A bird's-eye view of recreation

improving the application of scientific knowledge and tools in collaborative decision-making processes

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General introduction

1.1 Introduction

Achieving objectives for outdoor recreation as well as species conservation in nature areas is a challenge (Bell et al. 2007, Dustin and Schneider 2004). Since the end of the 19th century natural areas have been given protected status to safeguard them against the deleterious impacts of economic and urban development. In these protected areas land managers are expected to realize not only conservation objectives, but also social and economic objectives (Watson et al. 2014). One of these objectives is often outdoor recreation (Reed and Merenlender 2008). For example, the first National Parks in the USA were established for future generations to experience tranquillity and solitude and to enjoy the scenery. The declaration of Yellowstone as a National Park on 1 March 1872 stated that the park was 'dedicated and set apart as a public park or pleasuring ground for the benefit and enjoyment of the people' (Yellowstone Act, 1872: PL 17 Stat. 32; https://www.ourdocuments.gov/doc.php?doc=45&page=transcript).

Nowadays, outdoor recreation is permitted in most nature areas, areas where nature conservation is one of the main functions (Eagles et al. 2002, Balmford et al. 2015). Outdoor recreation has positive impacts on visitors, but can have negative impacts on nature (Archer et al. 2005). By visiting nature areas people develop an awareness of the importance of nature (Zylstra et al. 2014), which may result in an increased willingness to support nature conservation policy (Zaradic et al. 2009, Cooper et al. 2015, Halpenny and Caissie 2003). Visitors appreciate areas with high natural values (Siikamäki et al. 2015, Hornigold et al. 2016) and being active in nature areas has a positive impact on their health (Maller et al. 2006, Fuller et al. 2007, White et al. 2016, Bratman et al. 2015). On the negative side, outdoor recreation has a widespread impact on the ecological values in nature areas (Newsome et al. 2012, Larson et al. 2016). In response to these negative impacts, protective management actions are taken and outdoor recreation is limited by legislation (Hoffman et al. 2010, Geldmann et al. 2013, Gray et al. 2016). In many cases such limitations are felt to be a constraint on the development of outdoor recreation (Pröbstl 2003, Gaston et al. 2006, Bryan 2012) and as such may diminish public support for conservation actions (Mace 2014).

Conflicts between outdoor recreation and nature conservation have intensified (McCool 2016). In many areas site managers, responsible for recreation management as well as for achieving conservation aims in the nature area, are under increasing pressure to meet ambitious conservation targets (Butchart et al. 2015), but they are also under increasing pressure to make adequate provision for recreation in line with health policies that promote physical contact with natural environments (Maller et al. 2006, Bell et al. 2007). The challenge they face is to halt the decline of natural values while at the same time provide access to an increasing number of visitors (Eagles et al. 2002, Balmford et al. 2015).

To resolve this emerging conflict site managers need to seek solutions and decide on effective actions to reconcile opposing targets. Scientists argue that conservation managers should base their decisions on scientific evidence (Pullin et al. 2004, Sutherland et al. 2014), but since managers need to deal with differing and sometimes opposing views concerning the values and aims of protected areas, the use of scientific evidence alone is not sufficient to generate stakeholder-supported decisions (Hoppe 1999, McNie 2007, Hanssen et al. 2009). One reason for this is that often scientific evidence is ambiguous and therefore not credible to all parties in a conflict. Credibility is achieved when knowledge is considered reliable and scientifically adequate (Cash et al. 2003). Besides credibility, Cash et al. (2003) give two additional criteria for stakeholder acceptance of scientific evidence: salience and legitimacy. Salience is achieved when the scientific knowledge is relevant to the emerging conflict and is available. Legitimacy is achieved when the knowledge has been developed by a process that considers the values and perspectives of all relevant actors (Cash et al. 2003, Cook et al. 2013). Cash et al. (2003) and Sarkki et al. (2013) emphasize the trade-offs between credibility, salience and legitimacy; striking the right balance between them to ensure that knowledge is accepted is a challenge and requires involving all actors in the decision-making process (Heink et al. 2015, Sarkki et al. 2015). Scientists, site managers and stakeholders must therefore establish relationships and accept each other's knowledge if they are to build trust and break down the professional and cultural boundaries between them (Armitage et al. 2009, Berkes 2009 and Harris and Lyon 2013). Certainly at a time when support for biodiversity conservation in nature areas seems to be declining, it is important to cross these boundaries (Watson et al. 2014, Mace 2014) and take into account the pluralism of societal priorities and values regarding nature (Reed 2008, Mace 2014).

In this thesis I will narrow the scope of the subject by focusing on potential conflicts between hikers and bird species. Hiking is the most common type of outdoor recreation (Bell et al. 2007) and the conservation objectives for many nature areas include targets for bird species (Eken et al. 2004, Hoffman et al. 2010, Osieck and Mörzer Bruyns, 1981). Also, conflicts between people and birds can be expected as bird species are sensitive to disturbance by visitors (Blanc et al., 2006, Sutherland et al. 2006), even at low visitor densities (Bötsch et al 2017).

1.2 Credibility, legitimacy and salience of current knowledge concerning the impact of recreation on bird populations

To prevent or reduce conflicts between birds and hikers in nature areas, site managers rely on scientific knowledge (Buckley 2013, McCool 2016). However, current scientific knowledge is inconclusive and can support different, sometimes contradictory opinions about the nature and gravity of the problem and about which solutions are effective (Sarewitz 2004, Patt 2007). Marzano and Dandy (2012) even concluded that the widespread perception that recreation has a negative impact on nature values in forests is only partly supported by evidence. The existence of contradictory opinions makes it difficult to find new and alternative solutions in decision-making processes as both stakeholders and experts who hold opposing views will be able to find scientific evidence to support their particular point of view (Brown and Duguid 2000, Deelstra et al. 2003). An example of contradictory evidence on the potential negative impact of outdoor recreation on nature values concerns the Black Grouse (*Tetroa tetrix*). This bird is considered to be very sensitive to disturbance by hikers (Suchant and Braunisch 2004, Signorell et al. 2010), but Baines and Richardson (2007) were not able to detect differences in fecundity and survival of Black Grouse between different levels of disturbance. However, Steven et al. (2011) showed that in 61 out of 69 studies a negative impact of recreation on bird species was found and Bötsch et al. (2017) recently showed that even low levels of disturbance lead to a decrease in breeding bird territories and also species richness. Although reviews state that, in general, outdoor recreation has a negative effect on bird species, there is no conclusive scientific evidence that this applies to all species in all situations (Hill et al. 1997, Blanc et al. 2006, Whitfield et al. 2008, Steven et al. 2011).

Why is evidence from empirical research not conclusive? There may be two explanations for this ambiguity. A first and obvious explanation is that species respond differently because they differ in sensitivity to disturbance (Blanc et al. 2006, Møller 2008, Steven et al. 2011). Sensitive species tend to be species that breed or forage in open landscapes like heathlands (Yalden and Yalden 1990, Murison et al. 2007, Langston et al. 2007), open grasslands (Kerbiriou et al. 2009) and beaches (Burger 1995, Lord et al. 2001). Other species shown to be sensitive to disturbance include species that breed or forage in groups (Stillman et al. 2007, Bennet et al. 2011) or on the ground (Kangas et al. 2010, Thompson 2015) and species that are large (Weston et al. 2012), in decline (Møller 2008) or are not able to habituate to human presence (Klein et al. 1995, Miller et al. 2001). For example, Miller et al. (1998) showed that in North America densities of most species (Western Meadowlark, *Sturnella neglecta*, Pygmy Nuthatch, *Sitta pygmaea*, Western Wood-pewee, *Contopus sordidulus*, Chipping Sparrow, *Spizella passerina* and Solitary Vireo, *Vireo solitarius*) increased further away from trails, while densities of American Robin (*Turdus migratorius*) were higher near the trails. Also, data on Black-billed Magpies (*Pica pica*) and House Finches (*Carpodacus mexicanus*) indicated that densities were positively affected by the presence of trails, while Vesper Sparrow, (*Pooecetes gramineus*), Grasshopper Sparrow, (*Ammodramus savannarum*) and Townsend's Solitaire, (*Myadestes townsendi*) were more abundant in control sites than in sites near trails (Miller et al. 1998).

A second explanation for ambiguity lies in the complexity of the disturbance mechanisms. Disturbance will only occur at locations where a visitor and a bird are present at the same time (Pickering 2010). A disturbance event will result in physiological and behavioural responses by the individual bird (Le Corre et al. 2009), but this disturbance will not necessarily have an impact on the viability of the total bird population. A disturbance response by an alarmed bird involves the use of extra energy and time flying away, energy and time that is needed for vital activities like parental warming and feeding (Yalden and Yalden 1990, Verhulst et al. 2001, Goss-Custard et al. 2006). When visitor numbers increase, the sum of all disturbance events may lead to a critical reduction in available energy and a lower fitness of individual birds. As a consequence, the young in the nest could lose weight, increasing the probability of them dying. The larger the number of birds disturbed in an area, the higher the chance of an effect on densities, reproduction success or survival. Where high visitor numbers are spread over a large area, disturbance has been shown to have impacts on population size and population viability (Le Corre et al. 2009, Steven et al. 2011) (Fig. 1).

Scientific evidence is not evenly distributed over the different stages of this cascade of impacts (Buckley 2013). Most research on the impact of visitors on birds examines behavioural responses by individual birds; only a few studies look at population-level impacts (Blanc et al. 2006, Sutherland et al. 2006, Le Corre et al. 2009, Steven et al. 2011). Research into behavioural impacts can be conducted on individual birds, while research into population viability can only be conducted at larger spatial scales. However,

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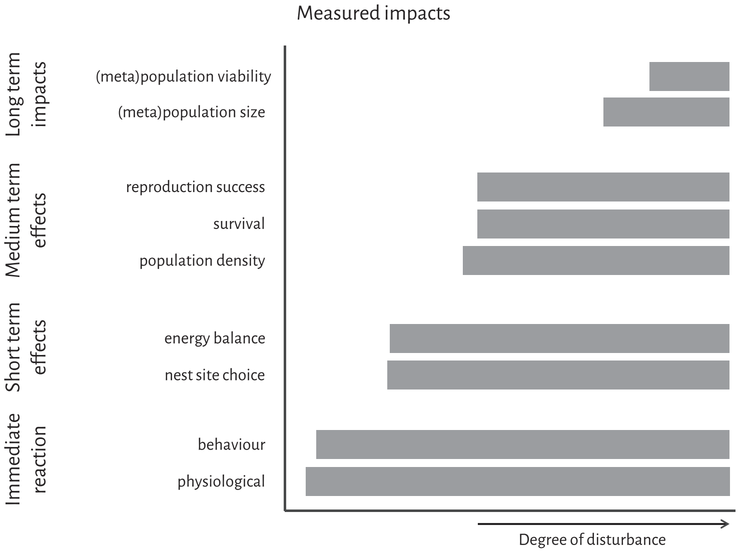

Figure 1. Measured effects and impacts of visitor disturbance on birds and bird populations (adapted from Steven et al. 2011 and Le Corre et al. 2009). The higher the degree of disturbance, the more likely it is that long-term impacts will be detected. The degree of disturbance (on the x-axis) depends on many factors, such as the number of visitors, the type of activity, the period in which the activity takes place, and the landscape. At low levels of disturbance, individual impacts, such as behavioural change, can be detected by direct observation. Impacts on (meta)population size and viability can only be detected at high levels of disturbance during long-term investigations.

detecting impacts at larger spatial scales is more difficult because other factors, such as changes in land use and climate change, have to be taken into account (Young et al. 2005). Impacts from these factors might even exceed impacts from recreation, making these even harder to detect (Gutzwiller et al. 2017). Nevertheless, taking large spatial scales into account is essential for an adequate assessment of the impact on population size and viability (Buckley 2013, McCool 2016, Gutzwiller et al. 2017).

A further complication with regard to scale is that most management actions are implemented at a local scale, while bird population viability is determined at a spatial scale that includes multiple nature areas (Suárez-Seoane et al. 2002, Suchant and Braunisch 2004, Opdam and Wascher 2004). The persistence of bird species depends on the dynamics within and between different populations (Opdam 1991, Hanski 1999, Opdam et al. 2003) and for many species, conservation depends on the presence of a network of nature areas at a regional or even biogeographical scale (Gaston et al. 2006, Cabeza and Moilanen 2001, Martensen et al. 2012). Therefore, site managers need information not only on the local situation but also about other areas. One of the main challenges is that managers from these different areas need to determine who is responsible for taking action to realize conservation objectives (EC 2014). According to

Cash et al. (2006), not being able to cross spatial and jurisdictional scales complicates negotiations between stakeholders and managers. Most current scientific knowledge and tools are not suitable for providing managers with spatial information that links local management actions to regional targets.

Managers will be much more able to choose between management options if they know the effectiveness of potential solutions (Gill 2007, Pullin et al. 2004, Cook et al. 2010). Adequate predictions are needed because further collaboration between recreation and conservation stakeholders depends at least in part on successful outcomes of management actions (Stankey et al. 2005, Williams et al. 2007). However, site managers often lack information on recreational use (Buckley et al. 2008, Mann et al. 2010) as well as information on the dose–impact relation between recreational use and bird populations (McCool 2005, Sutherland 2007). Moreover, as visitor distribution and densities are often heterogeneous, site managers are unlikely to be able to identify the locations in their area where bird populations are most likely to be affected by visitors or to determine by how much they should restrict visitor access to reduce impacts to an acceptable level (Coppes and Braunisch 2013, Hadwen et al. 2007). If managers do not have the scientific evidence they need on which to base their actions, they will fall back on their own experience (Dilling and Lemos 2011, Pullin et al. 2004). Although information based on local experience generally meets the criterion of salience, it often lacks credibility and stakeholders might question its legitimacy (Pullin and Knight 2009, Cook et al. 2013). For example, site managers use flight distances to create buffer zones where recreation is not permitted, based on the assumption that flight responses by individual birds affect the population density or viability (Ikuta and Blumstein 2003, Moran-Lopez et al. 2006, Livezey et al. 2016). As these precautionary management actions are taken only in the interests of bird conservation and restrict visitor access, recreation stakeholders may feel that these measures are unfair, which could undermine support for conservation actions (Redpath et al. 2013, Van de Molen et al. 2016).

In summary, for scientific knowledge on the impact of recreation on birds to be of practical use, it should be credible, salient and legitimate. For this knowledge to be credible, the local situation should be assessed using sound scientific evidence; for it to be salient, this evidence should be interpreted within the local context (area characteristics, target species, recreational use); and for this knowledge to be legitimate, it needs to be linked to conservation and recreation targets and open to deliberation, and the values connected with such targets should be negotiable. However, there are trade-offs between these three attributes and each attribute is perceived differently by different actors (Cash et al. 2003, Sarkki et al. 2013, Heink et al. 2015). Finding a balance between the attributes is important and shortcomings in any of these three attributes can jeopardize decision making (Cash et al. 2003, Cook et al. 2010). Therefore, I conclude that there is a need for science-based information on the relationship between recreation and bird populations that can be made site-specific and serve as the basis for deliberations and negotiations in collaborative decision-making processes involving site managers and other stakeholders.

1.3 Aim of the thesis

In this thesis I will provide new scientific knowledge and tools for determining the impact of recreation on birds that are derived from finding a balance between credibility, legitimacy and salience (Cash et al. 2003, Sarkki et al. 2013) (Fig. 2). My aim is to facilitate conflict management between outdoor recreation and biodiversity conservation in nature areas by helping managers and stakeholders to turn over-generalized discussions into discussions about opportunities and possible solutions (Margerum 2002, Redpath et al. 2013). The thesis has two main objectives. First, I want to explore how available data and knowledge can be made context-specific, thus making it more salient. To achieve this, I will integrate site-specific, local knowledge with generic scientific knowledge, taking into account the complexity caused by the different scales at which recreational activities affect bird populations (Gutzwiller et al. 2017). Second, I will explore how scientific information on the relationship between recreation and bird populations can help conflict management in local mixed stakeholder groups. I will show how scientific tools can help site managers to work with different points of view about potential impacts in decision-making processes (McCool 2016) and to open the debate between these mixed stakeholder groups to improve the legitimacy of the outcome.

I recognize that obtaining and incorporating site-specific information into the decision-making process is critical for achieving salience and legitimacy (Ansell and Gash 2008, Reed 2008, Raymond et al. 2010). This process opens the dialogue between different values and views (Reed et al. 2010), which is needed to cross the boundaries between different parties (Redpath et al. 2013, Berkes 2009, Harris and Lyon 2013). Being able to discuss each other's values and views is a necessary condition for joint problem solving and co-learning, which are essential features of collaborative management (Berkes 2009, Armitage et al. 2009). I will show how site-specific information and experience-based knowledge can be integrated with general scientific methods and models to increase the legitimacy and salience of the general scientific methods and models and at the same time increase the credibility of the site-specific information and experience-based knowledge (Fig. 2).

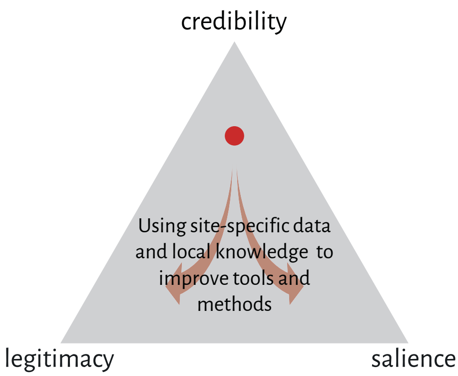

Figure 2. Schematic representation of the shift from credibility to salience and legitimacy that scientific knowledge and tools (red dot) must make if they are to be useful in negotiations on conservation management options between site managers, recreation stakeholders and conservation stakeholders.

1.4 Outline of thesis

In the following four chapters I will integrate site-specific data and local knowledge with scientific methods and models and relate local management measures to local and regional recreation and conservation targets. In these chapters I will address how this knowledge can play a role in decision making by managers of nature areas.

In Chapter 2, I use site-specific monitoring data from GPS tracking in the New Forest, UK, to develop a spatial statistical model to provide managers insight into which factors determine visitor densities. These insights are then used to derive rules of thumb and the model is used to provide an estimate of the visitor densities for the whole region. Three scenarios are presented to illustrate the impact of management measures on visitor densities in the area and on the potential disturbance of Nightjars (*Caprimulgus europaeus*).

In Chapter 3 I integrate individual-based models to assess the impact of different recreation accessibility scenarios on the population size and extinction risk of Skylarks (*Alauda arvensis*). Site-specific information on visitor numbers and habitat use of

Skylarks in the Amsterdamse Waterleidingduinen, the Netherlands, is combined with scientific knowledge about the effect of hiking on the density and reproduction success of this species. Where no dose–impact data on the population level are available, these individual-based tools are able to help managers combine their site-specific information and local knowledge to assess the impacts of different disturbance scenarios on conservation targets and recreation values.

In Chapter 4 I consider cross-scale relations. I provide a new procedure for assessing the impact of outdoor recreation on the conservation targets of protected bird species in the Veluwe, the Netherlands. I link processes within conservation units on the scale at which visitor patterns are managed to those on the regional scale that are relevant to bird species population dynamics. I use available bird monitoring data to derive dose–impact relations and determine the species for which outdoor recreation can be combined with the conservation targets for the Veluwe. The procedure provides output maps that connect the implications of local management to regional population targets. Local managers can use these maps in collaborative decision-making on where to take action and in discussions about each party's responsibilities for the conservation of a bird species at the regional scale.

In Chapter 5 I show how scientific tools that facilitate boundary-crossing between outdoor recreation stakeholders and nature conservation stakeholders helps to mediate between potential conflicts. This work is based on experiences from a research project in the New Forest, UK. It shows the value of transparency and clear information on how the interactions between recreation and bird species are incorporated into the scientific model, the value of incorporating local knowledge and site-specific data into the model, and the value of the spatially explicit model output. Stakeholders can become more effectively engaged in the decision-making process when spatial outputs show the locations of conflict areas and places where there are opportunities for solutions.

In Chapter 6 I reflect on how improvements can be made in the legitimacy and salience of scientific knowledge and tools and how this contributes to finding a balance between outdoor recreation and bird conservation. I explore how this will help to open up the debate between stakeholders and site managers, while taking into account the various perspectives on credibility, salience and legitimacy, and the trade-offs between these three attributes. Based on these reflections, I suggest directions for future research.

Developing tools and rules of thumb for managers to assess the impact of management interventions on visitor densities and bird populations in nature areas

Pouwels R., M. van Eupen, D.D.J. Walvoort, and R. Jochem. Subm. Developing tools and rules of thumb for managers to assess the impact of management interventions on visitor densities and bird populations in nature areas.

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Highlights

- GPS data provides information to understand what drives visitor densities
- Random forest models can be used as tool to assess the impact of interventions
- Current recreational use lowers the Nightjar population by 38% in the New Forest, UK
- Changing the location of car parks in relation to roads is an effective intervention
- Managers might use a simple algorithm for a first estimation of visitor densities

Summary

To manage the potential conflict between outdoor recreation and nature conservation, managers of nature areas need information to select effective interventions. For large nature areas information on visitor use is often lacking and managers often make decisions based on expert judgement. In this paper we use monitoring data gathered with GPS devices to develop a tool and derive rules of thumb managers can use to estimate the impact of management actions on visitor densities. Using a dataset of 1563 tracks from the New Forest, UK, we developed a random forest model and identified which landscape and environmental features account for the spatial variation in visitor densities. The random forest model shows that distance to car park, distance to roads and openness are the most important factors for predicting visitor densities. The model was used as a tool to assess the impact of potential management interventions on the population of Nightjar. As developing this type of tool requires a lot of data we also derived rules of thumb and a simple algorithm that managers of other nature areas can use to estimate the impact of their interventions on visitor densities. The derived rules of thumb show that changing the location of car parks in relation to tarmac roads can help managers to reduce local visitor densities by 80%. Further research in other nature areas should verify the feasibility of these rules of thumb and the simple algorithm.

2.1 Introduction

In many nature areas the dual mandate to protect natural values and accommodate visitors is a source of potential conflicts (Reed and Merenlander 2008) because recreation can have a negative impact on biodiversity values (Larson et al. 2016). On the other hand, allowing recreation in protected areas is thought to be important to build societal support for conservation in general and local nature management in particular (Thompson 2015). Nature managers can take measures to mitigate undesired effects of recreation on nature values, but these measures might have consequences for societal support. Consequently, managers need to plan actions with care and involve stakeholders in their decision making (Sutherland et al. 2014, McCool 2016). They need adequate monitoring data on the temporal and spatial distribution of visitors to know where biodiversity values coincide with visitor use (Hadwen et al. 2007, Hammitt et al. 2015). However, such data are often lacking (Eagles 2014) as methods are time consuming and often expensive (Orsi and Geneletti 2013, Cessford and Muhar 2003). Besides information on the current situation, managers also need to know what options they have to change visitor densities and what impact their measures are likely to have on social or ecological disturbance thresholds (Sayan et al. 2013, Larson et al. 2018). They need to understand what features of the landscape and path network will determine the temporal and spatial distribution of visitors (Hammitt et al. 2015).

Visitor densities tend to be very heterogeneous in nature areas (Hammitt et al. 2015). Entrances and car parks act as gateways to an area (Beunen et al. 2008, Larson et al. 2018). From these gateways visitors disperse using the path network (Meijles et al. 2014). Their distribution reflects the choices they make during their visit (Wolf et al. 2015). Research shows that different features influence visitor choices: specific attraction points, weather, physical features of the landscape, features of the path network, visitor preferences, the time they have available, the motives they have for visiting the area, the composition of the group and other visitors and users of the area (Arnberger and Haider 2007, Beeco and Brown 2013, Böcker et al. 2013, Hallo et al. 2012, Shoval 2010, Maldonado et al. 2011, Taczanowska et al. 2014, Torbidoni 2011, Van Marwijk et al. 2009, Schamel and Job 2017). As all these features will interact during a visit, it is difficult to identify which features account most for differences in visitor densities (Shoval et al. 2010) and which management actions will be effective in altering visitor distribution.

In recreation studies GPS devices are considered to be promising for gathering information on visitor densities and visitor behaviour (Beeco and Brown 2013). They provide accurate data on distribution, speed of movement and time spent at specific locations (D'Antonio et al. 2010, Beeco and Brown 2013). In recent years monitoring with GPS devices has also been used in combination with graph theory to evaluate the use of path structure (Taczanowska et al. 2014, 2017), in combination with recreation suitability mapping (Beeco et al. 2014), in combination with Public Participation GIS (Korpilo et al. 2017) and for spatial analyses of movement patterns (Van Marwijk and Pitt 2008, Renso et al. 2012). However, most studies using GPS devices for monitoring have focused on their utility for visual analyses and to find hotspots (Beeco et al. 2013). Few studies use monitoring information to understand what drives visitor densities in nature areas (Beeco et al. 2014). The exceptions are studies by Meijles et al. (2014) and Zhai et al. (2018). However, although both studies provide managers with information about which features determine visitor densities, this information might still lack relevance to managers. Managers not only need to know which features drive visitor densities, but also how visitor densities depend on these features, what the type of response curve is (Monz et al. 2013). This information would enable them to link potential management interventions, such as changing the features that drive visitor densities, to recognized values such as social and ecological thresholds.

In this study we aim to develop tools and rules of thumb that managers can use in decision-making processes with stakeholders to generate support for potential management interventions when visitor densities exceed social or ecological thresholds. For this support managers need to know how their interventions will lead to a change in visitor densities. We use monitoring data from GPS devices gathered in the New Forest (UK) to develop a random forest model (Breiman 2001) to identify which landscape and environmental features account for the spatial variation in visitor densities in the area. This model is then used as a tool to estimate visitor densities for the whole area. To illustrate its possible applications we use it to assess the impact of potential interventions on the population size of Nightjar (*Caprimulgus europaeus*), one of the protected species in the New Forest and sensitive to disturbance (Langston et al. 2007). As developing this type of tools needs much data and specialized expertise we also derived rules of thumb that managers can use to estimate the impact of management actions on visitor densities.

2.2 Study area

The New Forest is a large forest-heathland complex and Natura 2000 site in the United Kingdom. The area is around 57 000 ha in size and was designated as a Natura 2000 site for 11 habitat types, two habitat directive species and seven bird species (http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUCode=UK0012557, http://jncc.defra.gov.uk/pdf/SPA/UK9011031.pdf). It is a mosaic of woodland, heathlands, grasslands and mire systems and is managed by the Forestry Commission. Several hundred thousand residents live and work in small villages and medium-sized towns within the area or within a radius of 10 km. The New Forest is also a popular holiday destination all year round and is famous for its herds of horses (the New Forest pony) that roam the area. The area is easily accessible, with over 100 car parks from where visitors can use the dense network of over 2500 km walking trails (Fig. 1). An estimated 13.3 million people visit the area each year (Gallagher et al. 2007).

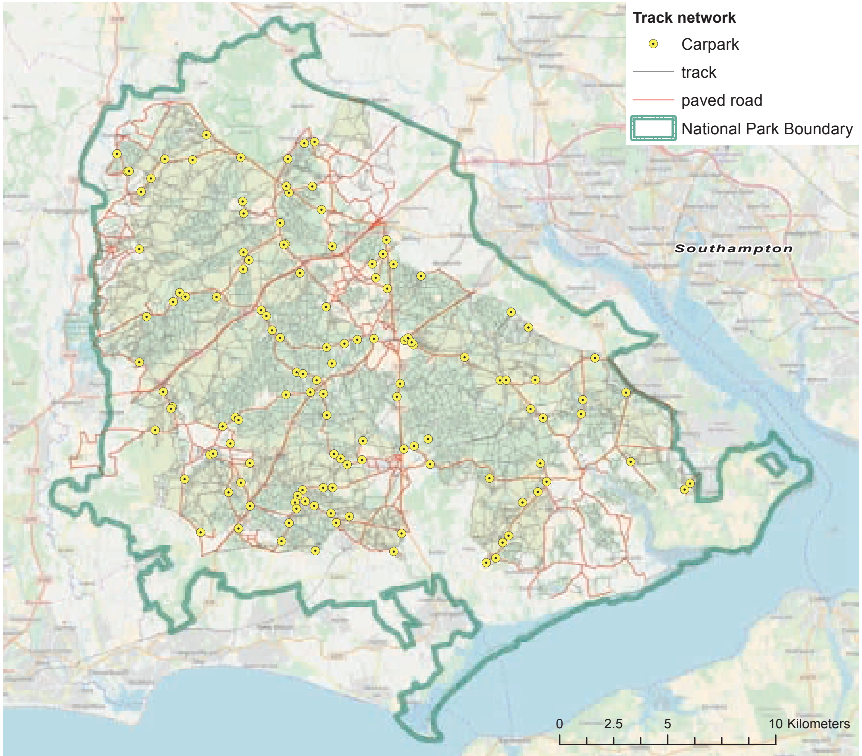

Figure 1. The New Forest study area located west of the city of Southampton in the UK. Indicated are car parks, path network and roads.

2.3 Methods

Our method consists of six main steps (Fig. 2). First we collected information on visitor distribution using GPS devices. In this step the monitoring data from the GPS devices was prepared for further analyses. Second, we selected explanatory variables that describe the landscape and environment of the New Forest. In the third step we performed an exploratory data analysis to better understand the relationships between the different explanatory variables and characteristics of the routes visitors had followed. In the fourth step we developed a random forest model (Breiman 2001) to estimate the importance of the variables and their interaction in explaining the spatial variation in visitor densities. In the fifth step we used this model as a tool to predict visitor density distribution for the whole area. We illustrate the possible applications of the model by using it to assess the impact of three potential management interventions on the Nightjar population. In the sixth step we derived rules of thumb based on the results of the previous steps. The steps are explained in the next six sections.

2.3.1 Data collection and preparation

The monitoring data with GPS devices were collected on 80 mostly consecutive days during spring and summer in 2004 as part of the PROGRESS research project (Gallagher et al. 2007). Visitors arriving at car parks were asked to participate in the monitoring project. The GPS devices were stored in a plastic carrying case that could be clipped onto the rucksack or jacket of visitors who participated in the survey. Participants were instructed to keep the device with the built-in antenna upward and at an approximate height of 1.5m. Two models of GPS devices were used, the Garmin eTrex and Garmin eTrex Venture. The devices were set to collect single data points at a variable rate to create an optimum representation of the track. After participants returned, the single data points were stored in a database using the Garmin transfer protocol. Additional information regarding the group size, number of dogs and use of a leash for the dog was added to the monitoring data by unique ID.

In total 1563 GPS tracks with 110 505 single data points were collected at 41 car parks. The car parks were selected by the managers of the area. The monitoring frequency differed between car parks; some were monitored over 10 days, while others were only monitored once (Appendix 1). As the number of GPS devices was limited, the proportion of visitors monitored at highly used car parks was probably lower than at less used car parks. As these proportions are unknown the dataset does not represent

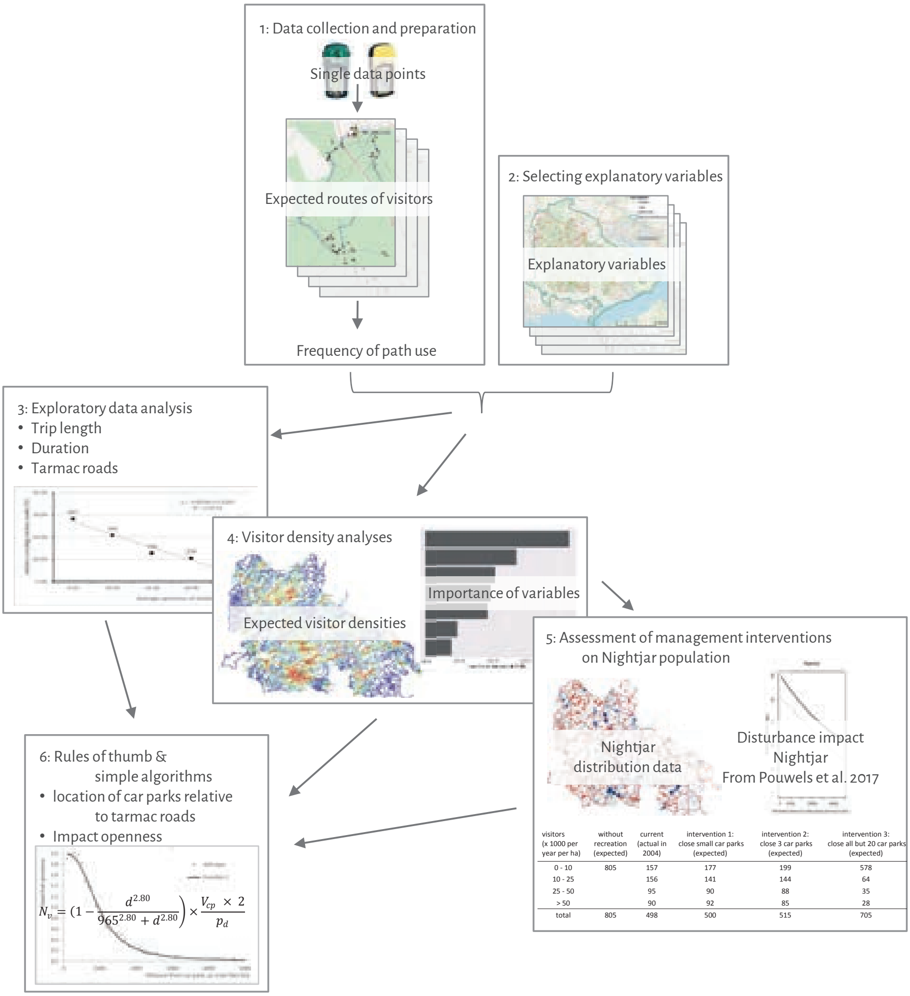

Figure 2. Schematic overview of the method. In the first step the monitoring data was collected with GPS devices and prepared for further analyses. In the second step explanatory variables were selected that described the landscape and environment of the New Forest, followed by an exploratory data analysis in the third step. In the fourth step we developed a random forest model to estimate the importance of the explanatory variables in predicting the frequency with which visitors use specific segments of the path network. In the fifth step we used these predicted frequencies to estimate the impact of three potential management interventions on the Nightjar population. In the sixth step rules of thumb and simple algorithms were derived from the results of the previous steps.

true visitor densities. Instead, we used the GPS tracks to construct the routes visitors were most likely to have followed in four steps (Appendix 2). The constructed routes were used to determine for each path the frequency of use by visitors from a specific car park by dividing the number of constructed routes by the number of visitors starting at that specific car park. Only car parks that had 10 or more routes in the database were taken into account, resulting in analyses based on 36 car parks (Appendix 1).

2.3.2 Selecting explanatory variables

We selected several information sources that describe the landscape and environment of the New Forest. We applied three selection criteria: the data had to represent features that (1) were known from previous research to have an influence on visitor behaviour and visitor densities, (2) vary across the New Forest and (3) represent the situation around 2004 when the monitoring data was gathered. The features we selected were: car parks, path and road network, vegetation type, openness, slope and traffic noise (Table 1). The information on the car parks was used to determine the distance of each point on the track to a car park, as it is known that visitor densities are higher near car parks (Meijles et al. 2014, Zhai et al. 2018). The path network was used to distinguish between different path types, as previous research suggested that visitors have different preferences for path surfacing (Beeco et al. 2014). The path network was also used to determine the distance to tarmac roads, as Henkens et al. (2006) showed that visitors avoid crossing tarmac roads and visitor densities might be lower near tarmac roads. The vegetation information was selected because vegetation types were found to determine the attractiveness of the landscape to visitors (De Vries et al. 2013), which may result in a spatial variation in visitor densities.

The openness of a landscape is considered one of the most important indicators of the visual landscape experience (Kaplan et al. 1989, Weitkamp 2011). In nature areas this openness strongly depends on the vegetation structure as perceived by visitors. Information representing landscape openness in the New Forest was not available. Instead, the Viewscape model (Jochem et al. 2016) was used to determine openness for each location in the area. ViewScape calculates the visible area of the landscape from sightlines within a radius of 3 km (Jochem et al. 2016). Two openness features were used as explanatory variables: the total visible area and the variation in sightlines. Slope was selected as visitors avoid steep slopes (Beeco et al. 2014) and lower densities are expected at steeper slopes. Traffic noise was selected as visitors prefer tranquil areas and densities are expected to be lower in areas with high noise levels (Benfield et al. 2010).

2.3.3 Exploratory data analyses

The dataset on the derived routes was analysed for basic characteristics, such as total trip length, maximum distance from car park, average group size and presence of dogs. Information on the explanatory variables was added to explore the relationships between these variables, visitor densities and characteristics of the expected routes followed by visitors.

2.3.4 Visitor density analyses

A random forest model was constructed to estimate which landscape and environmental features account for spatial variation in visitor densities in the area. For the analysis all maps were converted into a 10 x 10 m grid. This resolution was chosen to avoid information on different paths being assigned to one cell. We used the implementation by Wright and Ziegler (2017). Their implementation of random forests follows that of Breiman (2001) and is also suitable for large data sets. The frequency of use of a path by visitors from a specific car park was used as the response variable ('y' variable).

For practical reasons (data reduction to make the calculations feasible) only locations within 5 km of the car parks, as the crow flies, were taken into account; these amounted to more than 99% of the single data points of the GPS tracks. The model we constructed consists of 500 regression trees, each of which is based on a bootstrap sample from the original data. Each bootstrap sample has the same size as the original data and was obtained by simple random sampling with replacement. This means that some records of the original data set occur more than once, and some never. Data that were not in the bootstrap sample were used for 'out-of-bag' validation. The importance of the explanatory variables used (see Table 1) was computed in three steps. First, the out-of-bag mean squared error was computed for each tree. Then, this statistic was also computed for each tree after permuting each predictor variable. Finally, the difference between the two mean squared errors was averaged over all trees (Liaw and Wiener 2002).

2.3.5 Assessment of potential management interventions as an illustration of a practical application

To illustrate how the data and tools could be applied to support decision making we designed three potential management interventions and estimated the visitor densities for the whole area. The visitor densities were used to assess the impact of the interventions on the Nightjar population by comparing it with the current situation. We chose management interventions that restrict visitors by temporary or permanent closures of car parks as these are one of the most commonly used methods of reducing visitor densities in sensitive parts of nature areas (Hammitt et al. 2015). The three possible interventions assessed are: 1) closure of small car parks, 2) closure of relatively isolated car parks that are located near areas with many Nightjars and 3) closure of all but 20 car parks to concentrate visitors near the border of the area or near villages, for example Lymington and Lyndhurst (see Appendix 3 for more details on the chosen interventions).

Table 1. Selected explanatory variables used in the random forest model. The justification for the chosen variable is given in the third column (Source) together with the reference.

Variable	Variable determination	Source
Distance to car park	The distance to the car park was calculated as the crow flies.	Visitor densities are higher near car parks (Meijles et al. 2014, Zhai et al. 2018).
Path type	Five path types were distinguished, based on a path network map showing nine path types: unclassified dirt tracks (72% of total length), gravel tracks (3%), tracks on lawns (6%), cycle paths (8%) and tarmac roads (11%). The map was provided by the Forestry Commission.	Visitors densities depend on path type as visitors have different preferences for types of path surface (Beeco et al. 2014) and path width (Zhai et al. 2018).
Distance to roads	Distance to the nearest tarmac road was calculated as the crow flies.	Visitors densities are expected to be lower near roads as visitors avoid crossing roads (Henkens et al. 2006).
Vegetation type	11 Groups of vegetation types were distinguished, based on a vegetation type map containing 52 vegetation types. The vegetation map was provided by the Forestry Commission. Corine Land Cover map (EEA 2016a) was used to fill gaps in the vegetation map.	Visitor densities depend on vegetation types as they determine the attractiveness of landscapes, as perceived by visitors (De Vries et al. 2013) .
Openness:	Based on the vegetation map, two openness features were determined by the Viewscape model (Jochem et al. 2016):	Openness is an important factor for visitor preferences (Kaplan et al. 1989).
Total area	Total visible area; amount of area visible to a distance of 3 km.	
Variation	Standard deviation in the length of the 180° sightlines representing diversity in openness in the 360° view.	
Slope	The slope (in degrees) was based on the European Digital Elevation Model (EU-DEM) (EEA 2016b).	Visitors avoid steep slopes (Beeco et al. 2014).
Traffic noise	Traffic noise (in dB) was based on modelled noise levels for major traffic routes (DEFRA 2016). For the missing values a background noise of 35 dB was assumed (based on Pesonen 2000).	Visitors prefer tranquil areas and densities are expected to be lower in areas with high noise levels (Benfield et al. 2010).

For this assessment we used the random forest model developed in step four together with distribution data on the Nightjar (Newton 2010). The random forest model was used to predict relative visitor frequency on path segments for all car parks in the area. For each intervention the number of visitors at the car parks was used to calculate a map with the visitor densities per path per year. In order to calculate the expected impact of each intervention we used the dose–impact relationship between visitor densities and breeding pair density as described by Pouwels et al. (2017). This resulted in estimates for the total (potential) population size for the Nightjar in the New Forest area for each situation (See Appendix 3 for more details of the method used).

2.3.6 Deriving rules of thumb

The random forest model was used to determine the importance of the explanatory variables in explaining the spatial variation of the visitor densities in the New Forest. The relationship between the variables and visitor densities may be visualized in 'partial dependence plots'. However, as these variables might be correlated and interact with one another, interpreting these visualizations can be complicated or even misleading (Molnar 2019). Nevertheless, managers need these relationships to estimate the impacts of interventions. Therefore, we combined the results from the data exploratory analyses for the most important variables selected by the random forest model and derived rules of thumb and simple algorithms. These rules of thumb and algorithms may be used by managers to estimate the impact of interventions on visitor densities and help them to gain support for these interventions in decision-making processes with stakeholders. We focused on interventions related to restricting visitor use by temporary or permanent closure of car parks or by changing the capacity and location of car parks.

2.4 Results

2.4.1 Exploratory data analysis

The additional information from the GPS tracks shows that 40% of the tracks represent a single visitor, 40% represent two visitors and 20% represent visitor groups with more than two people. The average number of people for each track was 2.0 visitors. Two thirds of the visitors walked their dog. Most of them were on their own and 23% had the dog off leash. The average trip length of visitors without dogs was 5.4 km and of visitors with dogs 3.2 km. More than half the visitors stayed within a radius of 1000 m of the car park (Fig. 3).

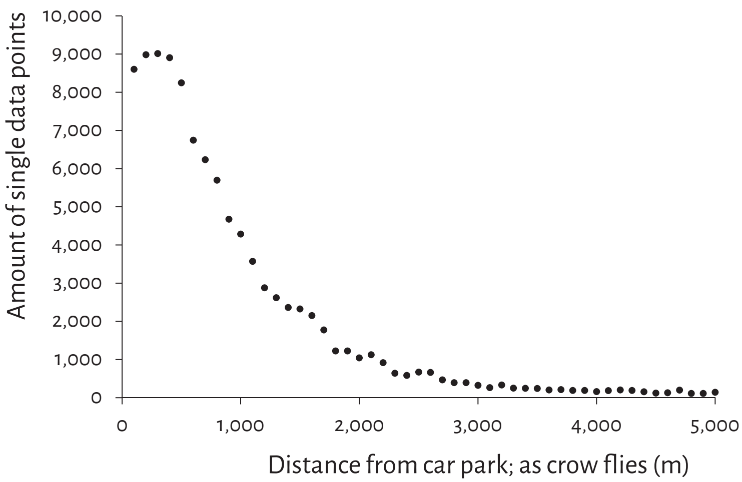

Figure 3. Numbers of single data points from GPS tracks after data handling (Appendix 2) at specific distances from the car park. Just 1.6% of all data points are found at distances exceeding 5000 m and are not shown on the graph.

The data also show that 17.6% of visitors cross roads or use them during their visit. Combining this data with other variables shows that visitors in open landscapes avoid crossing roads more often than visitors in closed landscapes. For visitors without dogs the probability of crossing roads declines from 41% in the least open landscapes to 13% in the most open landscapes. For visitors with dogs the probability is less than 10% in all landscapes (Fig. 4).

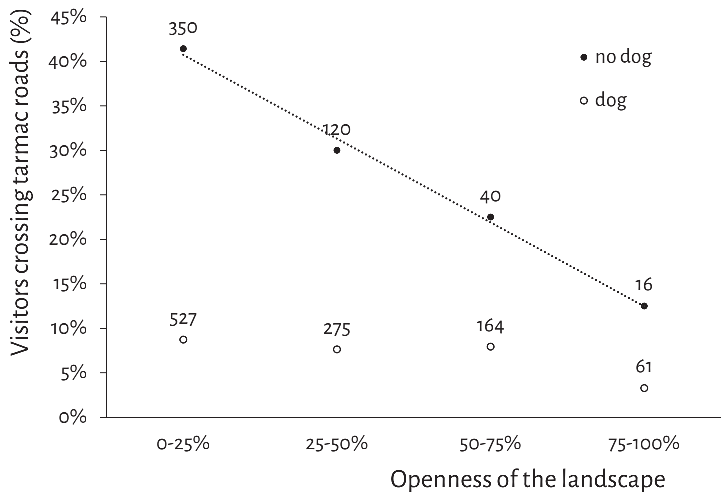

Figure 4. Probability of visitors crossing tarmac roads in relation to average openness of the landscape along the route taken. The number of routes in each openness class is given. The average openness is defined as the percentage of area that is visible within a 3000 m radius during the entire visit.

2

2.4.2 Impact of landscape and environmental features on visitor densities

The fitted random forest model explains 74% of the variance in the data. The models show that besides distance to car park, distance to road, openness related variables, path type, slope and vegetation type are important factors for predicting visitor densities (Fig. 5). Traffic noise showed a very low importance in the first models and was removed from the final dataset, suggesting that the distance to roads is a better predictor of visitor densities than the level of traffic noise itself.

2.4.3 Impact of management actions on visitor densities and current distribution of Nightjar

The random forest model shows visitor densities in the New Forest varying between 0 and 300 000 visitor groups per ha per year (Fig. 6). The current population of Nightjar in the New Forest, based on the survey from 2004, consists of 498 breeding pairs. The potential population size, without recreation in the area, is estimated to be 805 breeding pairs, implying that current recreational use lowers the population size by 38%. All three interventions lead to an increase in population size, but only the intervention in which all but 20 car parks are closed shows a large impact on the population size (Table 2).

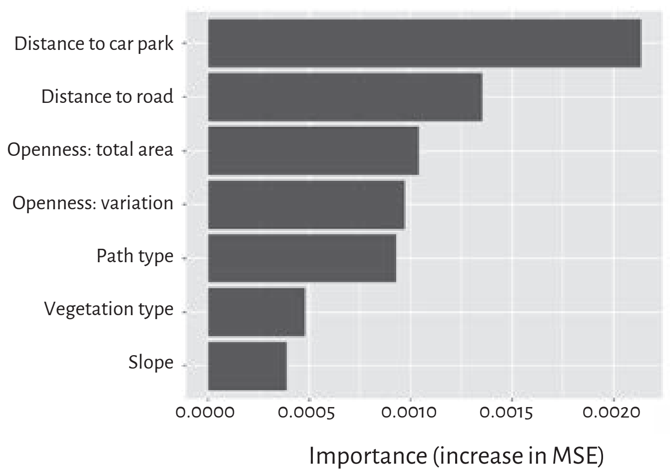

Figure 5. Importance of variables in predicting visitor densities.

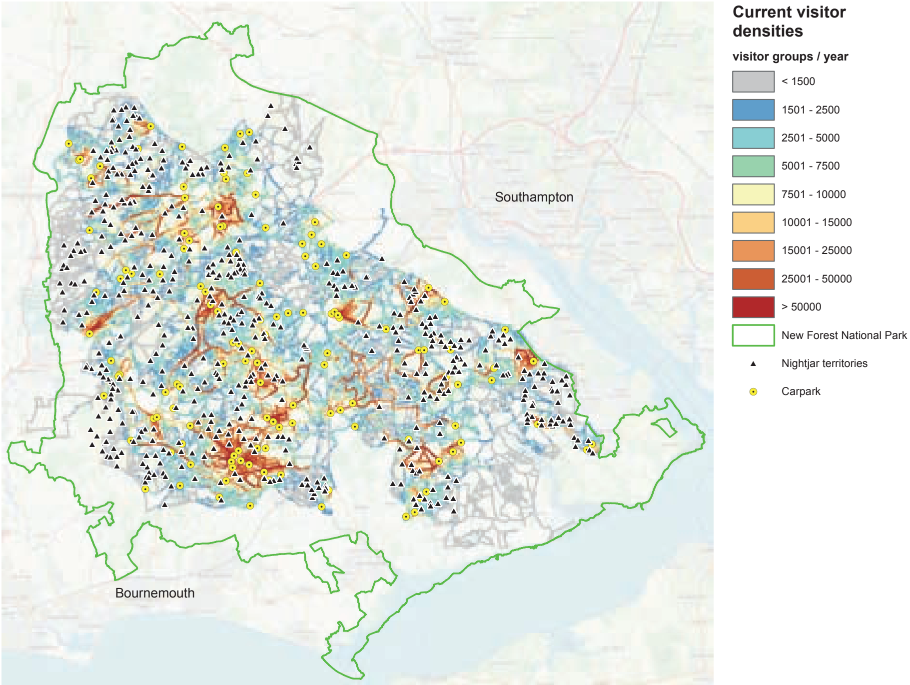

Figure 6. Visitor density map on the New Forest based on the random forest model and the current location of car parks and Nightjar territories. The area containing the highest visitor densities is located at Wilverley in the south.

Table 2. Predicted impact of potential interventions to amend the spatial variation of visitor densities on Nightjar breeding pairs in the New Forest, UK. The figures represent the current and predicted number of Nightjar breeding pairs over four visitor density zones (column 1) for four situations: the current distribution of car parks (column 3) and three interventions (columns 4–6). Column 2 shows the predicted number of breeding pairs for a situation without recreation.

visitors (x 1000 per year per ha)	without recreation (predicted)	current (actual in 2004)	intervention 1: close small car parks (predicted)	intervention 2: close 3 car parks (predicted)	intervention 3: close all but 20 car parks (predicted)
0 – 10	805	157	177	199	578
10 – 25		156	141	144	64
25 – 50		95	90	88	35
> 50		90	92	85	28
total	805	498	500	515	705

2.4.4 Rules of thumb

To estimate the impact of management interventions on visitor densities we derived two rules of thumb and one simple algorithm for managers. The first rule of thumb concerns the impact of tarmac roads on visitor densities: visitor densities are up to five times higher in areas on the same side of the road as the car park than on the opposite side of the road. Managers could use this rule of thumb to change visitor densities by relocating car parks. These interventions might reduce visitor densities by 80% in areas that are sensitive to disturbance without restricting visitor use completely. The presence of dogs might even be reduced by 90%. The second rule of thumb concerns the interaction between tarmac roads and openness. In woodlands the impact of tarmac roads on visitor densities is less distinct (around 78% reduction), while in open landscapes, like heathlands, the impact is larger (around 95% reduction). Combining both rules of thumb shows that managers might be able to reduce visitor densities by up to 95% by relocating a car park from one side of the road to another in open landscapes.

Results from the exploratory data analysis and the random forest model give a reliable estimate of how visitor densities decline with increasing distance from the car park. We used the frequency distribution of GPS locations, the single data points (Fig. 3), to derive a simple algorithm that estimates the number of visitor groups at a specific path segment. First, we chose an algorithm that describes the sigmoid declining curve and fitted the parameters for the correlation of single data points. This curve represents the probability that a visitor group is present at a specific distance (Function 1; Fig. 7). Next, we multiplied this by the number of visitor groups starting at a specific car park, taking into account that visitor groups will be present at a specific distance twice: when they enter the area and when they return to the car park. Finally, the number of visitor groups was divided by the number of paths segments at a specific distance class to account for a potential unevenness in path density over distance (Function 2). Managers can use Function 2 to acquire a first estimate of the number of visitors at a specific location (N_v). The parameters needed are quite easy to collect and are (1) the distance to the car park of interest, (2) the number of visitors that use the car park, and (3) the density of the path network around the car park. For locations within 5 km of more than one car park, the algorithm should be applied for each car park separately and the number of visitors per path segment should be summed.

$$f_{sdp} = 1 - \frac{d^{\alpha}}{H^{\alpha} + d^{\alpha}} \qquad \text{Function 1}$$

f_{sdp} fraction of single data point at distance d
d distance to car park (m)
H parameter at which visitor presence is 50% (m); 965 in Fig. 7
α parameter determining the rate at which visitor presence declines; 2.80 in Fig. 7

$$N_v = \left(1 - \frac{d^{2.80}}{965^{2.80} + d^{2.80}}\right) \times \frac{V_{cp} \times 2}{p_d}$$ Function 2

N_v Predicted number of visitors present at a path segment at distance d (per day or per year)
d distance to car park (m)
V_{cp} number of visitors starting at a specific car park (per day or per year)
p_d number of path (segments) at a specific distance class

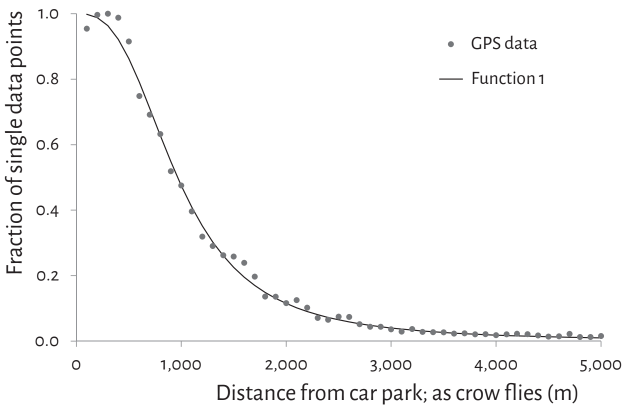

Figure 7. Fraction of single data points at a certain distance from a cark park. The parameter values of Function 1 are 2.80 for α and 965 m for H.

2.5 Discussion and implications for recreation management

2.5.1 Practical implications

In this paper we show that random forest models are suitable for modelling the complex interaction between different landscape and environmental features to explain visitor densities in nature areas. A random forest model was used as a tool to assess the impact of potential interventions on visitor densities and consequently on a population of a target species, the Nightjar, in the New Forest, UK. We focused on reallocating visitors, but interventions such as changes to path type or vegetation type could also be assessed. Although the GPS data only covered one third of all car parks, we believe that the data are representative of all car parks in the area and so the model predicts visitor densities for the whole area (Fig. 5). Random forest models based on GPS monitoring data are particularly useful in areas where managers need tools to estimate visitor densities and relate them to social or ecological thresholds. Managers could use these tools in decision-making processes with stakeholders to discuss and find support for potential interventions.

To discuss the effectiveness of interventions with stakeholders, managers need to know what measures are needed to lower visitor densities to certain desired levels. As the random forest model does not provide straightforward dose–effect relationships between a single variable and the visitor density, we derived two rules of thumb. Both use a simple algorithm to relate the location of car parks to visitor densities at specific distances from the car parks. Relocating car parks is effective as car parks act as gateways (Larson et al. 2018) and, as this present study has shown, their location accounts for much of the spatial variation of visitor densities in the area. These rules of thumb can be used by managers of nature areas who lack the resources or expertise to collect and analyse the type of data used in this study.

The distinctive downward curve of visitor densities corresponds with other distance decay curves (Yang and Diez-Roux 2012, Tratalos et al. 2013, Prins et al. 2014). The added value of our algorithm is that it is based on the single data points of the GPS tracks, which is a better representation of visitor densities than a curve based on the maximum distance visitors walk (Tratalos et al. 2013, Prins et al. 2014). A distance decay curve based on the maximum distance visitors walk implies visitors walk in a straight line back and forth. Our dataset shows that not taking into account the shape of the route visitors follow will result in underestimating visitor densities by approximately 10% between 500 and 1500 m from car parks.

2.5.2 Generalization of the results

Our results show that visitor densities in the New Forest depend on the interaction between several features of the path network and landscape as well as on the accessibility of the area. That distance to car park is an important factor confirms the conclusion of Meijles et al (2014) and Zhai et al. (2018). Our finding that visitors avoid crossing tarmac roads confirms the conclusion of Henkens et al. (2006). In addition, the total visible area and the variation in 180° sightlines are important predictors of visitor densities. However, the model outcomes show that the correlation is complex and not easy to interpret. The New Forest is expected to attract visitors who prefer open areas like heathlands as well as visitors who prefer closed areas like ancient woodlands. The results of our study reflect these mixed preferences. Also, Heijman et al. (2011) showed that respondents preferred a mix of open and closed forest, making it difficult to identify a correlation between openness and visitor densities. A variable that was not found to be important by our analytical method was traffic noise. This may be due to the lack of variation provided by the data (too coarse).

If our rules of thumb are to be useful, it is essential that they are applicable in a range of nature areas. Such areas should therefore have similar features to our study area. The most important features of our study area are its size (a few thousand hectares), the large path network with multiple car parks, the fact that it is a cultural landscape, common in western Europe, and the presence of just a few specific attractions. The steep distance decline curve has also been found in several other studies, suggesting that it is a generic description of the correlation between visitor densities and distance to car park (Yang and Diez-Roux 2012, Tratalos et al. 2013, Prins et al. 2014). One way of testing the validity of the algorithm for use in other areas is to compare the average trip length of visitors in the New Forest found in this study with other studies in similar areas. Such a comparison shows that the average trip length is in the same order of magnitude. Meijles et al. (2014) reported 4.8 km in a mixed forest and heathland area in the Netherlands, Taczanowska et al. (2008) reported 5.2 km in an urban forest park in Austria and Zhai et al. (2018) reported 3.4 and 3.8 km in two urban forest parks in China. Shorter lengths were reported by Sharp et al. (2008): 2.2 km for dog walkers and 2.4 km for walkers in the Dorset heaths (UK) and 2.5 km for dog walkers and 2.6 km for walkers in the Thames basin heaths (UK). In small nature areas the results might be less useful as the average trip length and maximum distance visitors penetrate into the area might be lower; Hornigold et al. (2016) uses 400 m as a typical distance covered by visitors entering nature areas in the UK.

2.5.3 Dealing with GPS data

Due to the large numbers of tracks and car parks where visitors have been monitored in the area we consider the dataset to be a good reflection of visitor behaviour and visitor densities in the New Forest. Using GPS devices for monitoring purposes always has limitations due to the accuracy of the locations stored by the GPS device. Especially in woodlands, single data points may lie some distance from the path network (Piedallu and Gégout 2005). Lack of accuracy can lead to errors in the dataset and we found that error handling is a time consuming part of the research (Meijles et al. 2014). Communication errors or breakdowns between the GPS device and satellites, usually for short periods, meant that some parts of the routes taken by visitors were missing. We used the travelling salesman algorithm (Appendix 2) to fill these gaps, but as the algorithm always chooses the shortest distance over the path network, some of the selected paths may not actually have been used. A relatively small part of the routes followed (15%) were constructed by the algorithm and we are confident that most of the paths were selected correctly as the visual check in step four of the data preparation did not show any unexpected results. Nevertheless, further research is needed to determine the accuracy of this algorithm in selecting path segments to complete the routes followed by visitors, based on the single data points collected by GPS devices.

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Linking ecological and recreation models for management and planning

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University of Arizona Press, Tucson, Arizona, USA.

Abstract

Most nature areas (e.g. national parks, regional parks, wildlife sanctuaries, etc.) are open for recreation. In these areas, recreation can be an extra stress factor for animal populations. Increased recreation pressure decreases the probability of long-term population persistence. Recreation goals and biodiversity goals need to be well balanced: what is the recreation pressure an area can support, and how should the recreation be distributed spatially and temporally in order to achieve both recreation and biodiversity goals. In this chapter we demonstrate how a linkage between an ecological and a recreation model can help managers in finding this balance, using a case study.

3.1 Introduction

Many nature areas in Northwestern Europe are open for recreational use. Visitors enjoy restorative health benefits of contact with nature and they experience many other valued aspects of visiting the countryside such as tranquility, open space, fresh air, unpolluted waters and scenery (Natural England 2006, Natuurmonumenten 2006). Health programs are set up to stimulate more people to visit nature areas (e.g., Natural England 2006) and managers must accommodate an increasing number of visitors. The policy of opening nature areas for recreation can conflict with the policy of protecting species in these areas (Drewitt 2007). In England, the Countryside and Rights of Way Act 2000 (CRoW) integrates freedom of rambling with protecting biodiversity. This integration should be evidence-based instead of believe-based (Bathe 2007). While the last decade has witnessed significant research on the impact of recreational activities on biodiversity, there is a need for more research to balance or integrate recreation and biodiversity (Sutherland et al. 2006, Sutherland 2007, Haider 2006).

In industrialized countries like the Netherlands, the persistence of many populations in the landscape depends on nature areas. Next to fragmentation, eutrophication, desiccation and pollution, recreation can be an extra stress factor for these populations and can threaten their persistence. Many studies have stressed the negative effects of recreational disturbance on bird behavior, distribution and breeding success (Blanc et al. 2006, Gill 2007, Mallord et al. 2007). However from a conservation viewpoint, the impact at the population level is of paramount importance (Sutherland 2007). Modeling the consequences of alternative recreational access scenarios will help policymakers choose appropriate mitigation measures (Taylor et al. 2007, O'Connell et al. 2007, Mallord et al. 2007). These models should include a recreational as well as a conservation viewpoint (Sutherland 2007). The main questions that should be answered are: does the area fulfill the expectation of the visitors? What are the impacts of recreation on species persistence? And is the viability of a population affected by the impact?

Models should be seen as part of a conceptual planning/managing framework that includes both scientific and managerial perspectives (Haider 2006). Scientists need the managers to give their research more focus as much as managers need the empirical data of scientists to help them develop standards (Cole 2004). The framework integrates three dimensions for managing multifunctional land use problems, including goals, monitoring and design (Fig. 1). These dimensions allow managers (or decision makers) to be fully aware of: (1) the desired future they wish to achieve; (2) the alternative routes to the future; and (3) consequences of those alternatives (Haider 2006). The framework implies that these dimensions can be independently considered. First, stakeholders negotiate goals with respect to biodiversity and recreation and come to operational management area objectives (goal setting dimension). Second, goal realization needs to be monitored as changes occur in the level and spatial/temporal distribution of recreational access that is provided for visitors (monitoring dimension). Finally, the development of future management plans should simultaneously consider dimensions of both nature and recreation (design and evaluation dimension). Models are a useful tool for this evaluation (Opdam et al. 2002).

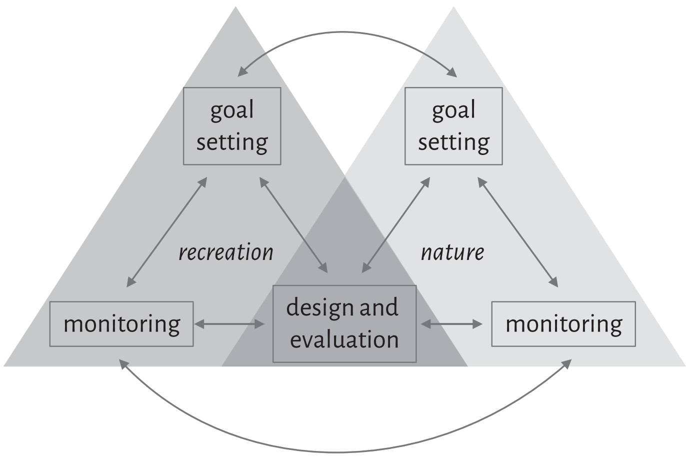

Figure 1. Planning framework for multiple land use in protected nature areas. The arrows within the triangle indicate information flows between the three dimensions. Establishment of a monitoring program should chart success in achieving management goals (e.g. Manning 2004). Analyses of monitoring data can also provide rules of thumb for goal setting (e.g. Fernandez-Juricic et al. 2005, Moran-Lopez et al. 2006). Monitoring data provides a basis for goal reassessment as well as defining design and evaluation strategies, which, in turn must be based on stated goals (e.g. Verboom et al. 2001, Opdam et al. 2002). Goals define results that should be produced and monitored in modeling the implementation of design strategies. Models often provide insight into what monitoring data are missing (Jochem et al. 2007).

The design dimension evaluates the effect of management plans toward realization of both recreation and nature goals. Plans for both nature enhancement and recreational access should be subjected to this evaluation. Few researchers have used models and monitoring data to integrate recreation and nature goals in evaluating future designs of an area, including Poe et al. (2006), Henkens et al. (2006) and Liley et al. (2006). In these models functional relationships are established between attributes managers can control and desired management goals.

Integration is possible only when the impacts of recreation and wildlife on each other are well understood. This is indicated by the arrow between the monitoring dimensions. However, monitoring is rarely integrated. Social scientists tend to monitor motivation and experience of visitors and ecologists tend to focus on recreation impact on animal behavior. Within the proposed framework, monitoring research should result in a description of the functional relationships between attributes that managers can control and the outcomes that managers seek (Cole 2004). Goal setting is rarely integrated. The inability to resolve the competing values of a diverse public (Cole 2004) make it difficult to establish agreed upon standards (Seidl and Tisdell 1999). Most so-called integrated goals are in fact nature goals that restrict recreation behavior within a certain distance or period of time from nests or colonies of sensitive birds (e.g. Moran-Lopez et al. 2006).

3.2 Recreation impact

Research examining the impact of recreation on animals is diverse (Hill et al. 1997, Blanc et al. 2006). This research can be categorized into four types (Gill 2007): change in distribution; change in behavior; change in demography; and change in population size and persistence. First, densities of birds are lower near paths (Vos and Peltzer 1987, Van der Zande and Vos 1984, Yalden and Yalden 1990, Riffel et al. 1996, Miller et al. 1998, Langston et al. 2007, Mallord et al. 2007 and O'Connell et al. 2007). Vos and Peltzer (1987) also illustrate that the intensity of use increases the distance over which this reduction occurs (Fig. 2).

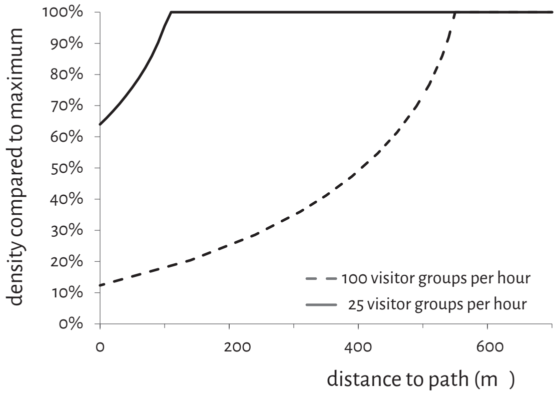

Figure 2. Schematic example of recreation impact on densities of nests of Curlew (*Numenius arquata*) (after Vos and Peltzer 1987).

Second, recreation has an impact on the escape behavior of animals like birds and mammals (Blanc et al. 2006, Gill 2007). The closer a visitor approaches, the higher the probability an animal will flee. Larger animals tend to flee at longer distances from an encounter with humans (Blumstein et al. 2005). Also the type of visitor and the way a visitor moves have effect on escape behavior. Ecotourists, hunters, browsers and visitors with dogs have a higher impact than cyclists or walkers. Unpredicted movement patterns of visitors and changes in speed or direction have a higher impact (Blanc et al. 2006). In periods when the escape behavior is an extra load on the scarce energy budgets of animals, recreation can have an impact on the survival of the animal or even the viability of the population. These periods are the winter, when food is scarce and energy costs are high (Gross-Custard et al. 2006, Stillman et al. 2007), and the spring, when energy budgets are directly linked to the number of offspring (Yalden and Yalden 1990, Murison et al. 2007, Langston et al. 2007). However, there is no guarantee that the behavioral response to disturbance is related to the population consequence, measured in terms of decreased reproduction or increased mortality (Gill et al. 2001). Birds exhibiting an escape behavioral response might actually be moving to alternative breeding or feeding sites (Stillmann et al. 2007). Stillmann & Goss-Custard (2002) document the seasonality of escape behavior for Oystercatchers. In late winter, when energy demands are higher and food quality is lower, Oystercatchers respond less frequently to disturbance. Individual based models, consisting of fitness-maximizing individuals, are one means of linking disturbance induced behavioral responses to population consequences (West et al. 2002, Stillmann et al. 2007).

Thirdly, research shows that reproduction of birds is lower when recreation pressures are high (Van der Zande & Verstraal 1984, Bijlsma et al. 1985, Vos & Peltzer 1987 Gaddy & Kohlsaat 1987, Miller et al. 1998, González et al. 2006, Murison et al. 2007). Adult survival also decreases with higher recreational pressure (Gross-Custard et al. 2006). Ecotourism can also be a cause of reduction in survival (Müllner et al. 2004). There might be a feedback between impact on density and impact on reproduction. Only Mallord et al. (2007) found no impact on reproduction for the Woodlark (*Lullula arborea*) in plots with and without recreation.

Fourth, lower densities, lower reproduction success and higher mortality rates might lead to lower survival rates of populations. Depending on the spatial and temporal characteristics of the impact on patch size, habitat quality and other stress factors the populations might go extinct (Blanc et al. 2006). There is little research on the impact of recreation on changes in population size or persistence. Mallord et al. (2007) modeled the consequences of several access scenarios for Woodlark populations in southern UK and found that compared to the current situation the same number of people distributed evenly across all sites leads to a major negative impact on the population. In the case study presented in this chapter we also use a model to translate the impact of recreation on the population size and persistence.

3.3 Case study

The study area is a dune area located near Amsterdam (the Netherlands) that is heavily used for recreation (Fig. 3). It is called the 'Amsterdamse Waterleidingduinen' and with an area of 3500 ha it is one of the largest dune areas in the Netherlands. In 1998, a total of 723,000 visitors used the area (Jaarsma & Webster 1999). Besides its functions for protecting biodiversity and ensuring recreational opportunities, the area is used by City of Amsterdam for producing drinking water. Yet its main function is protecting the lowlands against the sea.

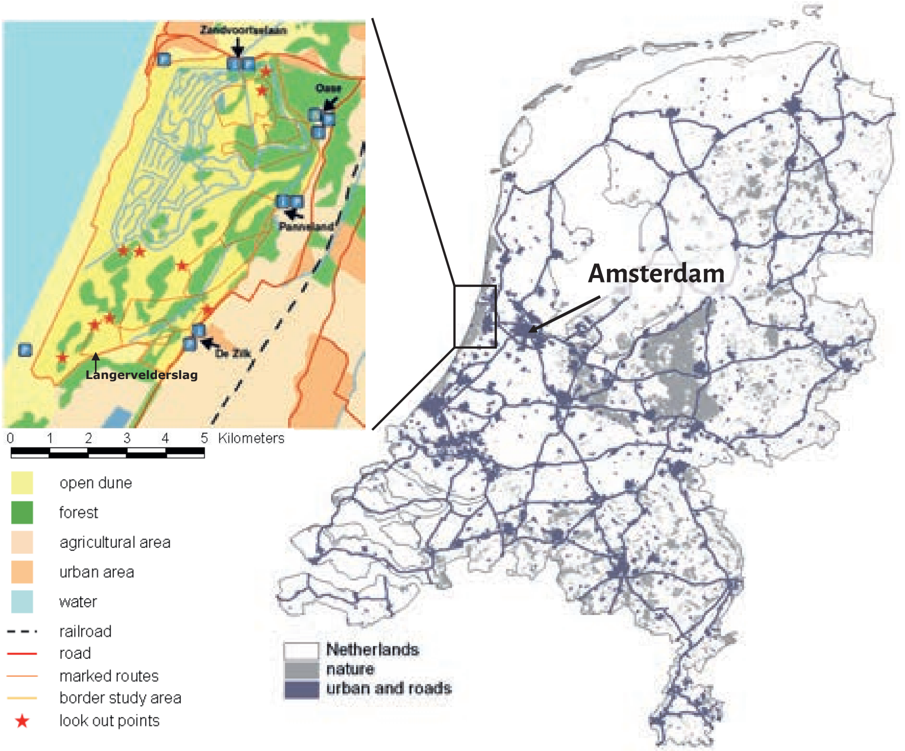

Figure 3. 'Amsterdamse Waterleidingduinen' dune area near Amsterdam. Black arrows (left figure) are entrance points.

In this case study, we illustrate the integrated use of an agent based model to simulate recreational behavior and an individual based model to simulate response of a population of avian species to alternative management scenarios (Fig. 4). The recreational simulation model is MASOOR (Jochem et al. 2007) and the population model is METAPHOR (Vos et al. 2001, Verboom et al. 2001). We chose an individual based population model because it allows us to translate the disturbance impact of recreational use on individual members of an indicator species to a population level. The combination of both models allowed us to evaluate alternative access scenarios from a conservation viewpoint and a recreational viewpoint.

In the case study, the Skylark (*Alauda arvensis*) was chosen as an indicator species. The Skylark is a species that showed a decline of 60% in the Netherlands during the last decade. In dune areas, this decline is even larger (Van 't Hoff 2002). The population decline in the dune areas is due to increased recreation pressure and habitat quality decline. One of the reasons is a change in vegetation structure brought about by a decline of rabbits. The numbers of Skylark and Northern Wheatear (*Oenanthe oenanthe*) show a correlation to the number of rabbits (Koning & Baeyens 1990).

The case study models three scenarios for management of the dunes, including: no recreation; the current pattern of recreational use; and a zoning scenario. In the zoning scenario, the central part of the nature area was closed for recreation. For each scenario both nature indicators (percentage of occupied patches and total numbers of Skylark) and recreation indicators (overall recreation density and total length of paths with low recreation densities) were assessed. The nature indicators were identified by the managers of the area. The recreation indicators were determined by the researchers after the study was conducted. We chose one indicator that relates to crowding and one indicator that relates to opportunities for visitors that seek tranquility. The exploratory study illustrates the integrated use of the two models to manage a nature area for both ecological values and high quality recreational experiences.

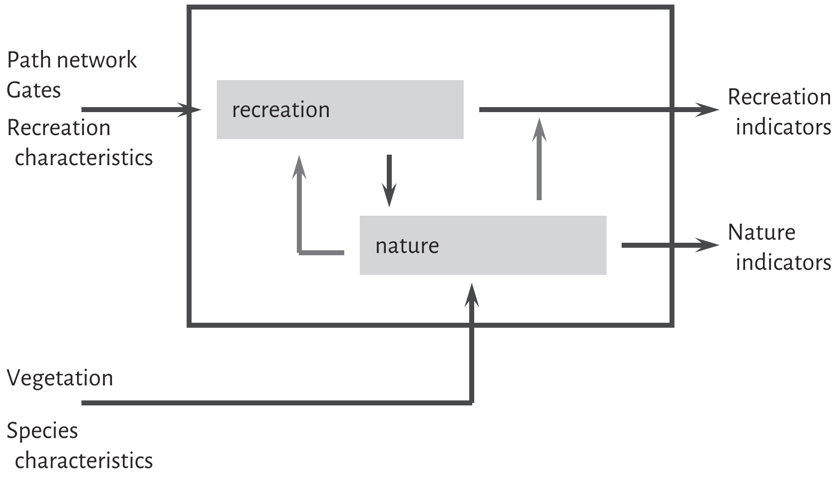

Figure 4. Instrument for evaluation of recreation and nature indicators. The inputs are GIS maps and process parameters. The outputs are tables and GIS maps for recreation indicators and nature indicators. The arrow between 'recreation' and 'nature' represents recreation impact. Grey arrows are not implemented in this case study.

3.4 Simulation models

3.4.1 MASOOR

MASOOR (Multi Agent Simulation of Outdoor Recreation) (see Jochem et al. 2007 for a complete description of the model) is a multi-agent recreational behavior simulation model. The model captures the transactional experience of different visitor types in natural areas containing a high density trail network.

The visitors are modeled as individual agents. Each visitor type is defined by specific behavior and goals. The visitors' behavior is contained in a hierarchical control system that provides a framework for identifying visit goals and constraints, defining path networks that enable goal attainment and specifying specific behavioral rules for navigating through the network in pursuit of goals. The benefit of a hierarchical control system in MASOOR is that it defines the symbolic landscape used by recreational visitors at multiple scales. Spatial characterization of these inputs is retained in a GIS framework, where, for example, the spatial configuration and actual attributes of the defined trails are stored as a fixed path network. The spatial and temporal outputs generated by MASOOR can be processed in GIS to provide the required output for the recreation impact.

3.4.2 Parameters of MASOOR case study

The area has five main entrance points (Fig. 3). In the case study, the entrance points are treated as exit points as well. This means that all visitors will make a circular trip. The distribution of visitors over the entrance points is based on counting from 1998 (Table 1) (Jaarsma and Webster 1999). Two types of visitors were defined and the mean duration of a trip is 2.5 hours (Bakker and Lengkeek 1999). The first type of visitors follows a marked route with an average length of 5 km and the second type of visitors follows randomly selected paths having an average length of 7.5 km. The standard deviation in trail length for both types of visitors is 1 km. For each scenario one model run with 50000 agents was done. There was no interaction between the agents.

Table 1. Distribution of visitors over the different entrance points (Fig. 2) (From: Jaarsma and Webster 1998).

Entrance point	% of total visitors
Zandvoortselaan	15.5
Oase	41.6
Panneland	21.5
Zilk	20.6
Langevelderslag	0.7

3.4.3 METAPHOR

The main processes that determine the fate of a population are birth, death and exchange (dispersal). METAPHOR simulates these processes. METAPHOR is a spatially explicit, individual based model that simulates the dynamics of a metapopulation. A simulation starts with a given number of individuals of different age classes and sex categories in a specified number of patches. In the case study the simulations started with each patch filled to carrying capacity. Carrying capacity is a linear function of patch area, truncated to discrete numbers. METAPHOR follows the life history of each individual. The first simulated event is formation of breeding pairs and reproduction, followed by a mortality event. Individuals age and finally disperse through the landscape. Reproduction and mortality are density dependent and stochastic processes. The dispersal algorithm is spatially explicit (Verboom et al. 2001, Vos et al. 2001).

Each year, METAPHOR assesses the state of sub-populations, thus, the state of the metapopulation. The results are, for example, the persistence probability of the metapopulation and the mean densities in the sub-populations. METAPHOR can be used to simulate the effects of changes in landscape pattern as well as processes within the metapopulation. Because each individual is assigned to a specific location the model is able to translate local impacts (recreation disturbance) into results on the landscape level (persistence). METAPHOR is a flexible tool that can easily be adjusted to meet the requirements of new applications.

Comparable models are ALEX (Possingham & Davies 1995), ALMASS (Topping et al. 2003) and RAMAS (Akçakaya 2000), which all have in common that they can be used for population viability analysis (PVA, see Brook et al. 2000) and differ in the exact formulation of density dependence, population structure, and dispersal algorithms. METAPHOR has detailed and realistic algorithms for these features, but lacks the interaction between species that characterizes ALMASS.

3.4.4 Parameters METAPHOR case study

In the case study, we used the model for evaluating the persistence of the Skylark (*Alauda arvensis*). The Skylark breeds in open vegetation without shrubs or trees (Topping et al. 2005, Beintema et al. 1995). Species density is directly correlated with the presence of more open landscapes (Van 't Hoff 2001). These conditions were used to select suitable vegetation types from a local land cover map (Van Til and Mourik

1999). We categorized three types of suitability: optimal, sub-optimal and marginal habitat. In optimal habitats, densities can reach 60 breeding pairs per square kilometer (Cramp et al. 1998, Teixeira 1979). In sub-optimal habitats, the densities where set at 30 breeding pairs per square kilometer while in marginal habitats the densities where set at 15 breeding pairs per square kilometer. Because Skylarks forage within 300-350 meters of their nest (Cramp et al. 1988), all patches within 300 meters of one another belong to the same local population. The dispersal capacity of the Skylark is estimated at 10 kilometers and 90% of all dispersal events are assumed to remain within this distance (Pouwels et al. 2002). All patches in the study area lie within this threshold distance and form one metapopulation. The main parameters for reproduction, mortality and dispersal are based on Cramp et al. (1988) and Beintema (1995) (Table 2). Mortality rates and reproduction used by Topping et al. (2005) for Skylark are within the ranges set for high and low densities in METAPHOR.

For each scenario, 100 replica runs were generated. Results were collected between years 150 and 250. It is expected that after 150 years the metapopulation in METAPHOR achieves a balance (Vergeer 1997).

Table 2. Main yearly parameters for the Skylark in METAPHOR.

Parameter	Probability
mortality low densities	0.2
mortality high densities	0.4
standard deviation mortality	0.05
reproduction low density	0.75
reproduction high density	0.35
standard deviation reproduction	0.1
fraction of juveniles that disperse	0.7
fraction of adults that disperse	0.1

3.4.5 Recreation impact: linking MASOOR and METAPHOR

MASOOR and METAPHOR are linked by the impact of visitors on two model parameters: density and reproduction. In their study, Vos and Peltzer (1987) related the impact of recreation on birds to the number of people on a path at the tenth busiest day in the year (mostly a sunny weekend day in spring). The result of MASOOR is translated into this output. The number of visitors on each path was scaled to 4500 visitors for the total area (the estimated number on the tenth busiest day). This resulted in visitor densities per path segment per hour. The recreation impact is calculated by using buffer zones. The width of the disturbance zones depends on the visitor densities (Vos and Peltzer 1987, see Fig. 2).

For the Skylark, Vos and Peltzer (1987) found a reduction of more than 50% in a zone of 40 meter when visitor densities were 5 groups per hour and a reduction of 100% in a zone of 40 meter when visitor densities were 20 groups per hour. These parameters were extrapolated to disturbance zones (Table 3). These parameters were used to define a buffer zone surrounding each path segment. Within the buffer zones, the density was reduced by 50%.

Table 3. Size of disturbance zone produced by varying sized groups of visitors used in the models.

Number of groups	Disturbance zone (m)
0-1	30
2-5	60
6-15	100
16-30	200
31-60	300
61-100	400
>100	600

Little is known about the reduction in reproduction success for Skylark. For Stonechat (*Saxicola torquata*), the percentage of nests that were abandoned in disturbed zones is 75% and for Curlew (*Numenius arquata*) the percentage is 64% (Vos and Peltzer 1987). Based on expert judgement, we chose a low reduction in reproduction of 25% in disturbed zones.

Because the impact is expressed as visitor impact for one day and the viability of the Skylark is simulated over 100 years the time scale of MASOOR differs greatly from the time scale of METAPHOR. MASOOR uses discrete event simulations (see Jochem et al. 2007) and METAPHOR uses discrete time steps (Vos et al. 2001).

3.5 Results

In the area, 11 populations can be distinguished. Some of the populations are completely within disturbance zones of recreation, while others are more or less disturbance free (Fig. 5a and 5b). In the zoning scenario, all paths near population 5, 6, 7 and 8 and two paths through population 4 have been closed (Fig. 5b).

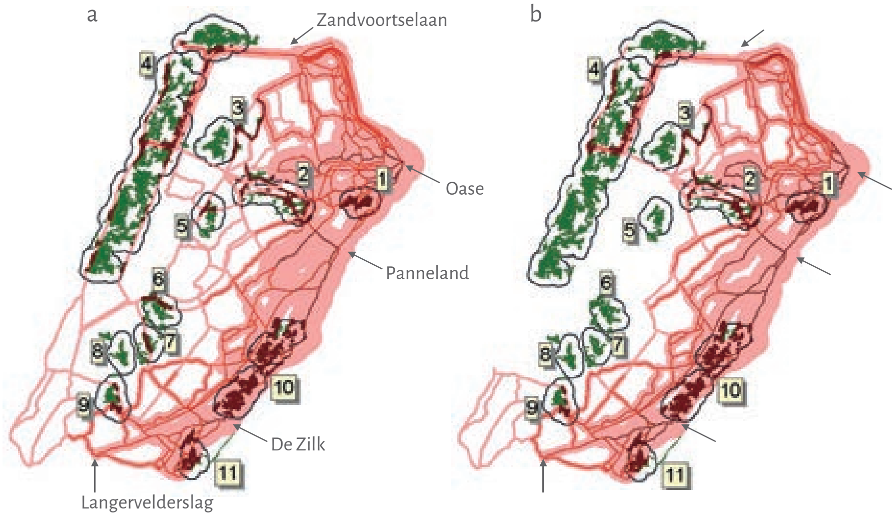

Figure 5a-b. Predicted zones disturbed by visitors in the scenario 'Present situation' (a) and 'Recreation zoning plan' (b). The disturbance zones along the foot paths are shown (light red). Entrances are indicated by black arrows. The populations are divided in a disturbed part (dark red) and an undisturbed part (dark green).

In the current situation, 35% of the habitat is disturbed while in the zoning scenario 28% is disturbed (Table 4). The simulation results show that the impact of zoning is most pronounced in protecting. In the current situation the disturbed area is twice as large as in the 'zoning scenario (Table 4). This results in a less stable population with an average of 14 breeding pairs. Because population 4 is the largest population in the metapopulation, a reduction in this population is expected to have the largest effect on the metapopulation (Vos et al. 2001, Verboom et al. 2001, Opdam et al. 2003).

In the zoning scenario, the number of breeding pairs were not significantly different from the scenario without recreation. Also the nature indicators (percentage of occupied patches and total numbers of Skylark) of the zoning scenario are the same as in the scenario without recreation (Table 4). The current situation has lower values of number of breeding pairs in the total population. Extinction frequency did not differ significantly between the three scenarios. All scenarios result in a viable metapopulation.

Table 4. Results of the simulations for three scenarios.

	no recreation	current situation	zoning scenario
% disturbed habitat	0	0.35	0.28
viable metapopulation	yes	yes	yes
population 4 (bp)	41	14	44
average total population (bp)	83	33	82
standard error total population	1.14	1.14	1.1

Note: Number of runs was 100. Population 4 corresponds with population 4 in Fig. 5a-5b. 'bp' is number of breeding pairs.

For the scenario without recreation, no recreation indicators can be determined by MASOOR. Compared to the current situation, the number of visitor groups per path length increased in the zoning scenario by almost 20 percent (Table 5). In comparison with the current situation, the length of paths in the zoning scenario containing less than 1 visitor per hour (i.e. tranquil paths) decreased by almost 40 percent.

Table 5. Recreation indicators derived from MASOOR for the three scenarios.

	no recreation	current situation	zoning scenario
visitor groups / km	-	3.7	4.4
tranquil paths (km)	-	62.6	38.4

3.6 Discussion

The results show that the zoning scenario achieves almost maximum achievable nature values in the case study area. As a next step, a scenario with zoning in population 4 only might be considered. Within a metapopulation the largest population is very important for the persistence and occupation of all the subpopulations (Verboom et al. 2001, Opdam et al. 2003). At the same time, the effects of the zoning scenario seem to produce a noticeable decline in the quality of recreational experience as compared with the current situation.

Choosing between the current situation and the zoning scenario is a political choice. If specific objectives or thresholds for nature indicators and recreation indicators that are agreeable to concerned stakeholders, scenario results can be explicitly compared. The existence of agreed upon objectives and thresholds may help managers resolve what might otherwise be considered an intractable situation.

This chapter illustrates how models can be part of the framework presented in Fig. 1. Local knowledge and monitoring data increase the quality and credibility of the results from the models. Stakeholder involvement is important not only at the start (scoping / goal setting) and at the end (evaluation) of the planning process (Bentrup 2001), but also during the spatial analysis of scenarios (Johnson & Campbell 1999). Since citizens participating in planning processes will not support what they do not understand (Theobald et al. 2000), decision support tools for choosing common and measurable goals need to be easily understood. The effectiveness of conservation management is thought to be closely linked to adaptive management processes that empower stakeholders, rather than by "ever-more precise techniques for prioritizing elements of nature" (Knight et al. 2006).

The results of the simulation models are useful in communication with stakeholders. Managers can show clearly what the effects of different scenarios are for attainment of both habitat goals and recreation goals. In an iterative and reflective process, indicators for nature and recreational quality can be compared across scenarios. Communicative action among participating stakeholder groups allows eventual construction of a consensus policy on recreational access. Managers of three large dune areas in and around the case study area put effort in the further development of MASOOR (Jochem et al. 2007). This was mainly because the model showed its usefulness in communication with stakeholders. See Jochem et al. (2007) for a discussion on this issue.

Euler stated: "Give me five parameters and I will draw you an elephant; six, and I will have him wave his trunk". This quotation (in Mollison 1986) illustrates the pitfalls of model parameterization and calibration and is often used as a criticism of using models. However spatial models may be the only objective tools for scenario studies. Translating scenario studies into model parameters can simulate effects of, for example, changes in land-use. While the exact quantitative model outcomes sometimes have high levels of uncertainty, when used for comparing scenarios the results are more robust (Verboom and Wamelink 2005). For example, in applying the NTM model, Schouwenberg et al. (2000) illustrate that the model output had a large uncertainty for a single prediction, but when scenarios were compared the uncertainty was much smaller. The best alternative predicted by the model is likely to be the best one in real life (Verboom and Wamelink 2005). It is in the comparative evaluation of scenarios that integrated use of models such as MASOOR and METAPHOR may have its greatest utility. Managers faced with the task of accurately estimating outcomes of specific scenarios may find use of the models more problematic.

Models are inherently sensitive to modification of input parameters. The predicted numbers of Skylark in the scenario of the current situation are 3 times higher than the actual numbers over the last years (personal communication with Antje Ehrenburg). Although the simulation defines the metapopulation as viable, a small change in parameter settings can cause much lower estimates of breeding pairs. The lower numbers in the current situation could also be attributable to other stress factors not considered in the simulations. A land cover map from 1990 was used, possibly overestimating open areas and carrying capacity. Successional changes in vegetation of some open dune areas may have led to the production of smaller patches and lower estimates of breeding pairs. In the case study, the Skylark populations in the Amsterdamse Waterleidingduinen are considered as a metapopulation on its own. In the agricultural areas to the East there is a large population of Skylarks. Because this population is declining also, the number of dispersal events to the dune area is difficult to estimate, but the large population will have at least a small positive effect on the actual population in the dune area.

Although both recreation and ecological models are being developed further, more effort should be put in the combination of these models. The integrated models should organize ecological, managerial and recreational information in a related manner, and subcomponents of the respective models should influence each other (Haider 2006). The output of recreation models should allow managers to place value on different aspects of the recreation experience as well as impact of recreation on nature. Also the impact of nature (development) on recreation should be implemented (grey arrows in Fig. 3). Do people appreciate the typical song of the Skylarks on sunny days? Visitors have strong preference for the preservation of species richness and scenic beauty. However, when there is a trade-off between these benefits visitors chose their favourite scenery at their favourite recreation site and prefer management options, which preserve biodiversity at other sites in an area (Horne et al. 2005). Visitors don't like to see changes in their own backyard.

In the case study no clear recreation goals were stated by the managers. In northwestern Europe, recreation goals are rarely specified. However, clear goals and thresholds are needed when future planning scenarios are to be comparatively evaluated and when recreation goals and nature goals need to be optimized. Integration of recreation and nature functions cannot be accomplished in the absence of explicitly stated goals. We think that the lack of clear goals is one of the reasons why modelling frameworks are not more widely used in Europe. Another main reason is the complex private and public ownership of nature areas in Europe (Haider 2006).

Future research should focus on the integrated monitoring and modelling of recreation and nature (Haider 2006, Sutherland 2007). Simultaneous consideration of both recreation and nature goals might lead to construction of scenarios not immediately apparent when only one set of values is considered (Önal and Yanprechaset 2007). General rules of thumb for predicting recreation impact should be developed (Sutherland 2007). Also there are still knowledge gaps of recreation impact on the population level, measures that can reduce human impact and the combination of recreation and nature at the scale of landscape planning (Blanc et al. 2006, Sutherland 2007).

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4

Harmonizing outdoor recreation and bird conservation targets in protected areas: Applying available monitoring data to facilitate collaborative management at the regional scale

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Highlights

- Visitor impact on breeding birds estimated by using monitoring data and models.
- Population reduction up to 28%, below politically determined conservation target.
- The results help managers to relate local impact to regional conservation targets.
- Maps inform manager networks where reduction of visitor densities is most effective.

Abstract

In protected areas managers have to achieve conservation targets while providing opportunities for outdoor recreation. This dual mandate causes conflicts in choosing between management options. Furthermore, the persistence of a protected species within the management unit often depends on how conservation areas elsewhere in the region are managed. We present an assessment procedure to guide groups of managers in aligning outdoor recreation and bird conservation targets for a regional scale protected area in the Netherlands. We used existing bird monitoring data and simulated visitor densities to statistically model the impact of outdoor recreation on bird densities. The models were used to extrapolate the local impacts for other parts of the area, but also to assess the impact on conservation targets at the regional level that were determined by the national government. The assessment shows impacts of outdoor recreation on Nightjar (*Caprimulgus europaeus*), Stonechat (*Saxicola torquata*) and Woodlark (*Lullula arborea*), reducing the regional population by up to 28 percent. The Woodlark population size was reduced below the level of the politically determined conservation target. The output of the regression models provides information that connects implications of local management to regional scale conservation targets. The spatial maps of bird densities can help in deciding where reducing visitor disturbance is expected to result in increasing bird populations, or where alternative measures, such as improving the habitat conditions, could be effective. We suggest that by using our assessment procedure collaborative decision making is facilitated.

4.1 Introduction

The concept of establishing protected areas for landscape features and nature values is an approach that has been in use for several hundred years (Jones-Walters and Čivić, 2013). National Parks have been protected to conserve biodiversity and safeguard experiences like the appreciation of tranquillity and magnificent scenery for future generations. Over the past century, due to the implementation of policies for biodiversity, the area of protected areas is now almost 15% of the terrestrial surface of the earth (http://www.wdpa.org/). The main objective of protected areas has shifted from a general safeguarding the landscape for future generations to a more specific protection of ecosystems, habitats and species. The Act that designated Yellowstone as the first US National Park in 1872 states that it should be "set apart as a public park or pleasuring-ground for the benefit and enjoyment of the people" (Eagles et al., 2002). However, following the IUCN (International Union for Conservation of Nature) categories for protected areas, nowadays the primary objective of protected areas is given as protection of species, ecosystems or landscapes (Dudley, 2008). Furthermore the EU (European Union) Birds and Habitats Directives, which together form the cornerstone of biodiversity policy in the European Union, require the establishment of an EU-wide network of protected areas (Natura 2000) and state that the conservation objectives should be met "while taking into account economic, social, cultural requirements and regional and local characteristics". Member States need to designate these areas and to adopt conservation measures which correspond to the ecological requirements of the specific values of the nature that they protect (EC, 1992, EC, 2009). Outdoor recreation targets are still taken into account, but the increased emphasis on biodiversity conservation objectives has led to a growing number of debates about whether outdoor recreation should be restricted in parts of protected areas (Reed and Merenlender, 2008, Marzano and Dandy, 2012), particularly in areas where population growth and economic developments have caused increased visitor numbers (Booth et al., 2009, Reed and Merenlender, 2008).

In this debate birds take a prominent place. They are susceptible to disturbance by visitors (Blanc et al., 2006, Sutherland et al., 2006), are of public interest (Emlen, 1995, Konishi et al., 1989), good ecological knowledge is available for many species (Konishi et al., 1989, Eken et al., 2004, McCarthy et al., 2012) and often conservation targets in protected areas include bird species (Eken et al., 2004, Hoffmann et al., 2010, Osieck and Mörzer Bruyns, 1981). The past 30 years have witnessed an increasing number of publications about recreational disturbance and birds (Kerbiriou et al., 2009). Overall, these studies conclude that recreational activities have diverse impacts (Blanc et al., 2006, Hill et al., 1997) that differ between bird species (Møller, 2008), but have little or no effects at the population level (Blanc et al., 2006). Most research demonstrates immediate responses of individual birds to visitor appearance such as a change in physiology or behaviour. For instance, human presence generates stress and birds may stop foraging (Thiel et al., 2011, Strasser and Heath, 2013). In such studies short term effects on individuals or breeding pairs are considered (Le Corre et al., 2009); for instance, a change in parental care (Yalden and Yalden, 1990) reduced foraging time resulting in lower survival rates (Goss-Custard et al., 2006, Stillman et al., 2007) or lower reproduction success (Langston et al., 2007, Murison et al., 2007, Yalden and Yalden, 1990, Strasser and Heath, 2013). Few studies deal specifically with the long term impact of recreation on bird populations (Le Corre et al., 2009), such as Mallord et al. (2007) and Kerbiriou et al. (2009) who both used simulation models to translate lower densities and reproduction success to population size and viability. Thus, implications of recreation to the objectives of biodiversity policy are still poorly quantified.

In protected areas management plans should ideally guide future developments while acknowledging targets that have been set concerning bird conservation (Dudley, 2008, Hockings, 1998). When management plans incorporate visitor management next to conservation management, managers are confronted with difficulties (Eagles et al., 2002). First, managers often lack monitoring data on recreational use (Buckley et al., 2008, Mann et al., 2010) and therefore are not informed about the visitor distribution, which particularly in large areas is often heterogeneous. Without explicit spatial information about visitor density it is difficult to predict impacts on breeding birds. Second, for most protected areas bird monitoring data are available but impact studies for recreational disturbance on bird populations are lacking (Sutherland et al., 2006), because managers lack resources to determine the impacts (Reed and Merenlender, 2008). Third, the scale of conservation objectives and the management of the area often differ jurisdictionally, temporally and spatially (Cash et al., 2006). For many areas one of the main challenges is to define responsibilities between different local managers regarding the realization of the conservation objectives (EC, 2014). In addition most management actions are local, while the survival of bird populations depends on management in a wider region (Opdam, 2014). Together with the lack of information and the mismatch that results from the differing scale of conservation objectives and the management of the area, the unfeasibility of predicting the impact of measures makes it difficult for key actors to decide about local measures. This might lead to a lack of public support (Pouwels et al., 2011).

In this paper we present an assessment procedure which provides information that connects local management to regional scale conservation targets, allowing collaborative decision making about taking measures to harmonize bird conservation and outdoor recreation. We do this through a case study of one of the largest protected areas in Northwestern Europe, the Veluwe Natura 2000 site in the Netherlands. In our approach we (a) quantify visitor densities, (b) analyse the impact of visitor densities on bird species and (c) demonstrate how the local impacts can be assessed with regards to regional conservation objectives. We demonstrate how long-term bird monitoring data can be used to help managers to harmonize outdoor recreation and bird conservation in protected areas.

4.2 Study area

The Veluwe (93,331 ha) is the largest forest-heathland complex and terrestrial Natura 2000 site in the Netherlands (Appendix 4). It is a mosaic of woodland, heathlands and shifting inland sand dunes. Almost one million residents live and work in small villages and medium sized towns within or in the vicinity of the area (<10 km). The area is easily accessible due to many parking areas from where visitors are able to use the dense network of almost 7500 km walking trails. The Veluwe is also a popular all year holiday destination; many camping sites, bungalow parks and hotels are present in the area. The area was designated as a Natura 2000 site in 2014 by the national government for 17 Habitat Types, seven Habitat Directive Species and ten breeding bird species. The Dutch province of Gelderland is responsible for the implementation of the Natura 2000 policy for the Veluwe. Achieving the conservation targets is further complicated because of the diversity of land owners who have a shared responsibility in balancing conservation and recreation interests.

4.3 Method

In our assessment procedure we distinguish three main steps (Fig. 1). First, we quantify visitor densities for the Veluwe as a whole using regional visitor monitoring data (f.e. CBS, 2011) together with recreation simulation models (Gimblett and Skov-Petersen, 2008). Second, for monitoring plots of breeding birds we determine the impact of visitor densities on bird densities using regression models. Third, we use the regression models to estimate recreation impacts in other areas and for the total Veluwe area.

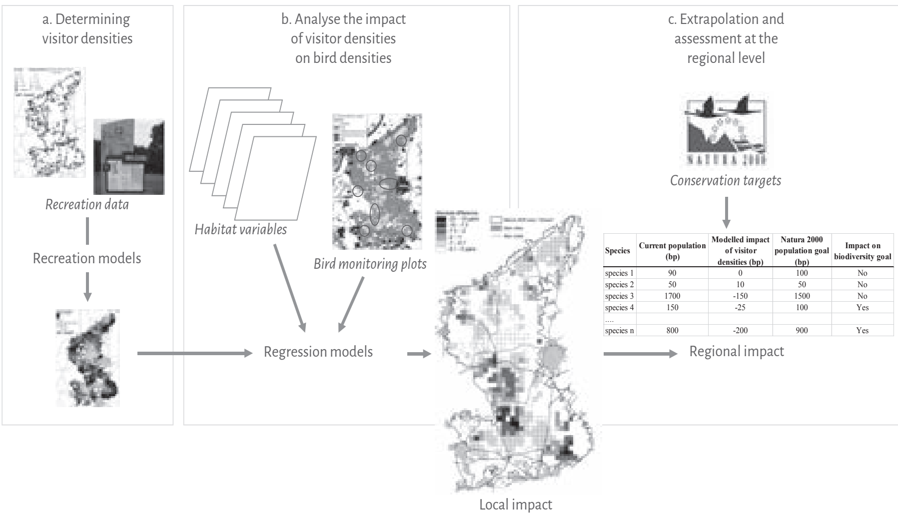

Figure 1. Schematic overview of the assessment procedure for helping managers to guide future developments regarding outdoor recreation and bird conservation; (a) determining visitor densities by using available data on departure points for visitors together with recreation models, (b) using bird monitoring data to determine the impact of visitor densities on the bird populations in the local plots and (c) extrapolation and assessment at the regional level. The regression models are used to predict the impact in areas outside the monitoring plots. The map can therefore be used to determine regional impacts and to distinguish local threats and opportunities for current and future visitor management.

4.3.1 Quantifying visitor densities

Although the Veluwe contains over 250 holiday accommodations, the estimated total visitor number associated with these tourist accommodations is a fraction of the visitors coming from medium-sized cities adjacent to the Veluwe, such as Arnhem and Apeldoorn. Therefore, in our analysis we did not distinguish between tourists and residents. Visitor densities in protected areas are largely determined by the availability of parking areas as these are the points of departure (Beunen et al., 2008, Kendal et al., 2011). To determine the location and size of parking areas GIS-data, hiking maps and Google Earth maps were used. During a three-day field trip we validated the input maps by ground truthing. Parking areas near sport fields, company sites and highways were left out as these are not likely to be used as starting point for walking and hiking. To distribute visitors over the parking areas we used the rule-based spatial model FORVISITS. In this model proximity of parking areas and their size are the most influential parameters (De Vries and Goossen, 2002). The number of visitors for each parking area was used as input for the rule-based spatial model MASOOR-SCAN (Jochem et al., 2008). MASOOR-SCAN distributes visitors over the area using a negative exponential algorithm within road compartments, based on the observation that visitors rarely cross asphalt roads (Jochem and Van Marwijk, 2008). This algorithm has been derived from GPS data that revealed that 90 percent of all GPS locations of the visitor presence are within a 3 km radius of the parking area. The output of the model is used as a proxy value for disturbance by recreation: the higher the predicted density of visitors the larger the disturbance.

We used two versions of outputs: one representing overall disturbance in an area and one representing disturbance only around the trail network. For the first version we used a kernel density method ('oil spill') where visitor densities are distributed across the area regardless of the trail network and for the second version visitors were limited to a trail network and are assumed to cause disturbance in a zone on both sides of the trail. As visibility and detectability are expected to be important factors regarding disturbance (Fernández-Juricic et al., 2005) we used a disturbance zone of 200 m wide in open landscapes of 100 m wide in woodlands. These disturbance zones are based on flush distances for Woodlark and Stonechat (Krijgsveld et al., 2008). For the second version we also added non-official parking areas as the field trip revealed that crossings of asphalt roads and dirt roads were used as small parking areas (one or two cars).

4.3.2 Determining local impact of visitor densities on birds

4.3.2.1 Bird data

We focus on three heathland breeding birds because they are prone to disturbance: Woodlark (*Lullula arborea*), Stonechat (*Saxicola torquata*) and Nightjar (*Caprimulgus europaeus*). For all these species (f.e. Vos and Peltzer, 1987, Liley and Clarke, 2003, Bijlsma, 2006, Mallord et al., 2007) there is evidence that recreation has a negative effect on breeding success or breeding densities. Bird data for these species are available from two sources: monitoring in sampling plots ('BMP') and large scale breeding bird surveys. Both the monitoring project and the surveys are based on the method of territory mapping (Hustings et al., 1985, Bibby et al., 2000). It involves standardised fieldwork and interpretation of the data to infer the presence and location of a breeding pair (Van Turnhout et al., 2008). For the monitoring scheme 6–12 visits are made to the sampling plots by volunteers coordinated by Sovon, Dutch Centre for Field Ornithology. The plots vary in size between 10 and 500 ha. Breeding bird surveys by professionals usually have less visits (3-5) and cover larger areas (>500 ha). Both data sources deliver number and location of breeding territories in specific areas that reflect breeding bird densities. From plots with multiple censuses in different years we used only the most recent one. Plots were excluded when they were smaller than 25 ha or larger than 1000 ha, contained less than 10% heathland or had extreme values for recreation densities. This selection resulted in 61 available plots for further analysis.

4.3.2.2 Habitat and other environmental variables

Bird occurrence can be explained by a number of habitat related factors such as vegetation type and soil type. Based on the ecological requirements of the bird species under study a number of potentially explanatory habitat variables were included in the statistical models describing land use and specific habitat features and soil condition (Appendix 5). These data were retrieved from a set of GIS maps (CBS, 1985, CBS, 2008, Clement, 2001, De Vries et al., 2003). Information about the disturbance by roads was also included in the analysis because traffic disturbance has been shown to affect the presence of these species (Reijnen and Foppen, 1995, Reijnen et al., 1996). For the traffic variable we used the maximum noise level (in dB) within the survey site.

4.3.2.3 Statistical procedure

For each species we constructed statistical models to link the abundance of the species in a particular sampling plot to the chosen explanatory variables. We developed generalized linear models with a Poisson distribution and log-link function using the statistical program 'R' version 3.2.2 (R Development Core Team, 2015). In the models the number of breeding birds in a plot was used as the dependent variable. In order to adjust for temporal trends in population levels the year of the census was included in the analysis. The mapping protocol was also included in order to adjust for differences in densities between the two bird monitoring datasets that were used. Area of the plot was included to account for the differences in plot size, but also added as a variable, Area2, to account for possible non-linear relationships with area (Nee and Cotgreave, 2002). Variables were selected with forward and backward stepwise variable selection with the R-function 'step' (Venables and Ripley, 2002). Given the limited amount of count data as compared to the available co-variables the number of interactions was held limited in order to prevent over-fitting. The habitat model thus accounts for differences in the number of breeding birds resulting from differences in habitat variables, traffic disturbance, year of the census, mapping method and area and is treated as a base model. For each species the best base model was selected by means of stepwise model selection based on the lowest AIC (Venables and Ripley, 2002). To this base model the four variables that represent the disturbance effects (the output of the MASOOR-SCAN model) were added separately. For each species the best model was selected by the lowest AIC (Burnham and Anderson, 2002).

4.3.3 Assessing local impacts with regards to regional conservation targets

The statistical models were used to make a prediction for the total population size within the Veluwe area. For this aim we made predictions on a 1 × 1 km grid. We determined all the relevant explanatory variables in these 1 × 1 km squares and, using the coefficients of the best statistical models, made predictions for the expected breeding bird numbers in each cell. We did this for two scenarios: one with the current recreation pressure and one without recreation. The difference between the sums of the two estimates gives an estimate of the impact of disturbance by visitors on the population size. The difference between the population size and population targets for the Veluwe was used to determine whether the impact of recreation disturbance would result in a population size falling below the conservation target.

4.4 Results

4.4.1 Visitor densities

The area of the Veluwe accommodates over 200 parking areas. This includes almost 50 small car parks that were not on the GIS-maps, but were encountered during the field trip. A large proportion of the parking areas with a large capacity are located near sand dunes and heathlands. We estimated that over 8.5 Million visitors hike and walk in the Veluwe each year. The models predicted large differences in recreational use in the area. The southeast part of the Veluwe near Arnhem in particular is intensively used with up to 200,000 visitor groups per year per ha, while some central parts are almost free of visitors (Appendix 6).

4.4.2 Local impact of recreation on bird densities

For all three species the base model with habitat variables explained most of the deviance. Adding the recreation variables to these models showed significant negative impacts of recreation on the breeding densities of all three species (Fig. 2). For Woodlark the best model showed good performance, explaining almost 86% of the deviance and included the kernel density method as a variable for recreation pressure. For Stonechat the best model also included the kernel density method and explained 71% of the deviance. The best model for Nightjar explained 64% of the deviance and included the trail network method (Appendix 7). The Nightjar shows the strongest effects of recreational pressure as it declines to 50% of its density at visitor densities of 50,000 visitor groups per ha per year. Under high recreation densities Woodlark densities drop by 70% (Fig. 2).

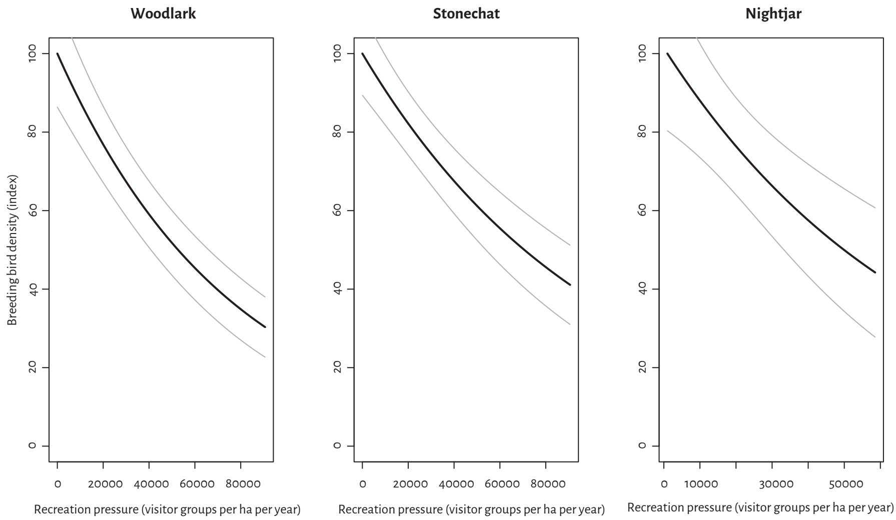

Figure 2. Relationship between recreational use and densities of Woodlark, Stonechat and Nightjar (shown as an index where the density in the absence of recreation is set to 100). Standard errors are shown in grey. Recreational use is given in visitor groups per ha and is based on the results from the scientific tools FORVISITS and MASOOR-SCAN.

In order to test the predictive power of the models a 5-fold cross validation was performed for the Woodlark model by using 80% of the observations for the model and 20% for the validation of the model. The average correlation between the predictions of the model and the 20% independent observations was 75.3% with a minimum of 67.6% and a maximum of 81.8%. The correlation of the full model between predictions and observations was 84.7%.

4.4.3 Impact of recreation on regional biodiversity targets

Although the overall relationship between recreational use and bird densities can be the same for some species, the exact local impact can differ between the species due to varying combinations of visitor numbers and the relevant habitat conditions of these species. The coefficients for the relationship between breeding bird numbers and visitor densities are similar for Stonechat and Woodlark (Appendix 7), but the regional impact for Woodlark is almost twice as high (Table 1). In a scenario without recreation the population size of Stonechat would expected to be 16% higher and the population of Woodlark 28% higher. For the Nightjar an increase of only 11% of the regional population is expected in the absence of recreation. Although population size of Nightjar and Stonechat are lower as a result of the impact of recreation, this impact does not push the population below the Natura 2000 conservation targets (Table 1). Only for Woodlark do the models show that the population size falls below the conservation targets.

Table 1. Current population estimates in breeding pairs (bp) based on the best model with recreation ('Expldev: percentage explained deviance; 'Signific.': significance of recreation variables from Appendix 5; 'Variables': recreation variables in the best model). Pressure1 represents the kernel option and is shown on the left in Appendix 6. Pressure2p represents the trail option with crossings of dirt roads. The regional impact is described as the increase in the total population in breeding pairs for the scenario without recreation.

Species	Population Current (bp)	Expldev	Signific.	Variables	Regional impact (bp)	Natura 2000 targets (bp)
Woodlark	2097	85.5	***	Pressure1	28%	2400
Stonechat	1120	70.6	**	Pressure1	16%	1000
Nightjar	892	64.2	**	Pressure2p	11%	610

4

4.5 Discussion

We present an assessment procedure based on long-term bird monitoring data and recreational models that provides information to local managers and other key actors that can support management decisions in relation to the interaction between outdoor recreation and bird conservation targets. With this information local decisions about management can be linked to regional biodiversity conservation targets. We tailored our approach around data that were available; no new monitoring programs had to be implemented. We suggest that the assessment procedure can be used in protected areas that have recreational pressure and surveys and/or monitoring programs for birds. In addition to data about the distribution of the birds, maps are needed that contain the most relevant characteristics of the habitat required by the birds that are assessed. Maps are required containing basic recreation data like parking areas and trail networks. Also remote sensing can be used to determine the extent and condition of habitats (Nagendra et al., 2013). When bird data are lacking the procedure cannot be applied. For protected areas, like Natura2000 sites, these might be available by existing monitoring programs (Evans, 2006). Otherwise, managers need to set up an effective monitoring program that will provide information on population densities within their area and also might provide insights into other ecological processes (Lindenmayer and Likens, 2010). Regarding rare species in protected areas monitoring data might be insufficient to derive statistical models. An alternative is to combine information of a wider set of areas to assess the impact of visitor use on population size.

In our procedure we use recreation models to determine the visitor densities in the area. As visitor densities concentrate near parking areas (Beunen et al., 2008, Kendal et al., 2011) and their numbers drop steeply with distance from these parking areas (Jochem and Van Marwijk, 2008) effort should concentrate on validating the location and size of the parking areas in the area. If monitoring data on visitor densities are available these can be used instead. Even spatially scattered data might be useful for validating the output of the recreation models. In our case study no monitoring data for recreation were available. We were therefore unable to calibrate overestimations or underestimations of the visitor densities at the Veluwe. As the relationship between visitor densities and bird densities (e.g. Fig. 2) is based on the output of the recreation models the exact numbers of visitor densities in Appendix 6 should be used with care. However, as the overall assessment uses the same maps for determining the relationship and predicting the bird densities (step b in Fig. 1) an overestimation or underestimation in visitor densities will have no consequence for the overall assessment (step c in Fig. 1). Our results regarding a 50% reduction in Woodlark density for around 55,000 visitor groups per year per hectare (Fig. 2) correspond well with the value of eight disturbance events per hour that Mallord et al. (2007) found for this species in southern England.

The kernel density maps provided the best models for predicting the impact of recreational use on breeding densities for Woodlark and Stonechat while the trail network maps provided the best model for Nightjar. The main difference between Nightjar and the other two species in relation to disturbance by outdoor recreation is that Nightjar is a nocturnal species. Breeding pairs are not actively foraging during daytime when visitors are present. It is however unclear whether this is reflected in the observed difference in significant model parameters. It can be argued that Woodlark and Stonechat use the area at a larger spatial scale for foraging during the presence of visitors and therefore not only the pairs that breed near the trail network are affected by visitors but also birds that breed within the area itself.

The assessment showed that only for Woodlark populations at the Veluwe are the effects of recreational impacts such that they fall below the set targets. This result contradicts the assumption in the current draft of the management plan for the Veluwe area that for this species recreation has an impact, but does not threaten the conservation target (Province of Gelderland, 2009). In order to increase the Woodlark population in the Veluwe managers are able to choose between many management options (i.e. Mallord et al., 2007). There are several options regarding reducing visitor densities or redirecting visitors to areas that are less sensitive for visitors (Eagles et al., 2002, Stigner et al., 2016). The spatial output of the statistical models can be useful for managers in discussing these options with stakeholders (Fig. 3). Spatial maps in particular provide guidance for the targeting of regional policies such as the 'grow and reduce' approach of the Province of Gelderland. This policy divides the Veluwe in areas where an increase in holiday accommodations is allowed and areas where a decrease is aimed for (Province of Gelderland, 2009). However, focusing conservation actions on one species, i.e. changes in accessibility for visitors, might have an impact on the habitat quality of other species in other parts of the protected area. The recreation models can be used to predict the effect of the management options on the spatial distribution of visitors for the area. The regression models for Stonechat and Nightjar can be used to predict if the impact of these options will lead to a conflict for these species or not.

The maps not only provide insight into potential conflicts between breeding birds and recreation, but also locations for possible solutions (Pouwels et al., 2011). For example, the output of the Woodlark model shows that many areas with high predicted densities coincide with areas with high visitor densities resulting in a decrease up to 25 breeding pairs per 100 ha (Fig. 3). As the Veluwe is managed by different nature organizations and private and public owners detailed information about where measures might have an effect is crucial in defining responsibilities regarding the realization of conservation targets (EC, 2014). The maps could enable managers and other key actors to collaborate on a management plan for the whole area, where measures can be defined with details about landownership, size and location and allow them to discuss how available funds should be shared between the responsible managers. The integration of local and scientific knowledge can help to build trust between different parties and thereby improves the quality of the process (Reed, 2008). To be effective over a longer period it is recommended that the management evolves into an adaptive co-management approach where social learning and joint problem solving can result in new knowledge to deal with problems at increasingly larger scales (Berkes, 2009).

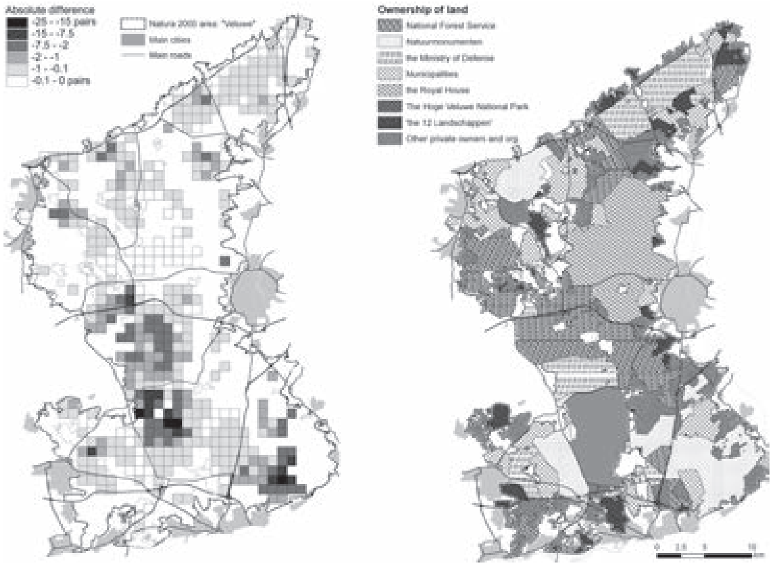

Figure 3. The impact of visitor density on the density of the Woodlark (breeding pairs per square km) (left Figure). On the right ownership of different parts of the Veluwe is given.

4.6 Conclusions

The impact of outdoor recreation on bird densities in local plots can be determined by using existing monitoring programs together with recreation simulation models. For the three analysed protected species of heathland, we found that in areas with high visitor densities the density of breeding pairs were 50 percent reduced in comparison to areas without visitors. The statistical models predicted bird densities under the influence of visitor density for all potential habitat patches in the regional Natura 2000 site the Veluwe. For Woodlark we estimated that the presence of hikers reduced the regional population by 28 percent, which leads to a population level below the conservation target. For Stonechat and Nightjar the regional population was reduced by 16 and 11 percent respectively, resulting in population levels above the conservation target.

We suggest that our approach can facilitate groups of local area managers with collaborative decision making regarding the dual mandate of achieving conservation targets while providing opportunities for outdoor recreation. The approach relates visitor numbers to conservation targets for protected bird species at local and regional scale level. We think that the spatially explicit output of the regression models inform about which management alternative might be most effective. In some areas reducing visitor numbers might be the most effective measure to increase bird densities while in other areas improving habitat characteristics is most effective. Providing a variety of solutions to increase the population of Woodlarks at different locations will increase collaborative decision making between different management units as well as different stakeholders (Van Herk et al., 2011).

Acknowledgements

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5

Reconsidering the effectiveness of scientific tools for negotiating local solutions to conflicts between recreation and conservation with stakeholders

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Abstract

The conflict between the conservation of biodiversity and recreation activities in the European landscape is intensifying. Managers of large nature areas are confronted with increasing numbers of visitors and decreasing biodiversity values. To accommodate the visitors while simultaneously protecting the biodiversity values they need to make changes in the landscape. Current legislation, a lack of knowledge on the recreation–biodiversity relationship, and the diverging point of view of stakeholders make it difficult to find consensual solutions. New approaches such as adaptive management and boundary management can help managers and stakeholders in the process of decision making. In these approaches the role of scientists has changed, as has the use of their tools. Using two research projects in Europe we explore how scientific tools are used in this new context. We argue that such tools (1) should be built on the interactions between recreation and biodiversity functions, (2) can be used interactively to encourage stakeholders to engage in a learning process, (3) allow local knowledge and data to be incorporated into them, and (4) generate output in the form of a map showing where the conflict areas and opportunities are located. These four key features will help managers to improve communication between themselves, stakeholders, and scientists, increase consensus between stakeholders on how the conflict should be perceived, explore solutions, and generate new knowledge. For future research we suggest investigating how adaptive management and boundary management can be used in a stepwise learning strategy and how uncertainties in the tools affect the learning process.

5.1 Introduction

To sustainably manage land for the prevention of resources being lost to future generations, land managers need to minimize negative trade-offs between landscape functions. They may decide to reallocate noncompatible functions by modifying the physical patterns of landscapes on which these functions depend. In doing so, managers often affect values attributed to these functions by groups of users, which may lead to conflicts (Young et al. 2005). In this paper we consider the relationship between biodiversity conservation and recreation activities such as walking, cycling, and horse riding in nature areas in Europe. European Union legislation, in particular the Habitats and Birds Directives, is intended to achieve better protection of valuable species and habitats. At the same time, however, health programs are urging the general public to go out into nature areas the EU legislation has been designed to protect. Together with economic developments and demographic trends this has resulted in an increase of recreational use of nature areas (Kerbiriou et al. 2009), and in an increase in the variety of types of outdoor recreation such as hiking, climbing, and canoeing (Naylor et al. 2009). However, there is evidence that stimulating biodiversity conservation and recreation functions of landscapes simultaneously may be incompatible (Young et al. 2005). Recreation activity has been shown to affect vegetation (Liddle 1991) and the population trends of species (Hill et al. 1997, Blanc et al. 2006), especially of birds, e.g., Golden Plover (*Pluvialis apricaria*; Yalden and Yalden 1990) and Black-tailed Godwit (*Limosa limosa*; Holm and Laursen 2009). Hence, nature managers find themselves confronted with a potential land use conflict between conservation and recreation activities.

Various options are available to solve this conflict. The managers of nature reserves are statutorily required to create conditions conducive for target species. To achieve this aim they may close parts of the area to visitors, improve habitats to increase the carrying capacity for target species, or construct new parking facilities to redistribute visitor pressure. However, current legislation on biodiversity conservation may restrict such options (Stankey et al. 2005, Williams et al. 2007). In addition, certain options risk alienating visitors; for example, physical adaptations to improve the habitat of species like cutting trees and raising groundwater levels may be perceived as negative by visitors (Van Marwijk 2008), and most people engaging in outdoor activities are not aware of their impact on wildlife (Blanc et al. 2006) and are unwilling to accept trail closures.

Thus, nature managers and recreation stakeholders may have opposing views about biodiversity conservation plans and actions, and nature managers and biodiversity conservationists may disagree about recreation plans and actions. To resolve this dilemma between recreational development and biodiversity conservation, scientists, policy makers, local managers, and user groups must together seek a solution (Cash et al. 2003). Scientists can contribute to conflict management by providing objective information (Young et al. 2005) and helping to justify management plans and actions (McCool et al. 2007). However, they are hampered by a shortage of knowledge, the inadequacy of their approaches, and the inaccuracy of their tools (Sutherland 2007; S. McCool, unpublished manuscript, http://umontana.academia.edu/SteveMcCool/Papers/395214/Outdoor_Recreation_in_the_New_Century_Frameworks_for_Working_Through_the_Challenges). The major gaps in knowledge concern visitors' spatial use of nature areas (Gimblett and Skov-Petersen 2008), the impact of visitors on biodiversity values at the landscape scale (Cole 2006, Sutherland 2007), and the effectiveness of measures to influence the trade-off between biodiversity conservation and recreational use (Wilhere 2002, Cole 2006). Despite having shortcomings, scientific tools such as knowledge systems, simulation models, and agent-based models have proved to be helpful in recreation management (Cole 2005, Gimblett and Skov-Petersen 2008). They have not only helped elucidate current visitor use and find management alternatives that better accommodated recreation–biodiversity combinations, but have also been important for communicating the implications of decisions (Cole 2005, McCool et al. 2007, Gimblett and Skov-Petersen 2008).

However, in the context of the emerging knowledge society (Nowotny et al. 2001), the effectiveness of such tools needs reconsideration. The role of science as a credible provider of irrefutable knowledge is being questioned (Hanssen et al. 2009). Stakeholders are becoming more involved in deciding about land use issues (Young et al. 2005) and often have a good knowledge of local history and conditions. Compared with scientists these stakeholders have opposing opinions about what should or should not be considered as a problem (Cole 2006, Fry et al. 2007) and know how to use the law to their advantage to preclude changes they consider undesirable. They exploit the uncertainties inherent in scientific tools when arguing their case (McCool et al. 2007) and question the credibility of the tools, even those built in accordance with quality standards (e.g., Refsgaard and Henriksen 2004, Brown 2006). In this paper, we therefore reconsider the effectiveness of current scientific tools in recreation–biodiversity conflict management as a part of a learning strategy of facilitation and pacification (Hanssen et al. 2009). We will identify the requirements of scientific tools for conflict management in the conceptual framework of adaptive management (McCool et al. 2007, Williams et al. 2007) and boundary management (Cash et al. 2003), and will illustrate their importance by drawing upon a recent application in a research project in northwest Europe.

5.2 New recreation management approaches

The recreation–biodiversity conflict is complicated by high levels of uncertainty and lack of consensus among parties about how to combine the conflicting landscape functions in nature areas (Young et al. 2005). To solve this type of conflict, two strategies have been proposed (Hanssen et al. 2009). The first, the pacification strategy, entails conducting research to decrease uncertainties, with the aim of enhancing consensus-building about solutions. The second, the facilitation strategy, entails building consensus about beliefs, ambitions, and directions of solutions before starting research to decrease the uncertainties. Managers can opt for the pacification strategy by following an adaptive management approach, and the facilitation strategy by following a boundary management approach (Fig. 1).

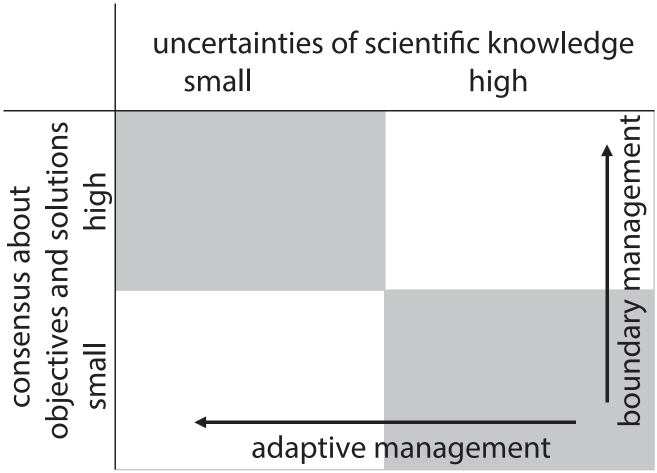

Figure 1. Managing the recreation–biodiversity conflict with the frameworks of adaptive management and boundary management. Figure modified from Hanssen et al. (2009).

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Adaptive management is an appropriate approach in the event that the involved parties are in agreement about the nature and extent of the problem, although it is uncertain whether the chosen measures will be effective because of uncertainty in knowledge or unpredictability of the system response (Williams et al. 2007). Influencing recreation behavior has highly uncertain outcomes (Cole et al. 1987, Cole 2006), and recreation–biodiversity relationships are poorly understood (Sutherland 2007). Under these conditions, adaptive management provides a proper approach to deal with uncertainty. In using scientific tools, their uncertainty needs to be known.

However, adaptive management is not designed to resolve conflicts about management objectives (Williams et al. 2007). In biodiversity–recreation interactions, there is often disagreement about the problem. In most cases recreation does not lead to direct death of individual animals; what makes it hard for recreation stakeholders to accept is that populations might be at risk because of high levels of visitors. In the event that the nature and the cause of a conflict is in debate, and at the same time the degree of uncertainty about effective solutions is high, the management strategy needs to be based on communication, translocation, and mediation (Cash et al. 2003). This so-called boundary management is considered an appropriate approach if the agreement on the impact of management options is low. Cash et al. (2003) proposed that in using scientific tools to transfer information, credibility, saliency, and legitimacy of information are critical factors to enhance.

Current recreation management approaches often show characteristics of adaptive management (Nilsen and Tayler 1997, McCool et al. 2007). Scientific tools are used to compare the possible effect of alternative solutions. In contact with stakeholders, these tools are typically used in a one-way direction to inform stakeholders about changes in management. However, boundary management requires that stakeholders are actively involved in the development and use of scientific knowledge and tools. Knowledge held by stakeholders is regarded as a valuable part of the knowledge base that should be shared in a common process of fact finding and design of solutions, and to decrease uncertainty. There is therefore a need for tools that can support both adaptive management and boundary management, developed in accordance with the demands of transdisciplinary research (Thompson Klein 2004). We propose using four guiding principles for this.

First, the tools must be able to cross the boundary between recreation and biodiversity. They must therefore be built around the recreation–biodiversity relationship and distinguish between parts of the relationship that are objective, e.g., the measured distances birds fly when disturbed by a visitor, and those that are subjective, e.g., the species chosen as a conservation target (Termorshuizen and Opdam 2009). The tools need to have "the right control knobs," which are compatible with the type of management action that managers can take.

Second, scientific tools must be able to support the engagement of stakeholders in a process of learning about the system and how recreation and biodiversity are interrelated (Margerum 2002). The tools need to be helpful in moderating the participation of stakeholders in the process in an interactive way, so that scientists, stakeholders, and managers can learn from one another. The participation of all actors in shared meetings will help actors on opposing sides to understand the relationship between recreation and biodiversity functions and how this relationship is related to each other's values (Lamers et al. 2010).

Third, the tools must be accepted as credible and legitimate in the local context (Cash et al. 2003) by both managers and stakeholder groups. Therefore the tools should be able to incorporate local knowledge and to be adjusted to improve their match with local conditions. Local knowledge could fill in knowledge gaps in the tool, and by experimenting with them local users may learn to discover the structure of the tools and the underlying assumptions, and thereby become able to judge the appropriateness of the tools for their case and their interests.

Fourth, tools should guide toward solutions by providing room to maneuver between possibilities and constraints (Horlick-Jones and Sime 2004). The tools should support the negotiating actors in finding a new design that solves the problem, takes full advantage of the opportunities of the area, and is socially acceptable. The tools should be capable of generating local maps showing these opportunities and conflicts.

We summarize these demands as the following four key features:

1. The tool is built on the relationship between recreation and biodiversity functions;
2. The tool can be used in an interactive way in a learning process to clarify the conflict;
3. The tool can be made context-specific with local data and knowledge;
4. The tool is based on spatially explicit relationships and its output is a map showing where measures can be taken.

5.3 Using scientific tools in the recreation-biodiversity conflict

To demonstrate and to discuss the importance of the four key features we will describe our experience with the use of scientific tools in a recent research project. The PROGRESS project took place from October 2003 until October 2007 (see www.forestry.gov.uk/forestry/infd-6aqeua). The research was conducted in the New Forest, which covers > 57,000 ha west of Southampton, UK. Centuries of grazing by deer and livestock, coupled with human management shaped the forest into a combination of heathland, ancient woodland, mire systems, grassy plains, and coniferous and deciduous enclosures. As part of the Natura 2000 network in Europe the New Forest is protected by the Habitat Directive (Council Directive 92/43/EEC) and the Bird Directive (Council Directive 79/409/EEC). These nature conservation legislations should safeguard natural values and stop the decline of biodiversity in the EU. Both directives also state that measures taken for this protection should take into account economic, social, recreational, and cultural requirements. For the New Forest recreation is important because it supports economically significant tourism industries in its surroundings. Over the last three decades the New Forest has experienced a significant rise in visitor numbers, and the estimation of more than 13.5 million visitors each year could pose a serious potential threat to the biodiversity of the area. As a result the land managers are looking for solutions together with scientists, local experts, and local stakeholders (Colas et al. 2008). The Forestry Commission consults a local stakeholder network about its activities.

In the PROGRESS project we built on this network. Apart from informing the public and trying to influence their behavior, the project organized a dialogue with a panel of 23 stakeholders to use local knowledge in finding solutions for nature–recreation conflicts and guide the direction of the project actions. These stakeholders represent different interest groups, e.g., local councils, conservation groups like The Royal Society for the Protection of Birds (RSPB), and recreational user groups (Table 1). The Verderers have a specific role among the stakeholders because they share the responsibility for the management of the New Forest together with the Forestry Commission. The Verderers derive their offices, powers, and responsibilities from the Act of Parliament in 1877 and are elected by the county. In meetings they were represented by up to three people. For the Forestry Commission the local input of the stakeholders is vital in sharing many management decisions and in fostering a more comprehensive understanding of forest issues and just as importantly, other peoples' views (see www.forestry.gov.

uk/forestry/INFD-6A5LAC). The role of the scientists involved was to facilitate and mediate. The team consisted of a social scientist, a conservation scientist, and a model engineer. Also a local scientist played an important role. He was an employee of the Forestry Commission and could therefore be regarded as a stakeholder.

During the project the role of the stakeholders in the New Forest took many forms (Lamers et al. 2010) and varied between meetings. According to the IAP2 Spectrum developed by the International Association for Public Participation (Ritzema et al. 2010) the role of the stakeholders evolved during the project from being informed to full decision making. At the start of the project the choice for the tools was made by the scientists and the managers and the stakeholders were informed. The stakeholders were consulted when conflicts between recreation, e.g., walking and cycling, and biodiversity, e.g., protected bird species, might occur and on how they could be solved. This consultation resulted in proposals for the locations of pilot actions the managers could implement like closing car parks, closing car parks only during breeding season, improving habitats of wader species, increasing awareness of visitors by signs of the sensitive areas, and rerouting the path network. The proposals combined the stakeholders' local knowledge of the area with scientific knowledge in such a way that site specific solutions could be found. The scientific tools were used to predict the effects of the proposed pilot actions on recreational values and biodiversity values. Predictions of the impact of pilot actions were shown on maps and discussed at public engagement events. During these events inhabitants of the area sometimes backed up the results and sometimes they disagreed. Finally the stakeholders decided to agree with four of the proposed pilot actions and disagree with one.

Table 1. Stakeholders involved in the PROGRESS project in alphabetic order. Together with the Forestry Commission they discussed the management alternatives and made decisions about the pilot actions.

Stakeholder	Website	Description
Beaulieu Settled Estate		Private estate in the New Forest
British Horse Society	www.bhs.org.uk	The UK's largest equestrian charity with over 60,000 members
Camping and Caravanning Club	www.campingandcaravanningclub.co.uk	The oldest and largest camping club in the UK, offering Club sites across the country
Countryside Agency	www.countryside.gov.uk	UK public body working to improve the quality of the countryside
English Nature	www.english-nature.org.uk	Government agency set up by the Department of Environment, Food and Rural Affairs to conserve wildlife, geology and wild places in England
Hampshire County Council	www.hants.gov.uk	Regional Government office
Hampshire Wildlife Trust	www.hwt.org.uk	Wildlife charity for Hampshire and the Isle of Wight
Livery Representative		Representing local livery yards and small riding stables
National Trust	www.nationaltrust.org.uk	Charity working towards conserving the UK's countryside and heritage through protecting the environment
New Forest Commoners' Defence Association	www.newforestcommoners.co.uk	Organisation that supports the rights of New Forest commoners to turn their stock out on the open Forest
New Forest District Council	www.nfdc.gov.uk	Local Government office
New Forest Equestrian Association	www.nfed.co.uk/nfea.htm	Organisation working towards preserving the tradition of freedom to ride in the New Forest
New Forest Local Access Forum	www.countrysideaccessforum.hants.org.uk/newforest/index.html	Advisory body of Forest professionals looking to improve access to the countryside
NEWFORCE	www.newforest-cycling.co.uk	New Forest off road cycling club
New Forest Association of Local Councils		An association that represents the interests of the local councils based in the Forest
National Park Authority	www.newforest-npa.org.uk	An association of selected members that act in the interests of the New National Park
New Forest Dog Owners' Group	www.newforest-online.co.uk/nfdog/index.htm	Organisation working towards the rights of dogs and their owners in the New Forest
New Forest Tourism Association		A group consisting of all the local tourism providers
New Forest Association	www.newforestonline.biz/NFA/	An independent organisation dedicated to protecting the traditional character in the New Forest
Ramblers' Association	www.ramblers.org.uk	UK charity looking after footpaths and the countryside for walkers
RSPB	www.rspb.org.uk	UK charity working to secure a healthy environment for birds and wildlife
SUSTRANS	www.sustrans.org.uk	A charity that encourages people to walk, cycle and use public transport
Verderers	www.verderers.org.uk	A statutory body that shares the management of the New Forest with the Forestry Commission

5.3.1 Integrating the recreation tool and biodiversity tool

To be salient, the tools must clarify the recreation–biodiversity relationship in a way that opens up perspectives for action (Sutherland 2007). The integrated recreation–biodiversity tool enables managers to model the functional relationships between the attributes they can control in one domain and the outcomes they seek in the other domain. In the project, the recreation tools had to evaluate the impact of changes in the path network, parking lots, and recreation characteristics on recreation patterns and objectives. The biodiversity tool had to evaluate the impact of changes in the recreation patterns and vegetation structure on habitat quality for species and biodiversity objectives. In other words, the managers had to be able to make minor adjustments using the right "tuning knobs" (Fig. 2).

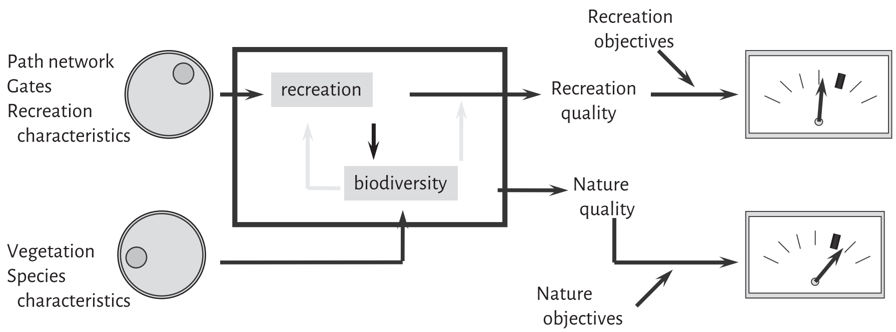

Figure 2. Example of management tool containing scientific tools for recreation and for biodiversity (adapted from Pouwels et al. 2008). The inputs are GIS maps containing landscape characteristics and attributes managers can control. The outputs are indicators that can be linked to objectives. The black arrow between the recreation tool and the biodiversity tool indicates the ecological footprint of recreation. The grey arrows indicate possible interactions between biodiversity values and recreation that have not yet been integrated, like the added value of a singing Skylark (*Alauda arvensis*) for visitors.

5

Because the interaction between recreation and biodiversity is often the main source of conflict, the way this interaction is implemented in the tools has to be made transparent. Also, uncertainties, or disagreements, about resources, parameter setting, and management effects have to be made explicit (Williams et al. 2007, Itami et al. 2008). At present, the only examples available are of recreation tools and biodiversity tools that are partly integrated (e.g., Mallord et al. 2007, Coombes et al. 2008, Pouwels et al. 2008). As yet, no tool has been developed to dynamically and concurrently model the behavior of animals and of visitors (see also Skov-Petersen 2008).

In the project we used the Multi-Agent Simulation Of Outdoor Recreation (MASOOR) recreation tool (Jochem et al. 2008) and the Landscape ecological Analysis and Rules for the Configuration of Habitats (LARCH) biodiversity tool (Opdam et al. 2003, Verboom and Pouwels 2004). The MASOOR model is an agent-based model that focuses on the simulation of the behavioral aspects of recreational movement in natural areas. The main task for the agents is to navigate through a network of paths by making choices at each junction and to achieve one or more recreational goals such as visiting a certain point of attraction, or walking for 2 hours. MASOOR predicts the densities of visitors on each path section and the number of encounters between different types of visitors. The LARCH model is used to determine the viability of landscapes for species. It uses different parameters for each species. Habitat is selected from vegetation maps. Suitability for local populations is determined using species-specific area requirements. The recreation tool and biodiversity tool were not fully integrated into a single interactive tool. The results generated by the recreation tool had to be translated into a recreation impact using a GIS. The map showing the recreation impact was inserted into the biodiversity tool during an interactive session. Combining the tools in this way made it possible for managers to discuss with stakeholders the impact of changes in the recreation pattern, e.g. of parking lots or on the habitat quality of wader species. This allowed them to decide which of the management alternatives would positively impact wader habitats (see Colas et al. 2008 for more information). Users said that the tools could be made more user-friendly by integrating both tools into one management tool.

5.3.2 The tool facilitates communication and helps clarify the underlying conflict

To serve as boundary objects (Star and Griesemer 1989), scientific tools should help clarify underlying conflicts and create understanding of the issues at stake. One of the benefits of simulation tools such as MASOOR is that users can actually see visitors moving across a dense path network (Appendix 8). The animation interface projected the results on aerial photographs and gave managers and stakeholders the impression that they could play with it like a computer game. Stakeholders familiar with the area will recognize the output and can get used to the tools (Kleijnen 1995), which makes it easier for them to participate in the process.

During interactive sessions with managers and stakeholders the animation tool helped us as scientists to explain the main processes simulated by the tool. Stakeholders reflected on what the tool showed, described the process from their own perspective, and specified their values, concerns, and way of thinking. This added valuable knowledge to the development of the tool, e.g., the effect of crowding was left out because stakeholders indicated that in the New Forest this had a minor effect on visitors' use of the area. As we started to discuss the main processes and parameters in the scientific tools with managers and stakeholders, they started to give feedback on how they perceived the processes underlying the conflict. In this process, all actors learned each other's values and began to understand more about the world on the other side of the table. This increased the credibility and legitimacy of the tools (Cash et al. 2003, Lynam et al. 2002, Fry et al. 2007). As an illustration, recreation stakeholders learned that seeing birds still present in the area is not a guarantee they are not being disturbed and biodiversity stakeholders learned why visitors like to follow some specific routes, such as a former railroad.

5.3.3 Adaptation to local data and knowledge

Adapting existing scientific tools in the light of local data will increase the reliability of their output as well as their credibility (Irvine et al. 2009), especially if the data were gathered in collaborative monitoring projects (Fernandez-Gimenez et al. 2008), because stakeholders can see how a tool deals with their local data. They can then respond to the output, improve it, and incorporate the tool into their mindset. However, most scientific tools are developed for specific case studies, which makes it difficult to apply them elsewhere (Sturtevant et al. 2007). It saves costs and developing time if tools are developed with modular architecture (Maxwell and Costanza 1997, Scheller et al. 2007) and with a separate database. Modular architecture allows new processes to be incorporated by making minor additions or adjustments to the tool. A separate database for each parameter makes it possible to change settings during interactive sessions, without making changes to the tool itself. Because both the MASOOR and LARCH tool have this modular structure, they are flexible in incorporating specific local conditions.

In the New Forest the LARCH tool was adapted by adding the slope of the land as extra input for determining the habitat of wader species. One of the adaptations made to the MASOOR tool was to remove the effect of crowding (e.g., Arnberger and Mann 2008) because stakeholders and managers expected this to have a minor effect on visitors' use of the area. At first the local scientist was very skeptical about using tools to predict potential bird distributions. However, after the biodiversity tool had been adapted in light of his local knowledge and he had been shown how the model's predictions improved as a result of inputting information he supplied (Fig. 3), he became an advocate of the use of scientific tools in stakeholder meetings. Legitimacy was gained because the local scientist affirmed that the tools reflected the local situation. Thanks to his detailed knowledge of the area he was able to discuss local settings with the stakeholders and could clarify the output of the tool in the local context. Thereby he played a crucial role as a key information conduit between the participants, i.e., stakeholders, managers, and the team responsible for modifying the scientific tools (as discussed in Sturtevant et al. 2007).

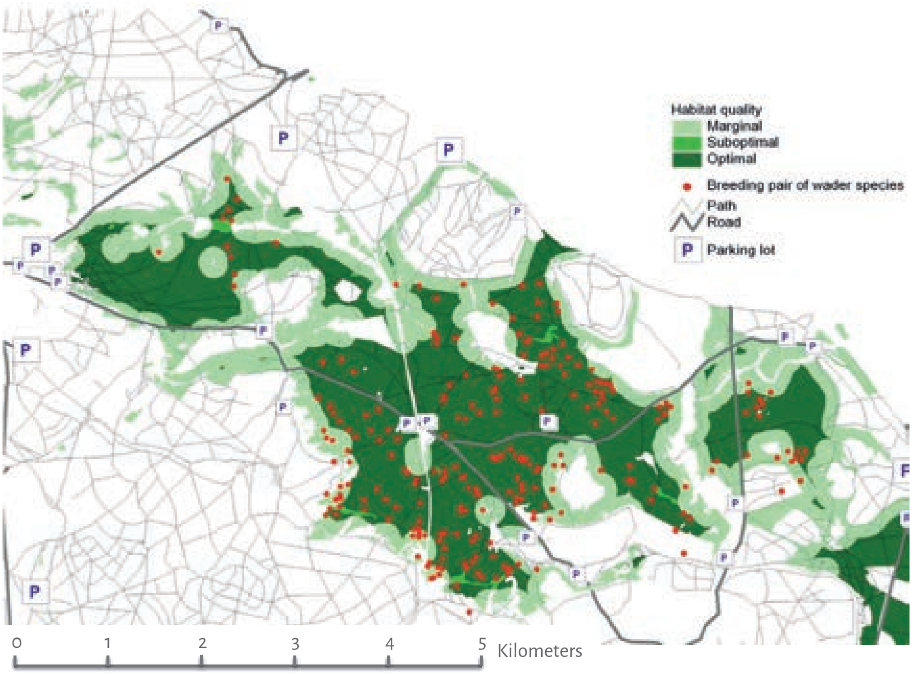

Figure 3. Map showing the potential habitat for wader species in part of the New Forest. The map used generic knowledge of habitat preferences from the database of the biodiversity tool LARCH (Opdam et al. 2003, Verboom and Pouwels 2004), but was amended by adding local monitoring data and information on landscape features in the New Forest that predicted the current and historic distribution of wader species in this area. Based on local maps consisting of vegetation structure and slope the habitat was classified as optimal, suboptimal, and marginal. In optimal habitat wader species can reach high densities and in marginal habitat low densities. The monitoring data had been gathered over several years and included four wader species: Lapwing (*Vanellus vanellus*), Curlew (*Numenius arquata*), Snipe (*Gallinago gallinago*), and Redshank (*Tringa totanus*).

5.3.4 The tool is based on spatially explicit relationships and its output is a map

In boundary management it is crucial to be specific about where recreation activities are incompatible with biodiversity conservation. Conflicts are often discussed in general terms (Margerum 2002), neglecting that the intensity of the recreation–biodiversity interaction may vary because of spatial heterogeneity in habitat types, distribution of species, and visitor patterns. Solving the conflict becomes easier when the critical locations are known. We expect that presenting the output as a map showing the nature and intensity of the recreation–biodiversity interactions will enable stakeholders to identify where the problem is located; this may reduce the tension between opposing views.

In our projects, to help managers and stakeholders identify obstacles to maintaining recreation and biodiversity values we visualized ecological disturbance zones (Fig. 4). In the New Forest, managers used the resulting map to discuss management alternatives with stakeholders. It became obvious that the easternmost parking lot had a much greater impact on the habitat quality of wader species than the other parking lots. On the basis of this spatial information, stakeholders agreed on decommissioning the parking lot. Based on the same map, the park managers also found opportunities to increase the capacity of two nearby parking lots without affecting the habitat quality elsewhere. Depicting recreation pressure to stakeholders visually in this way improved their acceptance of the decisions made (Colas et al. 2008). Our findings are in accordance with Skov-Petersen (2008) and Jochem et al. (2008) who combined scientific tools with a GIS and Google Maps to increase the usability of the scientific tools in a participatory process.

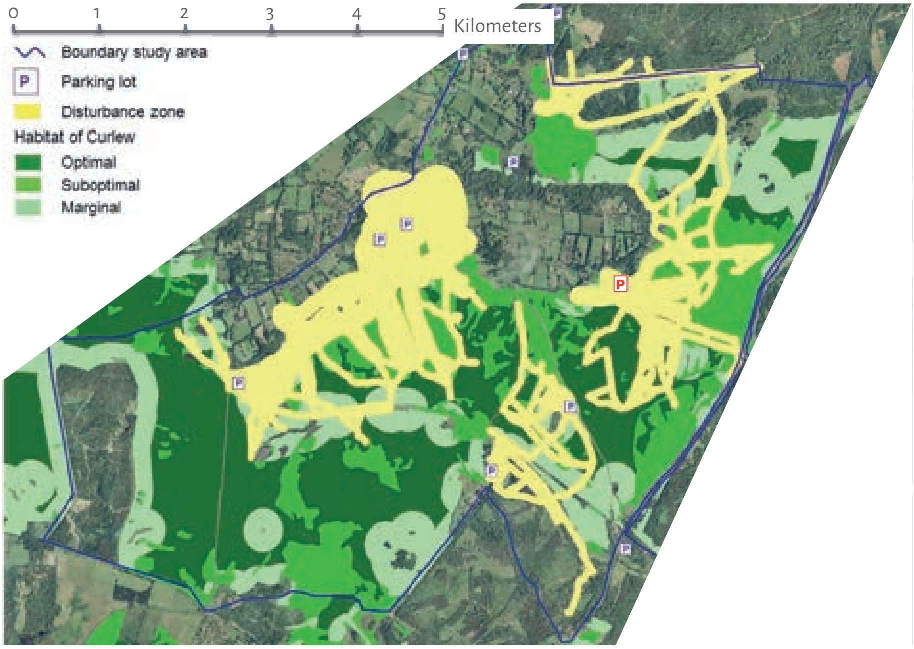

Figure 4. Map of the disturbance zones of visitors overlain on the habitat map of wader species, overlain on an aerial photograph. The easternmost parking lot is shown in red ('P'). Based on local maps consisting of vegetation structure and slope, the habitat was classified as optimal, suboptimal, and marginal. In optimal habitat wader species can reach high densities and in marginal habitat low densities.

5.4 Discussion

The participatory modeling in the PROGRESS project contributed to conflict resolution in a system with many uncertainties by combining elements of adaptive management and boundary management. We went through a collaborative learning process in which scientists and interest groups developed a common understanding of the local biodiversity–recreation system by combining generic scientific knowledge with specific knowledge of the local context. This resulted in an agreement about the problem that had to be solved and the solution that was most appropriate in the local situation. In this process the models played a key role as a means to learn and communicate the underlying mechanisms in the biodiversity–recreation relationship, which formed the basis for identifying the problem and designing the solution. As such, we applied the mix of objectives suggested by Voinov and Bousquet (2010), Souchère et al. (2010) and Simon and Etienne (2010). Previously, Pröbstl et al. (2008), Marceau (2008), and

Jochem et al. (2008) emphasized the role of recreation tools in mutual learning, but did not consider their effectiveness for boundary management in conflict solving. Because the relationship between scientist, managers, and stakeholders in boundary management is fundamentally different from the relationship in mutual learning without conflicts, it is important to reconsider the design of tools from a perspective of effectiveness in solving problems that have a high degree of uncertainty.

5.4.1 Uncertainty

In assessing environmental conditions, different types of uncertainties have been distinguished (Brugnach et al. 2008, Opdam et al. 2009). Incomplete knowledge is uncertainty due to lack of sufficient scientific proof, unpredictability is uncertainty caused by the stochastic behavior of the system under observation, and ambiguity is due to low uniformity in societal values and norms. The impacts of these sources of uncertainty on conflict solving are largely unexplored. Incomplete knowledge seems to be managed in adaptive management, whereas boundary management specifically aims to manage ambiguity. During the PROGRESS project we encountered uncertainties regarding incomplete knowledge and ambiguity several times. Uncertainties related to unpredictability were less present. Although we didn't analyze their impact on the common learning process at that time, we can reflect on the way we dealt with uncertainty in the various steps of the process in retrospect. The three criteria for effective transfer of scientific knowledge in participatory processes suggested by Cash et al. (2003) serve as an appropriate reference.

Only qualitative indications were available concerning the cause of the conflict, the decline of birds due to an increase in recreation. This influenced a number of choices we made, and in retrospect these can be considered as part of a strategy to minimize the impact of uncertainty on the credibility of scientific information. When choosing indicator species for biodiversity, managers want to be sure pilot actions will result in increasing population numbers. From a political point of view Natura 2000 species would be good indicator species. However, Kingfisher (*Alcedo atthis*) and Honey-buzzard (*Pernis apivorus*) probably will not profit from pilot actions because there is little overlap between suitable habitat for the Kingfisher and the current path network, and the population of the Honey-buzzard is so small that effects cannot be detected. Effects of pilot actions on the populations of Dartford warbler (*Sylvia undata*) and Nightjar (*Caprimulgus europaeus*) will also be difficult to detect because these are already increasing, probably because of climate change. Also stakeholders might disapprove with changes in the landscape for species that already flourish. We did expect effects of pilot actions on population of Woodlark (*Lullula arborea*). However, this species is breeding at large parking lots because the vegetation structure is optimal habitat. It would be very difficult to convince stakeholders that Woodlarks are affected by visitors. Therefore managers and stakeholders had to choose other indicator species. The chosen wader species are also expected to be sensitive to recreation disturbance and we found a large overlap in suitable habitats and recreational use. Managers were also interested in these species because large restoration projects had not resulted in increasing numbers yet.

Most scientific research on recreation disturbance focuses on walkers and dog owners. There is little research on disturbance by cyclist and horse riders. In the New Forest the largest user groups are also walkers and dog owners. Therefore the managers were able to demonstrate to the stakeholders that it was legitimate to take pilot actions regarding these user groups. To choose suitable locations for pilot actions the managers had to know how these user groups use the area. A large monitoring program was set up, including counting visitors, tracking visitors with GPS devices, questionnaires, and telephone surveys. The GPS tracks especially helped stakeholders to learn about the biodiversity–recreation relationship in the New Forest and decide which pilot actions should be approved.

Imperfect knowledge about the interaction between recreation and biodiversity sometimes resulted in the tools losing credibility. The level of sensitivity of wader species to recreational disturbance was not known and provided an escape route from the common learning process. In adaptive management this type of uncertainty should be embraced and reduced by pilot actions, but it can be argued that if knowledge is in short supply, there is no proof that a problem exists and no guarantee that a chosen solution will be effective in solving it. To reduce the possibility of the easy way out of doing nothing, boundaries between stakeholders and scientists from different disciplines should be crossed. In the project, we discussed the uncertainty with recreation stakeholders and conservationists and agreed that an effect was plausible; for determining cause-effect relations we used scientific knowledge from studies on comparable species and from expert judgment.

In the project ambiguity was the most difficult type of uncertainty. One stakeholder just didn't accept the fact that dogs affect breeding bird densities. In his opinion there were no conflicts. Although the tools were used to visualize relationships between recreation and biodiversity in stakeholder meetings and helped other stakeholders to engage further in the participatory process and clarify goals and values, this one stakeholder slowed down the process. In the end a survey among dog owners in the area showed that most dog owners didn't sympathize with this particular stakeholder's vision and arguments. This helped the managers and other stakeholders to neglect some of the arguments of this one stakeholder.

We suggest that incomplete knowledge on the biodiversity–recreation relationship in a spatially explicit landscape context may be key to whether a tool is accepted in conflict resolution because it is at the heart of the conflict. We therefore believe it is important to enlarge the body of knowledge on how recreation and biodiversity values and underlying processes are related (Cole 2006, Haider 2006, Sutherland 2007). Of particular importance are the impact of recreation on species populations, how management measures reduce this impact, and how recreation and biodiversity functions can be spatially combined in landscape planning (Warnken and Buckley 1998, Blanc et al. 2006, Sutherland et al. 2006). Such investigations should be based on better empirical data on recreation behavior (Van Marwijk 2009), for example, on the motives of visitors, their perception of the landscape, and the choices they make during their visit. The results might endorse management measures for achieving a more compatible recreation pattern.

As a topic of future research, we suggest investigating how the three types of uncertainties can be managed in adaptive management or boundary management. As a hypothesis, we propose that boundary management deals better with uncertainties related to ambiguity whereas adaptive management deals better with uncertainties related to incomplete knowledge (Fig. 5). Therefore we recommend that managing the recreation–biodiversity conflict should alternate between a pacification strategy and a facilitation strategy (Fig. 1). This option can be considered as a stepwise learning strategy of adaptive management, focused on dealing with uncertainties related to incomplete knowledge (Williams et al. 2007), and boundary management, focused on dealing with opposing views on the conflict and preferable solutions (Cash et al. 2003). The research should explore the possibility of discovering if the way uncertainties are clarified in the tools affects the learning process.

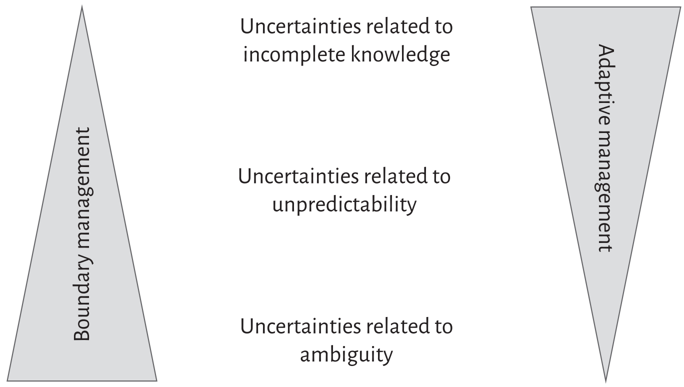

Figure 5. Schematic representation of types of uncertainties (Brugnach et al. 2008, Opdam et al. 2009) and the degree to which they are addressed in boundary management and adaptive management.

5.4.2 Complexity of the model

In conflict situations, tools may be rejected for various reasons because participants do not want to cooperate in finding a solution. Simple tools can be rejected because they are less precise and do not exactly describe the local situation; this makes an easy argument to a local stakeholder to reject the tool for lack of credibility. Complex tools may be rejected because they are not transparent and therefore not recognized as legitimate. Therefore, the creation of trust during boundary management is crucial for having models accepted as reliable sources of information, most importantly if complex tools are used (Voinov and Bousquet 2010). If the tools are flexible and adjustable to the local situation (Voinov and Bousquet 2010), their information is more credible to local users. Legitimacy and credibility are gained when models are selected because they have been used in comparable areas for comparable conflicts (Ritzema et al. 2010). In some situations complex tools might be rejected but the final results accepted (Lagabrielle et al. 2010), and developing and using the tools will be a means and not an end (Farolfi et al. 2010).

In boundary management it is relevant that the risk of rejecting information because it is considered untrustworthy is lower when the stakeholders are involved in the development of the scientific tools from the start. However when means are scarce it is difficult to develop a complete new tool. It's better to use existing tools and adjust them. Which tools will be used is again preferably a decision for the stakeholders, but in most situations the choice is made by the scientists (Voinov and Bousquet 2010). In the PROGRESS project the choice was made by the scientists and the managers because the scientists preferred the tools they had developed and used. The stakeholders accepted the tools because we started with a reflection in the first stakeholder meeting and the development of the tools during the project was an iterative cycle (Farolfi et al. 2010). In these meetings we explained the concepts behind the tools. In this way the tools were used to cross the boundary between recreation and biodiversity (Lamers et al. 2010). In some cases the use of the tools for evaluating management alternatives is less important than the discussion of the results (Voinov and Bousquet 2010, Itami 2008).

The biodiversity tool LARCH that we used in the PROGRESS project was simple compared with the recreation tool MASOOR. LARCH predicts potential suitable habitats for species in three classes based on four landscape characteristics. The tool does not model the population processes, but uses thresholds that are related to these processes (Verboom et al. 2001, Opdam et al. 2003). We think LARCH was accepted by the managers and stakeholders because the results were credible when compared to local knowledge and data, and the tool was salient and legitimate because it was simple and easy to understand. The MASOOR model is rather complex for lay people because it is based on a Hierarchical Control System in which agents interpret the world at different scales and autonomously navigate a given recreational track network. The navigation of the agents in the landscape is a random process based on multicriteria analysis using the preferences of the agents for the characteristics of the landscape, the goals agents try to reach, and the already followed route (Jochem et al. 2008). It is difficult for people to fully understand what the consequences are for the results when some parameters and equations will change. We think the most important reason for managers and stakeholders to accept MASOOR is the animated results. We also used a simple algorithm for predicting the use of visitors, but the managers and stakeholders chose the more complex tool because it was more salient. Legitimacy was gained in one of the meetings when an example of the results of MASOOR was presented. One of the stakeholders in the New Forest remarked, "that's the exact route I always take." This simple remark led to the acceptance of almost every stakeholder present.

We have addressed how scientific tools can be made more effective in helping solutions to be found for common conflicts between biodiversity and recreation functions. We discussed how four proposed features of interactive tools enhanced understanding of the other side's viewpoint, helped clarify the conflict, and assisted in exploring solutions. To achieve this, a tool needs to be built on the relationship between recreation and biodiversity functions, and be able to incorporate local knowledge and data. We also found that conflict resolution is enhanced by showing the model output as a map indicating where the conflict is located and where opportunities for solving the conflict can be created. These features could have a more general significance for understanding the role of tools in conflict management. We hope that future research can build on our insights to ensure that scientific tools not only facilitate communication in adaptive management, but also for the generation of new common knowledge that is so crucial for boundary management.

Acknowledgements

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6

Synthesis

6.1 Achievements

Natural areas are essential not only for species conservation but also for outdoor recreation (Balmford et al. 2015, Gray et al. 2016, Siikamäki et al. 2015). However, conflicts may arise when the conservation and recreational values that need to be protected are interrelated and under threat (Young et al. 2005). Finding the balance between the conservation and recreational functions is complicated because site managers of nature areas have to deal with stakeholders who hold differing and opposing views about which values are important (Mace 2014, McCool 2016). Managers are under increasing pressure to promote recreation because health policies advocate physical contact with nature (Maller et al. 2006; Bell et al. 2007), but at the same time they are being asked to regulate or even restrict visitor access by conservation policies that aim to halt biodiversity loss (Balmford et al. 2015). Moreover, it is crucial they get support from stakeholders for their actions in order to meet the growing demand for accountability (McCool 2016).

In this complex governance arena, there is a need to revisit the role of information about the interrelations between nature and recreation. Site managers need information to be able to predict the outcomes of their actions, such as changing access to the area for visitors or improving habitats for protected species (Pullin et al. 2004). However, in Chapter 1 I argued that current scientific knowledge and tools lack salience and legitimacy to be effective in decision-making processes involving both site managers and stakeholders. In this thesis I address three problems that limit the practical use of scientific knowledge about the relationship between outdoor recreation and bird conservation. First, current scientific knowledge is only able to predict the impact of actions that regulate recreation on a local level, while species conservation often requires coordinated action on a regional scale. Hence, there is a mismatch between knowledge about impacts and the scale at which managers need to take action for effective conservation. Second, most scientific knowledge about the impact of visitors on birds relates to short-term behavioural impacts at the individual level, while managers are increasingly expected to ensure the viability of populations. Therefore, current scientific knowledge about the relationship between biodiversity and recreation often fails to connect with conservation targets. Third, current scientific information and tools are not effective in facilitating societal debates about the interaction between outdoor recreation and bird conservation.

In this thesis I have demonstrated how scientific knowledge and tools can gain salience and legitimacy while maintaining their credibility when the three problems are tackled. First, I related the impact of local measures to regional conservation targets for bird species in three large natural areas that are characterized by high nature values and high visitor numbers. For the New Forest (UK) I determined the impact of changes in the capacity of car parks to changes in the population size of Nightjar (*Caprimulgus europaeus*) (Chapter 2) and the impact of temporarily closing car parks to the population of wader species (Chapter 5). For the Amsterdamse Waterleidingduinen (Netherlands) I linked access restrictions in the central part of the area to the viability of the Skylark (*Alauda arvensis*) population in the area (Chapter 3). For the Veluwe (Netherlands) I determined the impact of visitor densities on the conservation targets of Woodlark (*Lullula arborea*), Stonechat (*Saxicola torquata*) and Nightjar (*Caprimulgus europaeus*) (Chapter 4). Second, I provided new knowledge on the impact of visitors on the population size of Woodlark, Stonechat and Nightjar (Chapter 4). In this study I have demonstrated how existing monitoring data can be used to determine the impact of visitors on species. Third, the scientific knowledge and tools I present in my thesis have been used by the site managers of the Amsterdamse Waterleidingduinen and the New Forest to contribute to the debate with stakeholders about the interaction between outdoor recreation and bird conservation. The results of the Veluwe study are currently being used by the responsible authority to develop a regional plan for the area together with stakeholders. The fact that the knowledge and tools have been used in the debate between site managers and stakeholders could be interpreted as an indication that the new scientific knowledge and tools I contributed to this debate are perceived to be credible, salient and legitimate.

6.2 Key insights

In these four studies I integrated site-specific data and local knowledge into existing scientific tools and methods. The integration contributed to making scientific knowledge and tools context-specific and is critical for achieving salience and legitimacy in decision-making processes involving site managers and stakeholders (Fig. 1). Working with managers and stakeholders to integrate site-specific data and local knowledge with scientific tools and methods I gained four key insights, which I explain and discuss in the following four sections:

1. Connect the perspectives of managers, stakeholders and scientists. Using standardized scientific methods to relate concrete management actions in an area to acknowledged stakeholders values helps to harmonize the perspectives of managers, stakeholders and scientists on the credibility, salience and legitimacy of knowledge and tools.
2. Connect knowledge along a clarity–complexity axis. A combination of complex scientific methods and simple algorithms and rules of thumb derived from those complex tools helps to connect credibility with saliency and legitimacy in the complexity versus clarity trade-off (Sarkki et al. 2013). Simple algorithms and rules of thumb improve salience and legitimacy, while a potential loss of credibility is mitigated by showing how the simplified knowledge reflects the complex relations between local management measures and local and regional targets.
3. Discussing algorithms and parameters helps to bring about agreement on the measures to be taken. Discussions encourage stakeholders and site managers to enter into a dialogue about each other's values and help to build trust between all parties.
4. Different phases in the decision-making process may need different types of information.

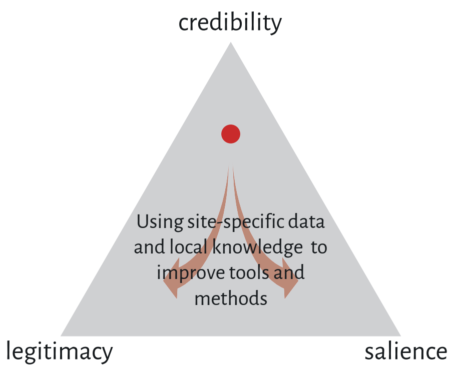

Figure 1. Schematic position of the thesis on creating a better balance between credibility, legitimacy and salience.

6

6.2.1 Connect the perspectives of managers, stakeholders and scientists

The more credible, salient and legitimate knowledge and tools are, the more useful they will be in decision-making process for all the parties involved. However, individuals in mixed groups will perceive and value each of these three attributes differently (Cash et al. 2002, Cook et al. 2013, Heink et al. 2015). To account for this variation in perception and valuation, I developed scientific tools that are able to link management actions to acknowledged stakeholder values (Fig. 2). This increases the value of the available knowledge and tools to site managers, stakeholders and scientists:

a. Site managers: the relevance of knowledge and tools is increased when managers are able to predict the impact on visitor densities of changes in access for recreation, for example by changing the location or capacity of car parks or temporarily closing parts of the area. The importance of this characteristic was previously advocated by Pullin et al. (2004) and Gutzwiller et al. (2017).
b. Stakeholders: the validity of knowledge and tools is increased when stakeholders can associate the output of the tools with the values they adhere to, as was advocated by Chan et al. (2016) and McCool (2016).
c. Scientists: confidence in knowledge and tools is increased when scientists can use standardized methods and develop tools that are based on accepted scientific methods and concepts (Nicolson et al. 2002).

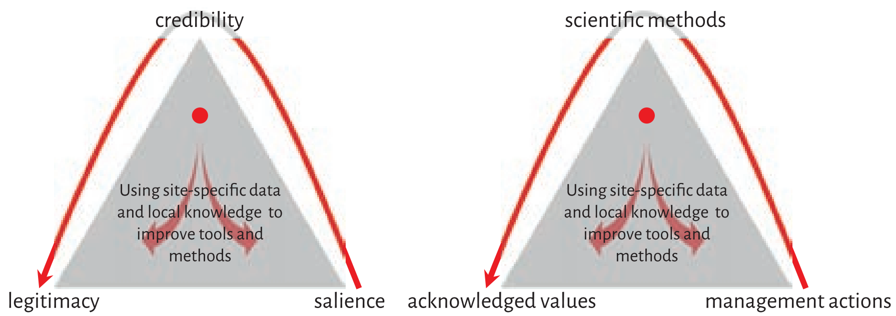

Figure 2. Finding a balance between credibility, salience and legitimacy by developing tools that use scientific methods to link management actions to acknowledged stakeholders values.

In Chapters 2, 3, 4 and 5 I showed that the tools are able to assess the impact on visitor densities in an area of temporal or spatial changes in access, such as temporary closures of car parks. I chose these factors as they have the largest impact on visitor densities in nature areas (Larson et al. 2018) and managers are able to alter them. Although no clear recreation targets have been set for any of the three study areas, the output of recreation models can be used to determine whether or not visitor densities exceed user density levels set by recreation frameworks such as ROS (McCool et al. 2007). In Chapter 3 I used an alternative recreation target, the total length of paths with low visitor densities in the nature area. The conservation targets I used in Chapters 3 and 4 can be directly linked to conservation targets such as population size and the long-term survival of bird populations. The stakeholders involved in the decision-making process need to decide which result best reflects their values. As no clear conservation targets were set for the wader species considered in Chapter 5, I used an alternative conservation target: 750 ha patches of suitable area without recreational use. This target was agreed upon with stakeholders and site managers during the study.

When site managers attempt to link management actions to acknowledged values they often face the difficulty of 'crossing scales' (Cash et al. 2006, Gutzwiller et al. 2017): most management actions relate to local changes in visitor access and habitat improvements, whereas most acknowledged values relate to regional or even national targets, such as population size. The tools I used in Chapters 3, 4 and 5 can all be used to cross scales as they relate the impacts of local management actions to regional impacts on bird conservation.

To link the management actions to acknowledged values in the different chapters I used statistical methods, individual-based models, simple algorithms and knowledge-based tools. The statistical methods were used to derive dose–impact relations from site-specific monitoring data. The models and tools were used to assess the impact of management plans on recreation and bird conservation targets. All these methods and tools are commonly used for these purposes in scientific research and their scientific credibility can be assessed according to standard modelling principles (see Refsgaard and Henriksen 2004) and peer-reviewed articles.

In my opinion, site managers, stakeholders and scientist will gain confidence in the use of new scientific tools when scientific methods are used to link management actions to acknowledged stakeholder values. The tools will then incorporate the attributes site managers, stakeholders and scientists value most (Fig. 2). A crucial part of this is being able to take into account the different perceptions of managers, stakeholders and scientists on credibility, salience and legitimacy.

6.2.2 Connect knowledge along a clarity–complexity axis

One of the main trade-offs in the relationship between credibility, salience and legitimacy is clarity versus complexity (Sarkki et al. 2013). In conflict situations, tools may be rejected for various reasons. Simple tools may lack credibility because they are imprecise and do not exactly describe the local situation. Complex tools may be rejected because they lack transparency and are therefore not recognized as legitimate. So how do we find a middle way between these two opposing views?

In Chapters 2 and 4 I showed how complex spatial statistic methods can be used to develop simple tools and rules of thumb. To be useful to managers these tools need to give answers to their questions and translate information into their professional language (Cash et al. 2003). In Chapter 2 I derived rules of thumb for the main factors that determine the visitor densities in nature areas. I used complex statistical methods to determine the features that together best explain visitor densities. These complex methods are needed as all these features interact and together account for differences in visitor densities (Shoval et al. 2010). However, these complex methods are difficult to interpret. For the most important features I used simpler statistical methods to relate their impact on visitor densities. The results can be used to derive rules of thumb and help site managers when they discuss measures with stakeholders, such as the temporary closure of car parks or parts of the path network. They can use this information to indicate where visitor densities might exceed accepted limits derived from recreation frameworks (McCool 2016) or bird conservation targets (Eken et al. 2004, Hoffman et al. 2010). The complex statistical model can be used to assess these impacts in more detail, which might be needed in situations where the potential conflict is delicate.

In Chapter 4 I used statistical methods to derive dose–impact relations between visitor densities and the population sizes of three heathland species; Nightjar (*Caprimulgus europaeus*), Stonechat (*Saxicola torquata*) and Woodlark (*Lullula arborea*). Scientific knowledge indicates that visitors have an impact on the breeding bird densities of all three species (Vos and Peltzer 1987, Liley and Clarke 2003, Mallord et al. 2007). To increase the salience of the derived dose–impact relations I used concepts site managers are used to working with: the number of visitors groups per hectare per year as the dose variable and the number of breeding pairs per hectare as the impact variable. This allows site managers to estimate the visitor densities they need to aim for in order to realize local population targets for these species.

Providing simple and easy to understand knowledge and tools, backed by more complex scientific tools, increases salience and legitimacy. Salience is increased because simple knowledge and tools are easy to use in terms of skills, budgets and time. Legitimacy is increased as simple tools are often more transparent and easy to explain. Credibility will not decline as the simple tools are based on complex scientific methods that can be used when more complex assessments are needed.

6.2.3 Discussing algorithms and parameters helps to bring about agreement on the measures to be taken

In Chapter 5 I described how in the New Forest we adapted existing scientific tools to the local context in a decision-making process with managers and stakeholders. We combined generic scientific knowledge with local knowledge in a learning process and helped to mediate between the various views on the relationship between outdoor recreation and bird conservation. The process of discussing the algorithms and parameters in the scientific tools played a key role in finding a common approach to solving local conflicts between outdoor recreation and bird conservation.

Explaining the algorithms and parameters of the recreation model enabled recreation stakeholders in the New Forest to argue that crowding is less relevant in the New Forest than scientific research indicates (Arnberger and Brandenburg 2007). This insight convinced the conservation managers that management measures such as the temporary closure of car parks and redirecting visitors to alternative car parks would not have a big impact on the visitor experience. Explaining the algorithms and parameters of the habitat suitability model for bird species revealed that the highest priority for conservation stakeholders was halting the decline of waders species. As these species inhabit specific habitats, such as wet heathlands and mire systems, recreation stakeholders could see that conflicts between recreational and conservation values are only likely to occur in parts of the New Forest. This shared understanding increased the consensus between stakeholders on how conflicts should be addressed and what solutions might be explored. This insight corroborates the conclusions by Cash et al. (2003) and Berkes (2009) that this process of learning and joint problem solving is needed to develop new knowledge that is credible and salient as well as legitimate. My results also support previous findings indicating that adapting tools to the local situation with stakeholders fosters the building of trust between stakeholders, site managers and scientists (O'Brein et al. 2013, Voinov et al. 2016).

6.2.4 Different phases in the decision-making process may need different types of information

Pictures, figures and tables are commonly used to convey information, and information on the impacts of outdoor recreation is no exception. A picture may be 'worth a thousand words', but the way a conflict is visualized will influence how stakeholders view the decision-making process (Voinov et al. 2014, 2016). Using data from the Veluwe area (Fig. 3) I will demonstrate that the ways of visualizing the relationship between outdoor recreation and bird conservation differ in credibility, salience and legitimacy (Fig. 4) and discuss how these differences might be useful in the different phases of the decision-making process.

The decision-making process can be divided into different phases for which information is needed (Williams et al. 2007), such as defining the problem, setting objectives, identifying potential management actions, estimating the impact of these actions and deciding which actions to implement. Simple messages, like options 5 and 6 in Fig. 3, can be used during the problem definition phase as they show the severity of the impact of visitors on the conservation targets. Visualizing the impact in terms of values that stakeholders find important emphasizes legitimacy and this type of information is often needed to support the decision-making process itself. Providing information on current visitor densities and breeding bird densities in different parts of the area, as in option 1, might also be used during this phase. However, it does not show the severity of the problem and stakeholders might argue that in some highly used areas the densities of a species like the Woodlark can be high. My opinion is that option 1 maximizes credibility, but in this example it lacks salience and legitimacy as the variation in data points is difficult to interpret.

Information that relates visitor densities to population size or conservation targets, as in options 4 and 5, can be used during the phase of setting objectives. Both types of information give clear indications of which objectives might be feasible locally or regionally. This type of information increases salience as well as legitimacy. Information linking attributes that managers can control to population size or conservation targets, such as options 2, 3 and 4, can be used during the phase of identifying potential management actions and during the phase of estimating the impact of management actions. For instance, option 2 shows site managers that the impact of extra visitors is higher in suitable areas with low visitor densities compared to areas with high visitor densities. Managers and stakeholders can use this information to choose the areas where management measures might result in a larger increase in the population at a regional scale. Option 3 shows that visitor density is just one of the variables that determine the population size of a bird species. For Woodlark, a larger population size might also be achieved by one or more of the following: changing the number of trees, increasing the area of heathland on suitable soil types, and reducing traffic noise. Chapter 4 described how spatial maps, like option 4, can be used in a collaborative decision-making process by the managers of a nature area (e.g. the Veluwe) as it shows for each local situation where reducing visitor densities will result in a larger population size for the area. Providing information on the impact on breeding densities increases salience and gives site managers and stakeholders insight into the severity of local impacts. However, this type of visualization will not indicate whether or not the conservation targets will be achieved.

All six options tell a different story. Although strong, clear messages, like options 5 and 6, are often seen as efficient ways to communicate knowledge, they simplify this knowledge and neglect the complexity of the impact of outdoor recreation on bird conservation. A strongly simplified message may be effective in communicating a problem and raising awareness, but to create solutions more complex forms of knowledge, such as options 3 and 4, are needed.

When choosing between simple and complex visualizations, particular attention should be given to uncertainties as they affect trade-offs between credibility, salience and legitimacy (Sarkki et al. 2013, Heink et al. 2015). Although Speigelhalter et al. (2011), Wardekker et al. (2008) and Morgan (2009) provided examples of how to express and visualize uncertainties in more comprehensible ways for stakeholders, Ascough et al. (2008) showed that giving consideration to the consequences of all uncertainties can be difficult and Redpath et al. (2013) argued that it can lead to a loss of stakeholder engagement in the decision-making process. Nevertheless, I agree with Ascough et al. (2008) and ní Aodha and Edwards (2017) that neglecting uncertainties is one of the pitfalls of using scientific models in decision making and that addressing the different types of uncertainties (Spiegelhalter and Riesch 2011, Brugnach et al. 2008) should be part of the process. In Chapter 5 I proposed a step-wise approach of adaptive management and boundary management for managing the different types of uncertainties. Using scenarios can also help to deal with uncertainties as it encourages an explorative dialogue between stakeholders and site managers about the risks involved (Voinov et al. 2016).

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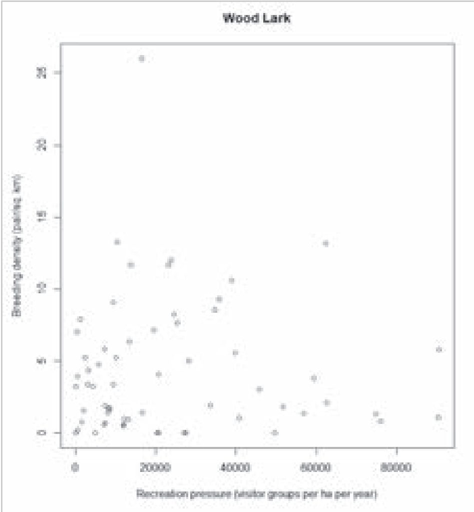

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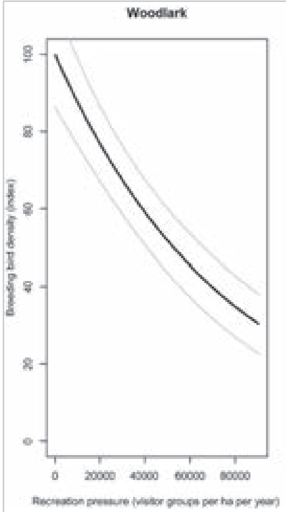
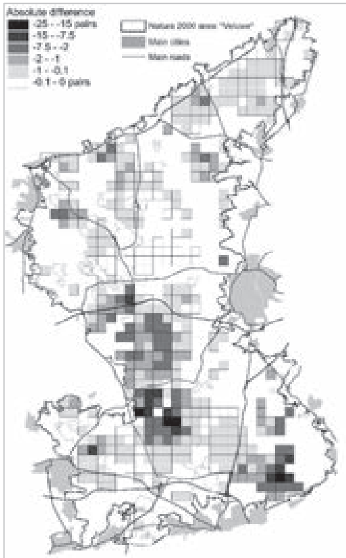


3

Woodlark	Estimate	Std. Err.	z value	p value
(Intercept)	-1.14783	0.49731	-2.31	0.02099
Area	0.00362	0.00025	14.42	0.00000
ProjectBMP	0.68473	0.12080	5.67	0.00000
ProjectDefense	0.61088	0.22636	2.7	0.00696
Soil_poorsand	0.00772	0.00218	3.55	0.00039
Soil_shiftsand	0.00680	0.00197	3.46	0.00054
Treedens3	0.02117	0.00414	5.11	0.00000
Buffer150	0.01603	0.00360	4.46	0.00001
Heathland	0.00684	0.00439	1.56	0.11881
Ntreespeckm	-0.11418	0.02679	-4.26	0.00002
Woodtyp2	0.02391	0.00600	3.98	0.00007
Woodtyp4	0.01300	0.00404	3.22	0.00129
Noise	-0.12852	0.03746	-3.43	0.00060
Pressure1	-0.00001	0.00000	-4.41	0.00001

4



5 Impact on population = -28%

6 Population is below target

Figure 3. Different ways of presenting data on the conflict between outdoor recreation and bird conservation, based on results from Chapter 5. From top to bottom: 1) original data in monitoring plots for breeding birds; 2) breeding densities of Woodlark against visitor densities based on the statistic model, including uncertainty; 3) parameters from the statistical model; 4) spatial output showing differences in population density across the Veluwe; 5) overall assessment of the Woodlark population in the Veluwe; 6) overall assessment of the conservation target for Woodlark in the Veluwe. In the example I assume that options 5 and 6 represent the values conservation stakeholders find important. The different ways of presenting this information also differ in their credibility, salience and legitimacy for site managers and stakeholders (Fig. 4).

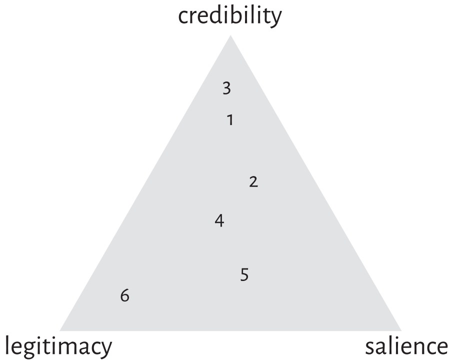


Figure 4. Difference in the credibility, salience and legitimacy of the different ways of presenting the impact of visitors on Woodlark in the Veluwe (see Fig. 3 for the six ways of presenting the data).

6.3 Reflection on the dynamics of decision-making processes

In the New Forest (Chapter 5) I observed that the perception of what is credible, salient and legitimate evolves during the decision-making process. Changes in perception can originate from the process itself and from external developments (Fig. 5). In Chapter 5 I discussed how the legitimacy of scientific knowledge about disturbance by visitors was continuously challenged by a local dog owners group in the New Forest. However, a survey in the area showed that most dog owners did not sympathize with the aims of this local organization, which led to a shift in power between the different recreation stakeholders and to acceptance of the legitimacy of this knowledge. My observations corroborate those of Reed (2008) that the decision-making process itself leads to empowerment, equity, mutual learning and trust between different stakeholders and site managers. Cundill et al. (2012) and Reed et al. (2018) show that mutual learning and increasing trust might lead to changes in the values and attitudes of stakeholders and, in turn, to changes in the perception of the credibility, salience and legitimacy of the knowledge and tools used in the process. Changes in credibility, salience and legitimacy can also be affected by external developments. An example during my research in the New Forest was the implementation of the Countryside and Rights of Way Act 2000 (CRoW Act). The two main purposes of this law are to improve opportunities for pedestrian access and to provide better conservation of wildlife, particularly in protected areas like the New Forest. Implementation of the CRoW Act may have consequences for parts of the areas that are normally closed to visitors. Another external development that could affect the credibility, salience and legitimacy of knowledge and tools is new knowledge about the impact of visitors on bird species. Bötsch et al. (2017) showed that even low visitor densities had an impact on the diversity and the density of breeding birds. Also, new types of outdoor recreation and new conservation policies would introduce new stakeholders into the decision-making process.

In the light of changes in stakeholder attitudes and social relationships, Kunseler et al. (2015) and Sarkki et al. (2015) suggested that flexibility or adaptability should be added as an attribute of scientific knowledge in addition to credibility, salience and legitimacy. In Chapter 5 I showed that this extra attribute is important for integrating site-specific data and knowledge into existing tools. How this will affect the use of tools in the decision-making process is a subject for further research. One aspect to consider is that adapting scientific tools during the process should follow guiding principles of scientific soundness, such as sensitivity analyses and validation (Refsgaard and Henriksen 2004, Nicolson et al. 2002), which may not be feasible or may affect the credibility of the tool. On the other hand, rigid tools may reduce legitimacy as stakeholders might argue that their values are not adequately taken into account. The balance between the credibility, salience and legitimacy of tools should therefore be evaluated at regular intervals during their development and use (Van Voorn et al. 2016). However, Sarkki et al. (2013) and Heink et al. (2015) state that although the three attributes are helpful in evaluating the effectiveness of scientific knowledge, they are difficult to apply.

As a first step, a checklist for scientific tools provided by Van Voorn et al. (2016) might be used to evaluate the level of credibility, salience and legitimacy. Although it has not been applied yet and some limitations have been addressed by Van Voorn et al. (2016), I propose using this checklist to evaluate the attributes of knowledge and tools in a decision-making process. Site managers and stakeholders can choose the most relevant criteria from the current list of 10 criteria for credibility, 13 for salience and 15 for legitimacy. The criteria could also be ranked if managers and stakeholders assign values to them (Cash et al. 2003, Sarkki et al. 2013, Van Voorn et al. 2016). Experiences with these assessments could be used to make further improvements at regular intervals. Experience from several applications in different decision-making process might result in defining minimum or preferred levels of credibility, salience and legitimacy.

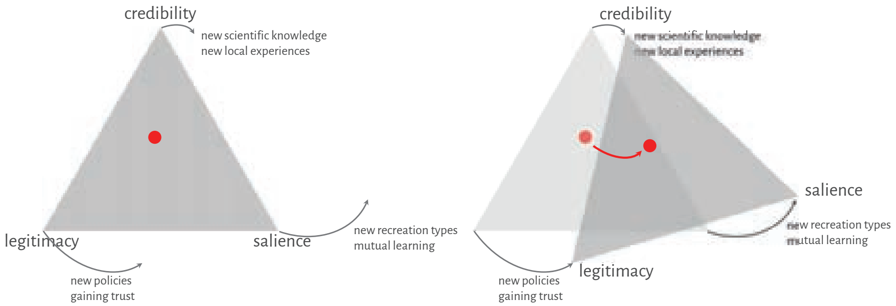


Figure 5. Internal and external developments can lead to changes in credibility, salience and legitimacy during the decision-making process (left). The scientific knowledge and tools used at the beginning of the process (represented by the red dot) must keep pace with these changes to avoid losing credibility, salience and/or legitimacy later in the decision-making process (right).

6.4 Future research

In this thesis I have provided examples of how science can help managers and stakeholders to balance outdoor recreation and nature conservation targets in nature areas. In my work I encountered several knowledge gaps that need to be covered in order to solve potential conflicts between outdoor recreation and bird conservation. I propose three main directions for future research to address knowledge gaps on the relation between outdoor recreation and nature conservation and the use of scientific knowledge and tools in decision-making processes with stakeholders.

6.4.1 The impact of outdoor recreation on the population sizes of bird species

Site managers and stakeholders need knowledge about the impact of outdoor recreation on bird species. In Chapter 2 I gave an example of how dose–impact relations can be used to estimate the impacts of changes in visitor use on the population of Nightjar. However, for many species little is known about such impacts (Steven et al. 2011, Buckley 2013, Sutherland et al. 2007) and dose–impact relations are urgently needed for species that are in decline and expected to be sensitive to recreational disturbance. Monitoring data on visitors and bird species is needed in order to derive these relations (Hadwen et al. 2007, 2008, Monz et al. 2013), but this type of monitoring is costly and difficult to implement at the population level. In Chapter 4 I propose a new approach that uses existing monitoring data for bird species with recreation models. This approach still needs to be tested for other species and areas. For rare species this approach might not be applicable, as monitoring data is insufficient for the statistical analyses. For example, the monitoring data for the Veluwe, the study area in Chapter 4, was insufficient for Northern Wheatear (*Oenanthe oenanthe*) and Eurasian Wryneck (*Jynx torquilla*), breeding bird species for which the area has been designated. For rare species, monitoring data from different areas might need to be combined. Further research is needed to show if combining different datasets for this type of analyses is feasible.

Where no monitoring data are available, managers might use the concept of ecoprofiles (Opdam et al. 2008). Ecoprofiles are a set of species that respond in a similar way to a pressure. Based on species characteristics such as body size (Weston et al. 2012), breeding location (Kangas et al. 2010) or habitat preferences (Blanc et al. 2006) species can be aggregated in ecoprofiles. Knowledge of the impact of outdoor recreation for one of the species may then be used for other species in the same ecoprofile. For example, in order to estimate the impact of recreation on the Tawny Pipit (*Anthus campestris*), a small songbird breeding on the ground in heathland, managers might consider using knowledge about the impact of outdoor recreation on Woodlarks (Chapter 4). Further research is needed on the effect of using ecoprofiles on the credibility, salience and legitimacy of the knowledge and tools used in the decision-making process.

Finally, in this thesis I focused on hiking as a recreation type. However, different types of visitor may have different types of impact. Visitors with dogs, for example, are considered to have a larger impact on breeding bird densities than visitors without dogs (Banks and Bryant 2007). Knowledge is needed on the differences in impact between different types of recreation.

6.4.2 Use different methods to find alternative solutions

In Chapters 3 and 5 I used scientific tools to assess the impact of management measures that restrict visitor use on bird populations. In natural areas where outdoor recreation and bird conservation conflict, restricting visitor access is often the first measure site managers propose (Hammitt et al. 2015). Most studies on recreation disturbance on birds also conclude that temporary or permanent restrictions on access to parts of natural areas should be considered by managers (Coombes et al. 2008, Bötsch et al. 2017). Although the reason and necessity for such restrictions are easy to explain and are accepted by most visitors, Hammitt et al. (2015) argue that restrictive measures should never be the first line of defence as they frustrate opportunities for nature experiences.

I propose that research should focus on extending the range of potential solutions to conserve bird species while providing visitors the opportunity to experience nature. For example, two alternative options mentioned in the literature are managing natural soundscapes (Francis et al. 2017) and raising awareness, for example by developing a code of conduct with stakeholders (Van der Molen et al. 2016). Managing natural soundscapes by reducing human induced sounds improves visitor experiences as well as conditions for bird species. Newman et al. (2018) showed that when visitors were asked to be silent as they enter a natural soundscape area, the noise levels were reduced by 15 dB. In the natural soundscape area bird abundance increased, but so did visitor satisfaction. Van der Molen et al. (2016) showed that developing a code of conduct for recreational boating in the Wadden Sea (Netherlands) promoted awareness and responsible behaviour among boat owners. Changing the management from restrictions in large parts of the area to use of the code of conduct was considered a success, as after four years no increase in disturbances were found.

Alternative solutions might be found in a joint design process with stakeholders. Design is based on values, helps to create alternative solutions (Swaffield 2013, Opdam et al. 2018) and enhances the salience and legitimacy of scientific knowledge through collaboration between scientists and practitioners (Nassauer and Opdam 2008). How current scientific knowledge and tools can be used in the design of site-specific solutions should be a subject of future research.

6.4.3 Provide knowledge to reduce potential inequality between outdoor recreation and bird conservation in nature areas

In discussions with stakeholders and site managers I noticed that the positive impact of outdoor recreation on nature conservation is often neglected. Discussions mostly focus on the measures that are needed to conserve bird species. One reason might be that in most nature areas there are no objectives for recreation and so conservationists would tend to raise their concerns about every future recreational development, while recreational benefits are ignored (Stenseke and Hansen 2014). The inequality between functions undermines the legitimacy of the decision-making process with stakeholders (Reed 2008, Redpath et al. 2013). I agree with Eagles et al. (2002) and Stenseke and Hansen (2014) that assigning value to a nature area for both functions is crucial for successful management. In the absence of recreational goals, site managers and stakeholders can deliberate on one or several goals during the phase of setting objectives. These goals might evolve during the other phases of decision making.

Further research is needed on how scientific tools should deal with evolving goals, how site-specific data and local knowledge can be translated into recreation goals, and how scientific tools should be developed to assess recreation goals that might differ between nature areas.

Another reason for inequality between the two functions might be that it is difficult to determine how visiting nature areas benefits nature conservation. Lack of knowledge on this positive impact on nature conservation might lead to neglecting this aspect of the relation between outdoor recreation and nature conservation. I noticed that asking conservation stakeholders the simple question 'Why do you want to protect this species' often triggers a good debate on the role of nature experiences and the value of physically connecting with nature. Even just the sheer enjoyment of experiencing nature leads to an increase in support for conservation (see also Zylstra et al. 2014, Lumber et al. 2017). Further research should be conducted on the contribution that visiting nature areas makes to the support for nature conservation. Questions that might be addressed are (see also Zylstra et al. 2014, Restall and Conrad 2015, Lumber et al. 2017): Do visits to nature areas increase support for conservation measures? Can thresholds be identified? What types of landscape do visitors connect with? What measures can site managers take to increase connectedness with nature? Knowledge is also needed on the impact of restrictive measures on visitors' experiences.

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Appendices

Appendix1 Dataset of GPS tracks (Chapter 2)

The original dataset was collected as part of the PROGRESS research project in the New Forest during spring and summer of 2004 at 41 car parks (Gallagher et al. 2007). Both models of the GPS devices used, the eTrex and eTrex Venture, were manufactured by Garmin and have 12 receiver channels. The nominal position accuracy is 15 m for the eTrex and 5 m for eTrex Venture. However, Rodríguez-Pérez et al. (2007) showed a decrease in accuracy in areas with a forest canopy for comparable device models. The positional accuracy is affected by stem density due to the lowering of the signal to noise ratio and the signal interception caused by electromagnetic waves penetrating through stems and canopies. At each car park, the GPS devices were turned on before data collection to ensure that the current almanac was stored and an accurate position was acquired. At the time of data collection, no selective availability was in operation. The devices have a storage capability for 2048 data points and were set to the 'Auto' record method for recording the tracks. This method records the tracks at a variable rate to create an optimum representation of the track. After participants returned, their device was connected to a laptop. A lightweight application, using the Garmin transfer protocol, read the data points into a database.

Table 1 shows the number of days the car parks were monitored and the number of tracks collected from each car park. Table 2 shows monitoring was conducted less frequently on Sundays. Sharp et al. (2008) showed that residents in the New Forest tend to use different car parks than visitors living outside the area. Combining the dataset with information from Sharp et al. (2008) indicates that visitors with dogs are mainly local residents (Fig. 1). The dataset used contains 14 columns of information (Table 3).

Table 1. Number of tracks gathered at each car park.

Car park	Times monitored	Total tracks
Acres Down	4	7
Anderwood	2	8
Andrews Mare	4	24
Ashley Walk	6	31
Beaulieu Heath	5	19
Blackwater	5	38
Blackwell Common	7	41
Bolderwood	7	75
Burbush Hill	6	25
Burley	5	20
Busketts Lawn	7	30
Cadnam Cricket	3	6
Clay Hill	4	29
Crockford	4	31
Deerleap	12	109
Dibden Inclosure	6	114
Fritham	4	22
Godshill Cricket	6	57
Hincheslea Moor	3	11
Kings Hat	5	30
Linford Bottom	6	61
Longslade Bottom	5	42
Longslade Heath	4	34
Millyford Bridge	4	19
Mogshade	1	2
Moonhills	9	77
Ober Corner	2	9
Pig Bush	7	56
Pipers Wait	5	32
Queens	14	119
Shatterford	8	41
Smugglers Road	5	44
Standing Hat	4	16
Turf Hill	5	57
Vereley	4	20
Whitefield Moor	6	41
Wilverley Plain	7	66
Woods Corner	2	19
Wooton Bridge	3	11
Yew Tree Bottom	4	24
Yew Tree Heath	8	46
Total	218	1563

Table 2. Number of tracks gathered on each day of the week.

Day	Times monitored	Number of tracks
Monday	11	210
Tuesday	12	262
Wednesday	12	272
Thursday	13	269
Friday	12	223
Saturday	12	227
Sunday	8	100
Total	80	1563

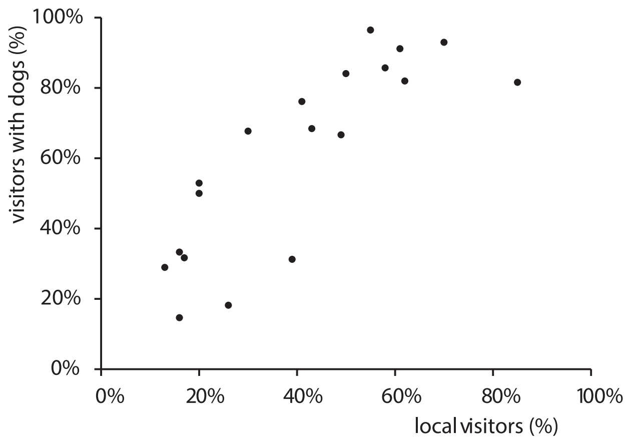


Figure 1. Relationship between percentage of local visitors (residents; from Sharp et al. 2008) and percentage of visitors with dogs (based on the GPS tracks) for 19 car parks that are available in both datasets.

Table 3. Explanation of headers in the added file (dataset.xlsx) containing data from the GPS tracks. The first 11 rows originate from the original dataset and the final three rows were added during the preparation of the dataset.

Header	Further information
ID	unique ID for each single data point
Track_ID	Unique ID for each track
Easting	Easting coordinate
Northing	Northing coordinate
Date_Time	time of storing single data point
Date	Date of survey
Car_Park_Name	Name of car park where GPS device was handed out
Car_Park_Code	Code of car park where GPS device was handed out
N_People	Number of people in the visitor group
N_Dogs	Number of dogs along the visitor group
Dogs_on_Leash	“Y” means dogs were on leash and “N” means dogs were off leash
Internal_Track_ID	Unique ID for each single data point starting at 1 for each track
After_Preperation	Single data point taken into account after preparation step
After_GIS	Single data point taken into account after GIS snapping procedure

Appendix 2 Data handling of GPS tracks (Chapter 2)

The data points of each GPS track were used to construct the expected route of a visitor or visitor group in four steps. The four steps are illustrated for one track in Figure 1. This track was chosen as it illustrates all the potential problems we encountered in constructing routes from single data points. The first step in the preparation of the dataset was the removal of outliers and data points that are considered redundant for further analyses. Outliers are data points that are located at large distances from the rest of the data points on a specific track. We found two types of outliers: outliers caused by researchers switching the GPS device on and off before arriving at a car park without resetting the device, and outliers due to errors in the communication between the GPS device and satellites (Piedallu and Gégout 2005). A visual check revealed that for some tracks two consecutive data points were outliers. To select these consecutive errors we calculated the average distance to the three previous data points and to the three following data points. We used the rule that one of the average distances had to exceed 500 m and the other at least 250 m to be considered an outlier. The dataset also contains clusters of single data points at the start of a visit and at the end of a visit, due to the handling time between researchers and visitors, and at locations where visitors probably had a short stop. These clusters of data points contain many data points that may be considered redundant for determining the route followed. To decrease preparation time single data points within 5 m of one another were reduced to one data point for further analysis (Fig. 1). The removal of outliers and redundant points resulted in a 5% reduction in the number of single data points.

In the second step, single data points were assigned to the path network using the snapping method from the ArcGIS Toolbox (http://pro.arcgis.com/en/pro-app/tool-reference/editing/snap.htm). We used the snapping rule to assign data points to the nearest path within a distance of 50 m. Single data points that are further away from the path network were excluded for further analyses (Fig. 1). This preparation step resulted in a 1% reduction of the single data points.

The third step was the construction of the routes. Many tracks missed single data points for small parts of the route followed. To fill these gaps a travelling salesman route algorithm was used in QGIS Desktop (v2.14.12) with GRASS (v7.2.0) (https://grass.osgeo.org/grass70/manuals/v.net.path.html). This algorithm constructs routes based on the order of data points. The shortest route between different data points on a path network are linked to one route. Information from the track logs was used for the order of the data points (Fig. 1). For 10 tracks no routes could be constructed as they contained too few data points. At this stage of the analysis the resulting dataset contained 1553 routes.

Finally, in the fourth step a visual check of the constructed routes was conducted using QGIS. During the check small segments, or 'dangling nodes', of the routes were deleted (Fig. 1). These segments originated from snapping a single data point to the nearest path. At crossings this sometimes resulted in allocating the GPS data point to a path the visitor most likely would have crossed instead of followed. Only segments of paths were deleted when the snapped point was within 100 m, as the crow flies, of the main route a visitor had most likely followed. The set of 1553 routes was used to derive rules of thumb. For the random forest model only car parks with 10 or more routes in the database were taken into account, resulting in frequency maps for 36 car parks based on 1521 expected routes.

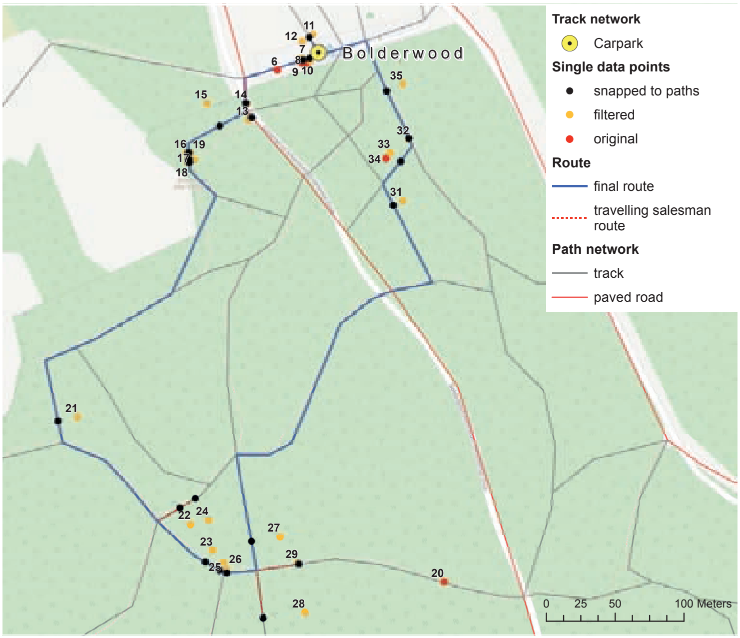


Figure 1. Overview of the preparation of the GPS tracks into visitor routes for track ID 1057, containing 35 single data points. The red dots show the outliers and redundant single data points. Numbers 1–5 are not shown as these are located 20 km from the New Forest in an urban area; the researcher probably forgot to reset the GPS device before the start of the study. Single data point 20 illustrates an outlier resulting from errors in communication between the GPS device and satellites. Single data point 30 is an even more extreme outlier at several hundred metres off the route and not visible at this scale. Single data points 6, 10 and 34 illustrate redundant data points. For this track all selected single data points (orange) are within 50 m of the path network (black dots represent the snapped data point). The travelling salesman route algorithm was used to derive the final route (the combination of the blue and dotted red lines). For this track the algorithm was needed to connect the route between single data points 19 and 21 and between 29 and 31. Based on a visual check the red dotted lines towards single data point 22 and 24, 28 and 29 were deleted resulting in a final route for this visitor group.

Appendix 3 Description of three potential management interventions used to assess the impact of possible management actions on the Nightjar population (Chapter 2)

The model was used to assess three potential management interventions that alter the capacity and use levels of the car parks. The capacities were based on the input maps of the car parks and the use levels were based on the local knowledge of the site managers. The current capacities and use levels were altered by the researches to simulate the three interventions and illustrate the potential of the model. The total number of visitors to the New Forest (13.3 million; Gallagher et al. 2007) were distributed over the car parks based on the combination of their capacity and use level.
The three potential management interventions are:

- Closing small car parks: All car parks with a capacity of less than 20 cars were considered closed. This resulted in the closure of 45 car parks and a redistribution of less than 10% of all visitors over the other car parks. Visitors that were expected to start from these 45 car parks in the current situation were redistributed in proportion to the number of visitors starting at the other car parks. Closing down small car parks may be expected to result in larger areas that are disturbance free.
- Focus on suitable areas: Three relatively isolated car parks located near areas with many Nightjars were considered closed. Visitors from these three car parks were redistributed to five surrounding car parks in proportion to the capacity of these car parks. The three car parks are Andrews Mare, Yew Tree Heath and Moonhills. It was expected that this scenario would have the highest impact per redistributed visitor as the measures focus on areas that are suitable for Nightjar.
- Concentrate visitors in a small part of the area: All but 20 car parks were considered closed. All visitors were distributed over these 20 car parks evenly. The total number of visitors that start their trip from these car parks corresponds to the two car parks that are used most in the current situation, Bolderwood and Wilverley Inclosure. This most extreme intervention was expected to concentrate visitors in a small part of the area, resulting in large undisturbed areas and an increase in population size of Nightjar.

First, the random forest model, based on monitoring data from 36 car parks, was applied to all the car parks in the area. This gave the frequencies with which visitors would be present at certain locations. For each scenario these frequencies were multiplied by the number of visitors starting from a specific car park. The results for all the car parks were summed to derive the estimated visitor density on the path network in the New Forest. Second, we determined the potential population of Nightjar for the situation without recreation. The Forestry Commission provided a map with the breeding pairs of Nightjar in the New Forest based on the 2004 survey, the same year as the GPS dataset (see also Newton 2010). We assumed this distribution reflects the habitat suitability for Nightjar, but should be corrected for the impact of the disturbance of visitors. In areas with high visitor numbers, the number of breeding pairs is expected to be much higher when visitors are absent. We used the dose–impact relationship of Pouwels et al. (2017) to correct the current distribution and estimate the potential population in the area for a situation without recreation by multiplying each breeding pair by the inverse of the index in Fig. 1. We used the maximum visitor groups per ha per year within a radius of 500 m as the disturbance level (x-axis in Fig. 1). This radius is based on research by Murison (2002) and Lowe et al. (2014).

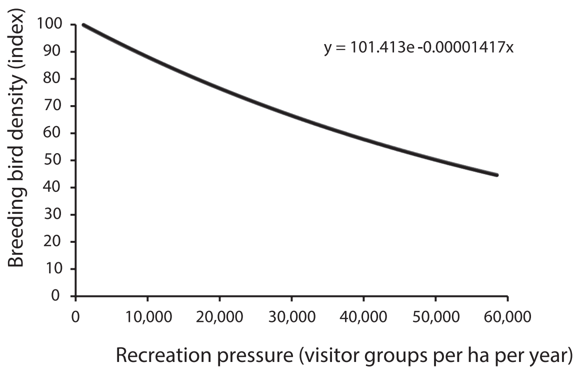


Figure 1. Dose–impact relationship between recreation pressure, in visitor groups per ha per year, and the breeding bird density index for Nightjar. The figure is taken from (Pouwels et al. 2017).

Finally, for the three interventions the maximum number of visitor groups per ha per year was determined within a radius of 500 m for each breeding pair. Using Function 1, the corrected number of breeding pairs was determined. The Cpd_i is summed to predict the population size. For the current situation this resulted in the number of breeding pairs from the survey itself as $Ibpd_i$ equals Ibpdcurrent. As some values within the 500 m buffers are very high, we cut off the impact of visitors at the impact of 100 000 visitors, resulting in a minimum index of 25% of breeding bird densities.

$$Cbp_i = \frac{1}{Ibpd_{current}} \times Ibpd_i \qquad \text{Function 1}$$

Cbp_i is the corrected number of breeding pairs for a specific intervention

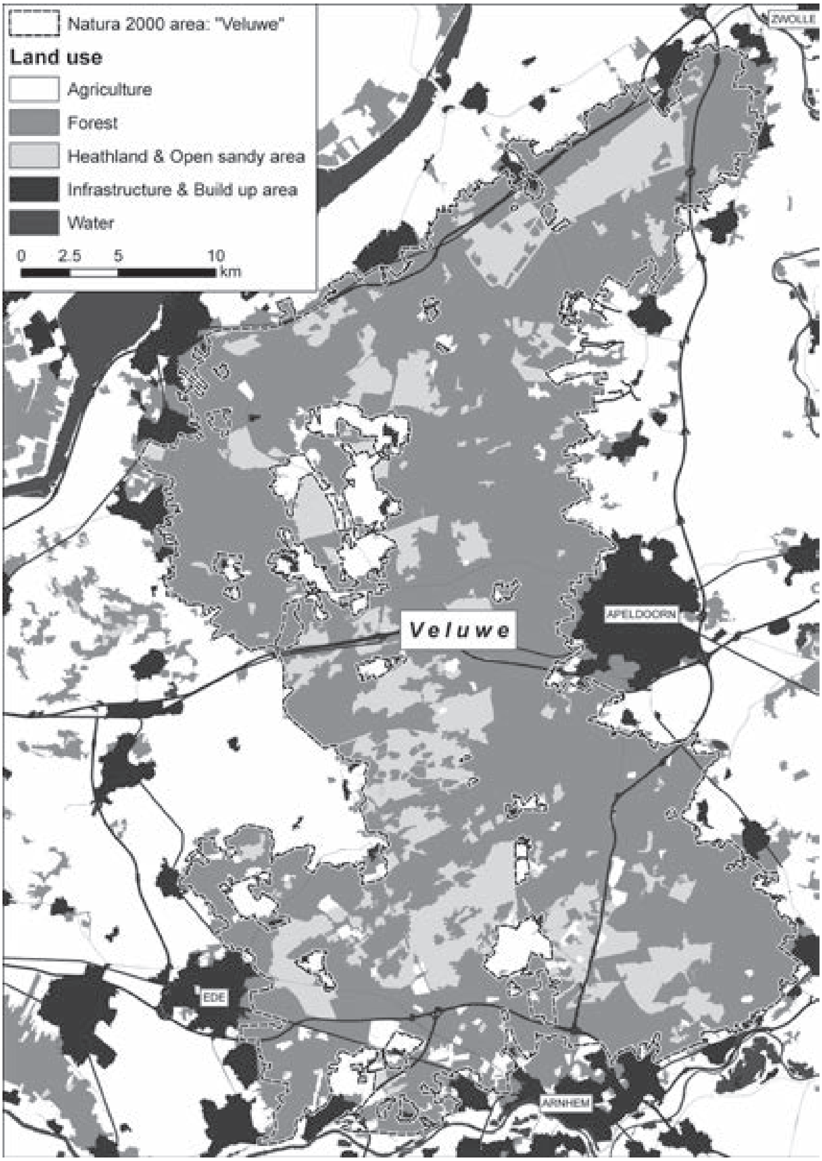
$Ipbd_{current}$ is the Index of the breeding pair density based on the recreation pressure in the current situation

$Ipbd_i$ is the Index of the breeding pair density based on the recreation pressure for a specific intervention

A

Appendix 4 Study area (Chapter 4)

The Veluwe, situated in the central part of the Netherlands, is the largest Dutch terrestrial Natura 2000.



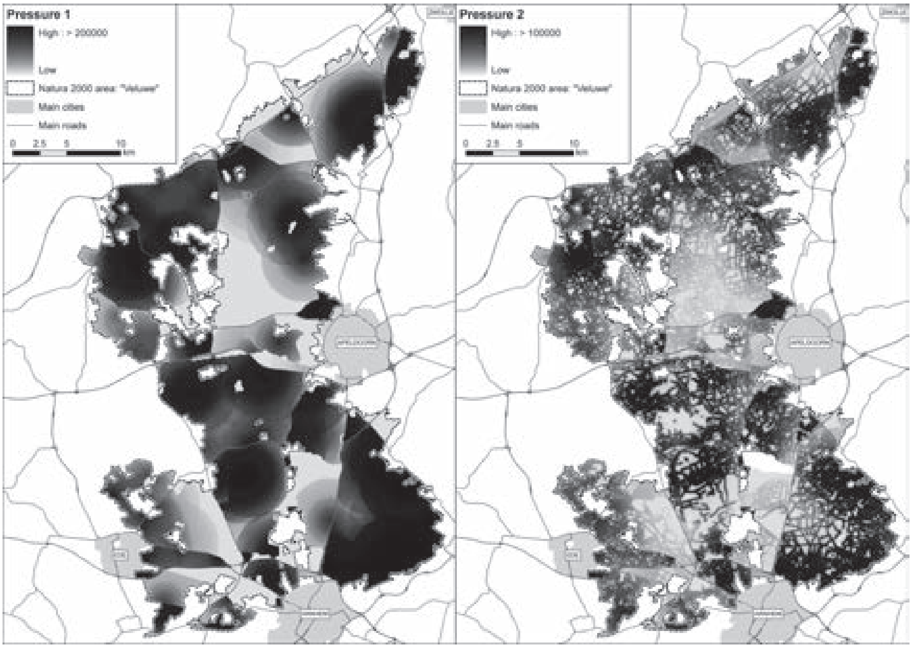
Appendix 5 Variables taken into account in the statistical models (Chapter 4)

Variable	Explanation
Area	Area plot in hectares
Project	Sampling method (factor)
Soil_poorsand	Percentage nutrient poor sandy soils
Soil_coarsesand	Percentage course sandy soils
Soil_shiftsand	Percentage shifting sand dunes
Treedens1-3	Density of free standing trees in three density classes (1=low, 3=high)
Buffer150	Buffer of 150 meter along forest edge
Heathland	Percentage of heathland within plot
Woodland	Percentage of woodland within plot
Ntreespeckm	Diversity of main tree species per square km
Woodtyp1-4	Age class of forest: percentage per age class (old forest is 1 and young forest is 4)
Noise	Noise level from roads (in dB)
Pressure1	Recreation pressure from residents based on kernel density method (in visitor groups per ha)
Pressure2	Recreation pressure from residents around trail network (visitor groups per ha)
Pressure2p	Recreation pressure from residents based around trail network combined with the non-official parking areas at crossings (visitor groups per ha)

A

Appendix 6 Predicted recreation densities (Chapter 4)

Result of the recreation models and input for the statistical models. Visitor densities (pressure) are given in visitor groups per ha. On the left the kernel version of the distribution of visitors across the area is given and on the right the trail version of the distribution of visitors across the area is given.



Appendix 7 Selected models for Woodlark, Stonechat and Nightjar (Chapter 4)

Estimates, standard errors, z values and p values are given for each variable. Variables are explained in Appendix 5.

Woodlark	Estimate	Std. Err.	z value	p value
(Intercept)	-1.14783	0.49731	-2.31	0.02099
Area	0.00362	0.00025	14.42	0.00000
ProjectBMP	0.68473	0.12080	5.67	0.00000
ProjectDefense	0.61088	0.22636	2.70	0.00696
Soil_poorsand	0.00772	0.00218	3.55	0.00039
Soil_shiftsand	0.00680	0.00197	3.46	0.00054
Treedens3	0.02117	0.00414	5.11	0.00000
Buffer150	0.01603	0.00360	4.46	0.00001
Heathland	0.00684	0.00439	1.56	0.11881
Ntreespeckm	-0.11418	0.02679	-4.26	0.00002
Woodtyp2	0.02391	0.00600	3.98	0.00007
Woodtyp4	0.01300	0.00404	3.22	0.00129
Noise	-0.12852	0.03746	-3.43	0.00060
Pressure1	-0.00001	0.00000	-4.41	0.00001

Stonechat	Estimate	Std. Err.	z value	p value
(Intercept)	0.54033	0.46038	1.17	0.24053
Area	0.01000	0.00111	8.98	0.00000
I(Area^2)	-0.00001	0.00000	-6.57	0.00000
ProjectBMP	-0.26531	0.10486	-2.53	0.01140
ProjectDefense	0.41214	0.16338	2.52	0.01165
Soil_coarsesand	0.00354	0.00179	1.97	0.04838
Treedens1	-0.01028	0.00378	-2.72	0.00653
Treedens3	-0.01197	0.00526	-2.28	0.02280
Buffer150	-0.01171	0.00277	-4.22	0.00002
Heathland	0.02140	0.00230	9.30	0.00000
Noise	-0.10027	0.03849	-2.60	0.00919
Pressure1	-0.00001	0.00000	-3.30	0.00095

Nightjar	Estimate	Std. Err.	z value	p value
(Intercept)	-125.47700	49.13613	-2.55	0.01066
Area	0.00781	0.00252	3.10	0.00195
I(Area^2)	-0.00001	0.00000	-2.18	0.02897
Year	0.06271	0.02447	2.56	0.01040
Soil_shiftsand	0.00878	0.00508	1.73	0.08400
Soil_coarsesand	0.01472	0.00380	3.87	0.00011
Treedens1	-0.01271	0.00588	-2.16	0.03055
Treedens3	0.01886	0.00831	2.27	0.02324
Woodland	0.03261	0.01324	2.46	0.01376
Ntreesrtkm	-0.21979	0.07020	-3.13	0.00174
Woodtyp1	-0.03495	0.01944	-1.80	0.07220
Woodtyp2	-0.02395	0.01347	-1.78	0.07549
Woodtyp4	-0.02805	0.01229	-2.28	0.02244
Noise	-0.20109	0.04840	-4.16	0.00003
Pressure2p	-0.00003	0.00001	-2.60	0.00932

Appendix 8 Animation of simulation results of MASOOR (Chapter 5)

Animation of simulation results of MASOOR showing visitors using the path network in part of the New Forest during the day. Each group of visitors is represented by one pair of feet.
To view the animation visit: https://www.youtube.com/watch?v=WXTm2sXlHU4

Summary

In urbanized landscapes nature areas fulfil a multitude of ecological and social functions which are increasingly appreciated by society. Where these functions come under threat, site managers feel the need to find solutions and take measures to protect them. In doing so they have to make choices, because different functions require different solutions and some of these may conflict. Moreover, in the current political and social climate, stakeholders often hold opposing views about which function is most important. A common example of such conflicts, certainly in the last twenty to thirty years, is between outdoor recreation and bird conservation in nature areas. In such cases, managers will be able to make more evidence-based, transparent and socially supported decisions if they can draw on scientific knowledge and make use of scientific tools, for example by predicting the impact of management interventions on bird conservation and outdoor recreation targets. However, the validity of using scientific knowledge and tools is under debate because it is not certain they can provide the desired clarity of information. Previous research has shown that for knowledge and tools to be used in environmental decision making, they must possess three attributes: credibility, salience and legitimacy. These three attributes are interdependent: an overemphasis on one of them is often accompanied by underdevelopment of the other two. However, finding the best balance is complex as each person involved in the decision-making process may value the attributes differently. Also, questions have been raised about scientific knowledge on the relationship between outdoor recreation and bird conservation. Although research shows that in most situations visitors have a negative impact on bird species, the evidence is often expressed in short-term and local impacts, such as flight distance. This type of knowledge lacks salience and legitimacy as managers need to be able to predict the impact of outdoor recreation on long-term and regional conservation targets, such as the population size of protected species.

This thesis focuses on understanding how scientific knowledge and tools could support conservation managers in finding a balance between outdoor recreation and bird conservation as two of the main functions in nature areas. I present new scientific knowledge and tools on the impact of hikers on bird populations. In four case studies, I integrated site-specific data and local knowledge into existing scientific methods and concepts to increase their salience and legitimacy, while at the same time maintaining their credibility. I discuss how this new knowledge and these new tools might help managers in a collaborative decision-making process with stakeholders. Finally, I reflect on the trade-offs between credibility, salience and legitimacy and propose directions for future research.

Often managers lack adequate monitoring data on visitor densities and have little or no insight into the effectiveness of interventions to restrict visitor use in areas where ecological or social disturbance thresholds are exceeded. In Chapter 2 I derive a tool and rules of thumb which link landscape and environmental features to visitor use and visitor densities. The tool can be used by conservation managers to identify and locate the impact of temporarily closing or changing the capacity of car parks on the density of visitors in particular parts of an area. In a study of the New Forest, UK, I used a large set of GPS tracks of visitor movements to develop random forest models to identify which landscape and environmental features account for spatial variation in visitor densities. The random forest model shows that distance to a car park, distance to roads and openness of the landscape are important variables in predicting the spatial variation in visitor densities. As an example I showed how the model for visitor densities can be used by managers in combination with monitoring data on bird species to assess the impact of changes in location or capacity of car parks on the population of Nightjar (*Caprimulgus europaeus*). As developing tools based on GPS data need large volumes of monitoring data and a large budget to collect them, I also derived rules of thumb and a simple algorithm that could be applied by managers to obtain insight into the possible impact of management interventions on visitor densities. The rules of thumb indicated that, because visitors avoid crossing roads, changing the location of car parks in relation to tarmac roads can reduce visitor densities in areas with a protected species by 80%.

To balance outdoor recreation and bird conservation, managers need to know how interventions in the pattern of visitor densities relate to conservation targets. In Chapter 3 I link management actions that restrict visitor access to the viability of the Skylark (*Alauda arvensis*) population. Site-specific data for visitors and Skylark were integrated into an individual-based recreation model and species population model for a large dune area in the Netherlands, the Amsterdamse Waterleidingduinen. Managers of coastal dune areas have for many years struggled to find a balance between recreation opportunities and nature conservation. Dune areas are very popular among local inhabitants and tourists and contain high nature values. Knowledge of the impact of visitor densities on Skylark densities and breeding success was available from research in similar areas in the Netherlands. This knowledge provided a crucial link between the recreation and population model and was used to link changes in path network to the population size of the Skylark. Site-specific recreation data and the local knowledge of managers on visitor preferences were used to adapt the recreation model to the local situation. The species population model was adapted to the local situation using site-specific bird data and the local knowledge of managers on the habitat preferences of the Skylark. The models predicted that creating a disturbance free zone in the centre of the area, containing optimal habitat patches for the Skylark, would result in a large increase in the total population from 33 to 82 breeding pairs. However, creating the disturbance free zone would reduce the total length of the path network visitors could use by 20%. This case study showed that being able to compare the impact of alternative management actions on the interaction between outdoor recreation and bird conservation will help managers and stakeholders to consider which actions provide the best solution in terms of recreation and conservation targets.

In nature areas where conservation targets for birds are not being achieved, managers need to understand what the impact of outdoor recreation is on these targets and where management interventions might contribute to achieving the targets. In Chapter 4 I address the interaction between local management actions and bird conservation targets on a regional scale. I integrated available site-specific monitoring data on breeding birds with scientific tools and spatially statistical methods to provide managers with scientific information that links local impacts of outdoor recreation to regional conservation targets for the Veluwe area in the Netherlands. For three heathland species, Nightjar (*Caprimulgus europaeus*), Stonechat (*Saxicola torquata*) and Woodlark (*Lullula arborea*), dose–impact relationships between visitor densities and population size were determined. The dose–impact relationships for the three species showed that population densities already started to decline at low visitor densities. At high visitor densities, 50 000 visitors per hectare per year, breeding pairs of Nightjar and Woodlark declined locally by up to 50%. Using the dose–impact relationships to estimate the regional population of Nightjar, Stonechat and Woodlark in the Veluwe revealed a reduction of up to 28% due to the impacts of outdoor recreation. This would bring the Woodlark population size to below the conservation target. The derived regression models can have added value for managers as the output maps provide an estimate of the impact of recreation disturbance on bird densities in local areas. Groups of local managers of nature areas can use these maps to discuss how they can collaborate in taking actions to achieve regional conservation targets, while providing opportunities for outdoor recreation at the same time. The results of this research are already being used by the Province of Gelderland for a new recreation management plan for the area. The province is responsible for the implementation of the conservation targets for the Veluwe.

Where managers engage stakeholders in management decisions, tools and knowledge should be able to support the deliberation and negotiation processes. In Chapter 5 I present a case study of the New Forest, UK in which scientific tools were applied in a collaborative effort to find a balance between providing access to hikers and the conservation of wader species. Together with stakeholders and managers I used site-specific data and local knowledge to adapt existing recreation and bird population tools to the local context of the New Forest. In this process managers and stakeholders were able to explain how they perceived the relationship between outdoor recreation and bird conservation. Based on this research I proposed four criteria for scientific tools to improve their salience and legitimacy. First, scientific tools should use site-specific data and be able to include local knowledge. Often scientific tools are specific for one particular site only or are too general. Being able to adapt the tools to the local area context in collaboration with local experts will increase their salience and legitimacy and is crucial for their acceptance by local stakeholders. Second, tools should link the impact of management actions to both recreation and conservation targets. Stakeholders will then see that their values are being taken into account. Third, tools should generate spatial output that identifies conflict areas as well as locations for opportunities for recreational development. This increases the salience of the tools as it helps managers and stakeholders to develop alternative solutions and create negotiation space. Finally, the design of the tools should structure discussions and help stakeholders to explain their view of the local context. These discussions lead to a co-learning process between recreation stakeholders, conservation stakeholders, managers and scientists.

The integration of site-specific data and local knowledge into scientific methods and tools contributes towards the salience and legitimacy of that knowledge and those tools. In this research I made knowledge and tools context specific for the different study areas and I related local measures to the regional conservation targets of those areas. The fact that the integrated tools have been used by site managers to discuss their plans with stakeholders could be interpreted as an indication that the integrated tools are perceived to be credible, salient and legitimate. However, integration of data and knowledge does not automatically result in adequate levels of credibility, salience and legitimacy because there are trade-offs between these attributes. From the four studies I gained four key insights:

1. Connect the perspectives of managers, stakeholders and scientists by using standardized scientific methods to relate concrete management actions in an area to acknowledged stakeholders values. This increases relevance for managers when they are able to predict the impact on visitor densities of changes in recreation accessibility, such as changing the location or capacity of car parks or temporarily closing parts of the area. Validity for stakeholders is increased when they can associate the output of the tools with the values they acknowledge. Confidence for scientists is increased when they can use standardized methods and develop tools that are based on accepted scientific methods and concepts. Building scientific tools on this principle helps to harmonize the perspectives of managers, stakeholders and scientists on the credibility, salience and legitimacy of knowledge and tools.
2. Connect knowledge along a clarity–complexity axis by combining the development of complex scientific methods with the use of simple algorithms and rules of thumb based on these complex tools. This combination helps to connect credibility with salience and legitimacy in the complexity versus clarity trade-off. Simple algorithms and rules of thumb improve salience and legitimacy, while a potential loss of credibility is mitigated by showing how the simplified knowledge reflects the complex relations between local management measures and local and regional targets.
3. Discuss algorithms and parameters helps to bring about agreement on the measures to be taken. One of the most important merits of using scientific tools in stakeholder decision making is that the tools themselves provide structure for discussion. This structure should be used to discuss choices that have to be made when adapting tools to the local situation. These discussions encourage stakeholders and site managers to enter into a dialogue about each other's values and help to build trust between all parties and a shared understanding of the local situation.
4. Different phases in the decision-making process may need different types of information. In the problem definition phase, simple messages are needed that show the severity of the impact of visitors on the conservation targets. In the phase of setting objectives, information is needed that relates visitor densities to the population size or bird

conservation targets as it can give indications of which objectives might be feasible in an area. During the phases of identifying potential management measures and estimating the impact of these measures on population targets, information is needed that links the features managers can control to visitor densities and population targets. Managers and stakeholders can use this information to choose between different options. Maps or other spatially explicit information sources are especially helpful to managers and stakeholders in this phase as they show for each local situation where measures might result in an increase in population size.

The research in the New Forest also shows that the perception of credibility, salience and legitimacy evolved during the decision-making process. These changes originated from the process itself as well as from external developments and could affect the credibility, salience and legitimacy of knowledge and tools used in the process. If the process itself leads to empowerment, equity, mutual learning and trust between stakeholders and managers, the values and attitudes of managers and stakeholders may change, in turn changing the perception of the credibility, salience and legitimacy of the knowledge and tools used in the process. Also, new knowledge may be generated or new policies may be developed, leading to changes in the credibility or legitimacy of the knowledge and tools used. The ability to respond flexibly to or adapt to these changes should be added as an extra attribute of scientific knowledge and tools in addition to credibility, salience and legitimacy.

I propose three main directions for future research to offer further support to managers and stakeholders in finding the balance between outdoor recreation and bird conservation in nature areas:

1. Research on the dose–impact relationships between outdoor recreation and bird conservation. For many species there are knowledge gaps regarding the impact of outdoor recreation on population densities and population size. Information on these dose–impact relationships is urgently needed for species that are in decline and sensitive to visitor disturbance.
2. Research on alternative solutions to potential conflicts between outdoor recreation and bird conservation. In nature areas where potential conflicts between outdoor recreation and bird conservation occur, one

of the first management measures is restricting visitor use in parts of the area. In some situations the necessity for restrictions is easy to explain to stakeholders and support for the restrictions will usually be forthcoming. However, restrictions also prevent visitors having unique nature experiences and should therefore not be the first management measure for discussion. I propose that research should focus on extending the range of measures that conserve bird species while giving visitors the opportunity to experience nature at the same time, such as managing natural soundscapes and raising awareness by developing a code of conduct together with stakeholders. Alternative solutions might also be found in a joint design process. How scientific knowledge and tools can be used in the design process should be a subject of future research.

3. Research into the impact of outdoor recreation on support for bird conservation. The positive impact of outdoor recreation on nature conservation is often neglected. This might lead to inequality between these two functions, which could undermine the decision-making process. One reason for this may be the absence of recreation goals in most nature areas. Another reason may be the lack of knowledge on this positive impact. Further research is needed on how visiting nature areas contributes to support for nature conservation.

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In 2000 the managers from the Amsterdamse Waterleidingduinen, the Netherlands, approached me and my colleagues to develop a tool they could use to assess the impact of their management plans on both the visitor distribution in the area and the population size of protected bird species like the Skylark. Their goal was to use this tool for communication purposes, mainly to find support for their planned management actions. A few years later managers of the New Forest (UK) and Fontainebleau (France) wanted to use the same tool in a decision-making process with stakeholders. In the course of this research project (PROGRESS; 2003-2007) my interest in the role of scientific knowledge and tools in processes, where nature conservation conflicts with outdoor recreation, started to develop. At the end of the PROGRESS project Paul Opdam triggered the start of my PhD-thesis by raising the question to assess the role of scientific knowledge and tools not only from an applied perspective, but also from a scientific perspective. I'm very grateful for the guidance he and Ruud Foppen provided during the writing of this thesis. I suppose that the question "Okay, that is why managers want to know this, but what is the scientific question?", is a sentence that will stay with me for the rest of my career.

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About the author

Rogier Pouwels was born on 1 August 1970 in Roermond (the Netherlands). During his childhood in Tungelroy he attended VWO at Bisschoppelijk College in Weert. He studied Biology at Utrecht University and graduated in 1994. After several short employments at Utrecht University, ATO-DLO, IBN-DLO and Pink Elephant he obtained his current position in 1998 at Wageningen Environmental Research (WENR, IBN-DLO and Alterra in former years). At WENR he has been coordinating the development and application of biodiversity policy assessment tools for Dutch provinces, the Directorate-General for Public Works and Water Management, Ministry of Agriculture, Nature and Food Quality and PBL Netherlands Environmental Assessment Agency. Since 2005 he manages the biodiversity research program at WENR conducted on behalf of PBL and has cooperated in many research projects to assess the impact of current and future policies on conservation targets, like 'Redesigning the Dutch National Nature Network' and the 'European Nature Outlook'.

Colofon

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