018). Indeed, one might argue that the information provided to people to encourage nature interactions (e.g. website and leaflet lists of species for particular sites, information boards on sites) might usefully target species and groups for which probabilities of their being available are greatest at the times when those interactions are most likely to be sought.

## 6 | PROBABILITY OF DETECTION GIVEN AVAILABILITY ( $p_d$ )

Alongside the probability of an organism being available for detection, the probability that it will be detected when it is available is key to determining human–nature interactions. This is essentially a measure of the conspicuousness of the organism to the sensory systems of the observer. This will depend on two groups of factors.

### 6.1 | Organism and environment

The first group of factors concerns the organism and its environment. Of these, how far away the organism is from the observer is arguably the most important, with one that is further away and with a greater likelihood of structures (e.g. vegetation, buildings) blocking views or sound propagation being less likely to be detected. In the context of estimating abundances, absolute distance from an observation point

or perpendicular distance relative to a transect is often controlled for to enable distance sampling techniques to be applied (Buckland et al., 2015). In the context of human–nature interactions, it is obviously the absolute distance from the observer that is most critical. For visual detections the probability of detection tends to decline progressively, and often rapidly, with distance (Buckland et al., 2015), while for auditory detections the probability of detection tends to be relatively flat with distance before then declining rapidly (DeJong & Emlen, 1985). During the public movement ‘shutdown’ in the United Kingdom in response to COVID-19, it was notable how much more frequently public and media references were made to people’s increased awareness of the sounds than of the sights of wildlife (pers. obs.), presumably because of the powerful impact of reductions in background noise (from vehicles etc) on the distances over which bird song in particular could be heard.

Other factors in this first group influencing the probability of detection include habitat complexity, weather and background noise (which can mask visual and auditory detection), and features of the organisms, such as their body size, colouration and behaviour (Anderson, Marques, Shoo, & Williams, 2015; Bas et al., 2008; Denis et al., 2017; Emlen & DeJong, 1981; Johnston et al., 2014; Newson, Evans, Noble, Greenwood, & Gaston, 2008; Pacifici, Simons, & Pollock, 2008). Given that for many people their nature interactions occur foremost in towns and cities, it is notable that the detectability of birds has been found to be poorer in urban than in other habitats (Johnston et al., 2014), an effect that is readily explained by the physical complexity of urban areas, with many potential barriers to observing and hearing animals, and often ordinarily high levels of background noise. This difference may, however, be less extreme than would otherwise be the case because interaction with humans has changed species behaviours, such that, for example, the flight initiation distances of many bird species are shorter in urban than in rural populations (Møller, 2008), and shorter in urban populations for bird species that have longer histories of urbanization (Symonds et al., 2016). Many survey techniques assume that an organism does not move in response to the observer, but this may happen frequently and could serve to increase (e.g. by drawing the attention of the observer) or decrease (e.g. by fleeing from the observer) the likelihood of a nature interaction.

The probability of detection of an individual organism can itself be a declining function of the local abundance of the species or group of species (i.e.  $N$ ), even for expert observers (Bart & Schoultz, 1984). This can be caused by observer confusion among multiple individual organisms through overloading of their ability to deal with detection cues from multiple individuals ‘simultaneously’. For less expert observers this function could actually decline very sharply, if consciousness of and ability to distinguish between cues from multiple individuals is low.

### 6.2 | Observer abilities

The second group of factors influencing the probability of detection given availability for detection concerns the observers themselves. Observers can vary substantially in their abilities to detect organisms (Table 1), with these differences occurring even among experts

**TABLE 1** Examples of studies of the impact of observer identity on species detection

| Taxon  | Method                      | Key findings  | Study   |
|--|-----------------------------|---|---|
| Laysan Finch<br><i>Telespiza cantans</i>               | Walked transects            | Significant differences in counts among observers, but not explained by census experience   | Morin and Conant (1994)                               |
| Birds  | Roadside transects          | Observer effects on species richness, and on counts of 50% of 369 species   | Sauer, Peterjohn, and Link (1994)                     |
| Seabirds   | Ship-based transect surveys | Significant differences in counts between different teams of two observers. Three out of five teams observed <16% of Guillemot <i>Uria aalge</i> and <10% of Kittiwake <i>Rissa tridactyla</i> individuals compared with team reporting highest densities                                   | van der Meer and Camphuysen (1996)                    |
| Forest birds   | Point counts and transects  | Observer effects most apparent for small birds foraging in low shrubs, frequent calling active birds and midstorey undercanopy foragers with distinctive behaviour  | Cunningham, Lindenmayer, Nix, and Lindenmayer (1999)  |
| Grassland songbirds                                    | Line transects              | Detection probabilities among observers ranged from 0.43 to 1.00 for Henslow's Sparrow <i>Ammodramus henslowii</i> , from 0.44 to 0.66 for Grasshopper Sparrow <i>A. savannarum</i> , and from 0.60 to 0.72 for Grasshopper Sparrow for birds detected within 58–100 m of the transect line | Diefenbach et al. (2003)                              |
| Songbirds  | Song simulation system      | Observers detected between 19% (for worst observer, lowest singing rate, and least detectable species) and 65% (for best observer, highest singing rate, and most detectable species) of true population  | Allredge et al. (2007)                                |
| Birds  | Point counts                | Observer differences for estimates of richness and probability of detection of three exemplar taxa  | Lindenmayer, Wood, and MacGregor (2009)               |
| Birds  | Recordings                  | Listeners differed significantly in the mean number of species reported, ranging from 7.8 to 10.6 species per stop, compared with 12.6 confirmed on the recordings  | Campbell and Francis (2011)                           |
| Sardinian mountain newt <i>Euproctus platycephalus</i> | Creek surveys               | Observers differed in detection probability   | Casula, Vignoli, Luiselli, and Lecis (2017)           |
| Small vertebrates                                      | Walking nocturnal surveys   | Observers differed in detection of different taxa   | Lardner, Yackel Adams, Knox, Savidge, and Reed (2019) |

and the overall breadth of variation, although not well-documented, undoubtedly being very much wider across the general public. Understanding this variation will be critical to understanding the occurrence of human–nature interactions, because if it is large then even under identical environmental circumstances different people will have dramatically different nature experiences.

Some between-observer variation in the probability of, consciously or otherwise, detecting an organism is associated with differences in sensory abilities, including as a consequence of age-related deterioration in eyesight and hearing. Of these, impacts of hearing loss on detection have been best investigated, with evidence that age-related changes in hearing sensitivity across the frequency spectrum coincide with known difficulties in detecting species that call at these frequencies (Emlen & DeJong, 1992), that detection frequencies of such species decline with observer age (Farmer, Leonard, Mills Flemming, & Anderson, 2014), and that this can influence documented temporal trends in species abundances when the age structure of observers changes through time (Farmer et al., 2014).

Much between-observer variation in the probability of consciously detecting an organism is associated with differences in knowledge and experience, including the observer's behaviour in the presence

of and towards wildlife (Jiguet, 2009; Johnston, Fink, Hochachka, & Kelling, 2017). The extent to which this knowledge and experience can readily be improved sufficiently to change these detection probabilities remains an open question. There are examples in which this has been found to be achievable (McLaren & Cadman, 1999), although in the main such work has focussed on people with by general standards initially quite advanced skills (for which improvements may be more challenging). This is, however, a vitally important issue to understand as it bears on the value of, and emphasis to be placed on, campaigns to improve natural history knowledge and expertise. If skills can be readily improved, then this may be one way of reducing the extinction of experience of nature interactions, which is driven both by the opportunities to experience such interactions and the orientation towards gaining those experiences (Soga & Gaston, 2016).

The probability of many species being available for detection may also be lower for people's general nature interactions than for expert observers because the latter may use equipment that increases this probability (e.g. hand lenses, binoculars, telescopes, acoustic detectors).

In abundance estimation, a single detection of a given individual organism is sufficient for it to be counted, further detections

add nothing, and steps are often taken to avoid the latter occurring (e.g. by making count periods brief), so

$$p_d = 1 - (1 - p_{1d})^c, \quad (6)$$

where  $p_{1d}$  is the probability of detecting an average detection cue and  $c$  is the number of such cues (McCallum, 2005). In the context of human–nature interactions such ‘double-counting’ is much less of a concern if one at all, with multiple detections constituting multiple interactions, and there being no necessary benefit to shortening the time spent engaging in interactions simply in order to reduce the likelihood of multiple detections. Indeed, in the latter case it is more realistic that  $p_d$  includes multiple detections of the same individual.

Techniques have been developed for improving abundance estimates by using pairs of observers either to make independent counts or to improve the number of detections (Aldredge, Pacifici, Simons, & Pollock, 2008; Marsh & Sinclair, 1989; Nichols et al., 2000; Thompson, 2002). The presence of multiple observers will also tend to increase the number of nature interactions of any one observer, through drawing attention to organisms that they would otherwise have missed. Here the non-independence of observers is not a concern, and may indeed be something to be actively encouraged.

Thus far, I have focussed simply on the probability that an individual organism will be detected by an observer if it is available to be detected. In the context of estimating occurrences and abundances it is important not just if an individual that is present is not detected (a false negative) but also if an individual is detected when it is not actually there (a false positive), and the frequency with which these errors occur has been a focus of some research attention (Groom & Whild, 2017; Miller et al., 2012). One might argue that while false negatives reduce human–nature interactions, false positives matter a good deal less, as there may nevertheless be benefits to be obtained by a person from positive human–nature interactions that did not actually occur but which they perceived to do so (although this would obviously not extend to false-positive interactions with species that cause undue anxiety).

In a similar vein, in the context of human–nature interactions whether organisms that are detected are correctly identified (or indeed identified at all) may not be a major concern, while a low identification error rate is obviously vital when estimating species occurrences and abundances. The failure correctly to identify a species whose observation might have brought disproportionate benefit would clearly be a missed opportunity, but the incorrect identification of another species as one that does bring such pleasure may well provide benefit to the observer concerned. Species misidentifications can occur regularly among experts (Scott & Hallam, 2002), and tests of identification skills among the general public have almost invariably revealed these to be quite poor (Dallimer et al., 2012; Huxham, Welsh, Berry, & Templeton, 2006; Prokop & Rodak, 2009; Robinson, Inger, & Gaston, 2016). There is evidence that the levels of expertise are systematically associated with different kinds of detection errors, with experts more likely to report false-positive records of rare species than of common species and less skilled observers more likely to report false-positive records of common

species than of rare species (Farmer, Leonard, & Horn, 2012). However, this is likely to be a complex issue, with circumstances under which less skilled observers regularly mistake individuals of a common species for those of a rare one that they are especially keen to see.

## 7 | RELATIVE IMPORTANCE

The relative importance of  $N$ ,  $p_a$ ,  $p_b$ ,  $p_v$  and  $p_d$  to the number of nature interactions a person has in a given place and time is likely to vary markedly. For detection of some groups of more obvious organisms,  $N$  is likely to have an overwhelmingly positive impact, but may make relatively little or no difference for those that are more inconspicuous (e.g. those that are small bodied). The importance of  $p_a$ ,  $p_b$  and  $p_v$  will depend heavily on how and when a person visits an area, and are likely to have a major influence on detections; even when  $N$  is large, if  $p_a$ ,  $p_b$  and  $p_v$  are small there may be few detections. Increasing  $p_a$  and  $p_b$ , by encouraging and facilitating the wider exploration of areas, will be an effective way of increasing people's nature interactions, and even more so if this exploration is done at times that maximize  $p_v$ . The relative importance of  $p_d$  will depend again on the group of organisms, strongly increasing detections when these are obvious and attract attention, and minimizing detections when these are inconspicuous and elusive. In addition,  $p_d$  will depend on human factors that an individual observer may be able to do relatively little about (such as how good is their vision and hearing, although glasses and hearing aids may help), and others, such as knowledge and experience of how to detect organisms, that they may be able to develop through time.

## 8 | CONCLUSION

A major challenge to the development of an understanding of human–nature interactions and personalised ecology has been the lack of any formal theoretical framework within which new findings can be placed, and which can help shape the direction of future research. Detection functions offer a valuable contribution in this regard, providing a fundamental descriptor of how in a given place and time the basal unit of human–nature interactions, the individual detection event, is obtained. Consideration of such functions underlines the importance of determining the relative importance to human–nature interactions of the actual abundance of wildlife, how people sample areas for these interactions, what proportion of the species' population is available to be encountered and the probability that individual organisms will be detected by observers (Table 2).

A diversity of factors, many of which have been mentioned, influence the different components of detection functions (Table 3). In discussing human–nature interactions, in the conservation biology literature attention tends to be paid foremost to factors concerned with wildlife, including the effects of trends in its dynamics and how it is affected by and responds to human disturbance. However, in the literature focussed on the human well-being benefits of human–nature

**TABLE 2** Case studies of how the different components of detection functions can shape numbers of human–nature interactions in a given place and time (other factors shape whether those areas are visited in the first place)

#### Small urban greenspace

Most visitors to small greenspaces (e.g. in Penzance, UK, opposite) may not actively be seeking nature interactions, but will be passing through or using those areas for other purposes. Many detections that do occur will not be conscious ones. The population sizes ( $N$ ) of many species in small greenspaces tend themselves to be small, especially because habitat structures are often simplified and dominated by alien species. Observers can, however, in effect readily sample high proportions of these spaces for nature interactions ( $p_a$ ), and do so in a relatively unbiased fashion ( $p_b$ ) because even using formal access paths places limited constraint on what can be seen and heard. Much of the day active biodiversity associated with such spaces has a high probability of being available to be detected ( $p_v$ ), with many of the animals having a high tolerance to disturbance, although there may be substantial proportions of the biodiversity that are night active and thus not available to most visitors. The probability of detection ( $p_d$ ) of many species is likely higher in small urban greenspaces than in many other environments, although observer skills in this regard will differ greatly



[photograph courtesy of G4G project]

#### Agricultural landscape

Most visitors to agricultural landscapes (e.g. in Azores, opposite) will not actively be seeking nature interactions, but will be passing through or using those areas for other purposes. Many detections that do occur will not be conscious ones. The population sizes ( $N$ ) of wild species tend to be small, especially because natural habitat is scarce and habitat structures are often simplified. Observers can readily sample only small proportions of these landscapes for nature interactions ( $p_a$ ) and only in a quite biased fashion ( $p_b$ ), because access is highly constrained and footpaths and roads tend to be associated with habitat that is unrepresentative (e.g. hedges, verges). Much of the day active biodiversity associated with such landscapes has a moderate probability of being available to be detected ( $p_v$ ), with many of the animals having some tolerance to disturbance, although there may be substantial proportions of the biodiversity that are night active and thus not available to most visitors. The probability of detection ( $p_d$ ) of many species is likely to be higher than in many other environments because of the frequently simpler habitat structure and the concentration of wildlife to the periphery of fields



[photograph copyright of author]

#### Large national park

Most visitors to large national parks (e.g. Kruger National Park, South Africa, opposite) will be actively seeking nature interactions, and moving through these areas for that purpose. Many detections that do occur will be conscious ones, although doubtless many others will also occur. The population sizes ( $N$ ) of many species tend to be larger than elsewhere, especially when levels of protection from anthropogenic pressures are high. Observers can, however, readily sample only small proportions of these spaces for nature interactions ( $p_a$ ) and do so in a highly biased fashion ( $p_b$ ) as they are usually constrained to certain areas and routes, and in many cases to vehicles (other than at designated sites). Much of the day active biodiversity associated with such parks is likely to have a low probability of being available to be detected ( $p_v$ ), with few of the animals having a high tolerance to disturbance, and substantial proportions of the biodiversity being night active and thus not available to most visitors. The probability of detection ( $p_d$ ) of species is likely to be extremely variable but often very low, and for many visitors will be highly dependent on the availability of expert guides



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**TABLE 3** Factors that influence different components determining an individual person's human–nature interactions or personalised ecology

|   | $N$ | $p_a$ | $p_b$ | $p_v$ | $p_d$ |
|---|-----|-------|-------|-------|-------|
| Trends in wildlife populations                | X   |       |       |       |       |
| Level of human disturbance                    | X   |       |       | X     | X     |
| Habituation of wildlife to people             |     |       |       | X     | X     |
| Physical accessibility of site to observer    |     |       | X     |       |       |
| Period spent outdoors by observer             |     | X     |       | X     | X     |
| Time of day when observer outdoors            |     |       |       | X     |       |
| Field skills of observer                      |     |       |       |       | X     |
| Field equipment (e.g. binoculars) available   |     |       |       |       | X     |
| Wildlife identification abilities of observer |     |       |       |       | X     |
| Sensory abilities of observer                 |     |       |       |       | X     |
| Number of observers present                   |     | X     | X     |       | X     |

$N$ , population size of plant or animal species;  $p_a$ , proportion of area sampled;  $p_b$ , proportional bias of spatial sampling;  $p_v$ , probability of being available for detection;  $p_d$ , probability of detection given availability.

interactions, more attention is paid to influences on the frequency of those interactions of factors concerned with the humans themselves, including how and when they interact with nature. Both sets of factors are clearly important, and while wildlife has to be available for interactions to take place, this is far from a sufficient condition.

This paper has explicitly focussed on people's human–nature interactions, and has differentiated these from their human–nature experiences. Interactions are necessary for experiences although, as mentioned earlier, perceived but not actual interactions may also contribute. Thus, understanding interactions is a cornerstone of personalised ecology. The experience that follows from a particular interaction may, however, be hugely variable. The same interaction might vary greatly in the form and degree of benefit or cost that it provides to different people, or even to the same person at different times. This variation depends on some of the same factors as do the determinants of interactions themselves, but is likely much more heavily influenced by the circumstances or context of those interactions and the characteristics of the observer (e.g. emotional state, attitudinal state, short and long-term history of previous experiences, novelty of the interaction). Likewise, a given set of interactions could lead to great differences in the overall form and degree of benefit or cost to different people, and thus very different sets of interactions could lead to benefits or costs of similar form to different people. Unpacking these issues will constitute an exciting avenue of research, and one that needs to be heavily informed by existing understanding of the components of experience in entirely other contexts than human–nature interactions.

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## CONFLICT OF INTEREST

K.J.G. is editor-in-chief of *People and Nature*, but took no part in the peer review and decision-making processes for this paper.

## DATA AVAILABILITY STATEMENT

No data were collected for this paper.

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